NCV3 Introduction to Electronic and Digital Concepts for Robotics

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Lecturer Guide

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Contents

Icon key

Whenever you see the following ICONS in this textbook, this is what they mean:

INDIVIDUAL ACTIVITY

Indicates an activity to be done alone.

PAIR ACTIVITY

Indicates an activity to be done in pairs.

GROUP ACTIVITY

Indicates an activity to be done in groups.

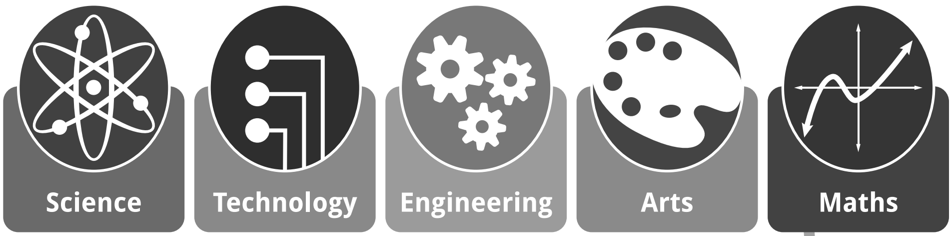
SUMMATIVE ASSESSMENT

This is the activity that students will need to complete and tear out to be handed in as part of their assessment mark.

1. Overview of the subject

With the advent of the Fourth Industrial Revolution (4IR), new mechanisms and approaches are required to enable students and those already settled in existing career paths to upgrade their skillsets. This notion is particularly important in the computer science and engineering disciplines, as the educational sector needs to keep up with the pace at which new technologies are developed and deployed.

The driving forces for the market and the world of the future are rooted in competitiveness. Successes and failures depend on which technologies are applied and how they are applied, rather than on the technologies themselves. Another contributing factor is the speed at which the knowledge of the technology changes (Fernandez, et al. 2015).



1.1 Main subject aim

Electronics and Digital Concepts for Robotics (EDCR) aims to equip students with functional 4IR technology capabilities through the transfer of necessary trade-specific skills, knowledge, values and attitudes (SKVAs).

1.2 Electronics and Digital Concepts for Robotics Level 3

Electronics and Digital Concepts for Robotics Level 2 covered the basics of electronics and was designed to introduce the field of learning. The assumption was made that the student had no previous electronics background.

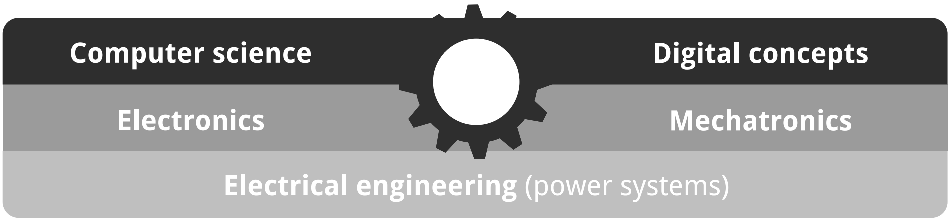
In Levels 3, students continue the theoretical and practical implementation of the learning material. Repetition of some of the work will be noticed, since laying a solid foundation of knowledge is important. The subject aims to transfer the necessary trade-specific SKVAs to students.

Electronics and Digital Concepts for Robotics focuses on the understanding and application of electrical and electronic principles. The subject focuses on four main areas of specialisation, namely:

- Electrical (power systems)
- Electronics
- Digital electronics
- Mechatronics
- Computer science.

The term *mechatronics* describes the integration of electronic engineering, electrical engineering, computer technology and control engineering with mechanical engineering. This process forms a crucial part of the design, manufacturing and maintenance of a wide range of engineering products and processes. Consequently, there is a need for engineers and technicians to adopt an interdisciplinary and integrated approach, involving skills and knowledge that are not confined to a single subject area. They should be able to operate and communicate across a range of engineering disciplines.

In the following section, the respective areas of specialisation are described and placed within the intended context.



Electronics

Electronics as a component in EDCR introduces the learner to analogue electronics utilising mainly light current applications. In Level 3, students further explore discrete electronics through the examination of semiconductor devices and their various applications. They will also be introduced to instrumentation – how to use instruments to take measurements and reach subsequent conclusions based on observations.

Towards Level 3 and 4 students are introduced to integrated circuits and how simple circuits are combined to form more complex circuitry for the purpose of establishing communication and control. A student who takes Electrical Technology specialising in Electronics will be able to source solutions to problems using electronic applications and innovations made to existing circuits. The student will be able to construct, test and commission basic electronic circuits.

Electrical engineering

Electrical engineering (power systems) refers to various applications of electricity using heavy current from the mains supply. In Level 2, the student was introduced to direct current (DC) and other practical applications. In Level 3, light industrial, single-phase applications that use motors and transformers will be introduced. The focus is on the generation, distribution and application of three-phase power in motors and transformers.

Mechatronics

As mentioned earlier, mechatronics is the integration of electronics, electrical engineering, computer technology and control engineering with mechanical engineering. A wide range of engineering products and processes relies on this process for their design, manufacturing and maintenance. It is therefore essential for engineers and technicians to apply an interdisciplinary and integrated approach, encompassing skills and knowledge that are not confined to a single field.

Digital concepts

This aspect of the curriculum has strong links to computers, programmable integrated circuits, Boolean algebra, microcontrollers, system control, processors and programming. In Level 2, the student was introduced to the principles of electricity and electronics, like any electronics student.

In Level 3, the focus shifts towards digital electronics and Boolean algebra. Students are introduced to communication systems as these form the corner stone of digital systems. At the same time, they will learn about different aspects of motors and how motors are controlled using pulse-width modulation. This opens the world of robotics and the interface between the digital world and the real world, such as mechatronics.

Computer science

The link between computer science and EDCR has already been emphasised with reference to the digital concepts. The subject also has additional pedagogical and developmental advantages. These are summarised in the figure below.

Creative thinking

EDCR incorporates creativity, imagination and elements of fun. This promotes the allure of the subject and motivates students to further explore and learn.

Engagement

Practical (hands-on) learning enables students to learn new fundamental skills while promoting concentration and developing psychomotor abilities.

Preparedness

Technological advancements necessitate new opportunities to prepare students for the future. This aspect basically relates to the development of skills that will prepare students for the rapidly changing world. It stimulates and develops students' engineering intuition and accentuates meaningful problem-based learning.

Computational thinking

Computational thinking is a problem-solving process that encourages students to develop sets of skills that include decomposition, pattern recognition, abstraction and algorithm design.

Evaluation

This entails that the student engages in critical self-reflection and assessment in order to determine the degree to which the artefact or design meets the set criteria. It allows the student the opportunity to reflect on areas that require possible further attention and practice.

Communication

This skill is essential, as it allows students the opportunity to share ideas, both verbally and in other means, and stimulates collaboration and group-directed learning.

Perseverance

Creating and designing electronic-based tools and artefacts are a challenge and present students with the opportunity to hone and develop a never-give-up attitude. It also imparts determination, which is vital in any technological, design and scientific endeavour.

Collaboration

EDCR as a subject incorporates a range of skills and indorses an environment of learning among students with different talent sets. Using each student's strengths could promote an ethos of collaboration and harness goal-directed development or teamwork.

Abstract thinking

This is the ability to think about aspects and things that are currently not present. In the field of robotics, it is related to symbolic thinking and the realisation of ideas.

Programming

Programming is a medium, a literacy or a form of communication and expression. It presents the robotics student with a means to explore and practically experience the aspects encapsulated in computation. Programming involves coding and students need to design and present step-wise solutions and transform the abstract into the symbolic.

Fun

Students engaging in robotics as a subject are stimulated due to the fun nature of the subject. The subject can present positive user experiences and encouragement.

2. Development of learning and teaching support materials and teaching strategy

The developers of any learning and teaching support material (LTSM) should consider the fact that a curriculum statement and syllabus, such as the one provided here, is made up of various contextual topics and subject outcomes and therefore should not be used as a table of contents for writing textbooks. The topics and subsequent numbering of subject and learning outcomes also do not necessarily indicate the sequence in which material should be presented.

Knowledgeable subject experts and LTSM developers will logically group different subject and learning outcomes and will present these in an educationally sound, coherent and sequenced manner to provide students with an authentic integrated learning experience. Core competencies and skills should be presented, covering both the theoretical and the practical aspects of the subject.

Lecturers should design their own work schedules (or use/adapt the work schedule provided in the Facilitator's Guide) to appropriately group and sequence content, considering comfortable pacing of the curriculum matter.

The subject outcomes (SOs) and learning outcomes (LOs) presented should not be seen as stand-alone topics, but relevant SOs and LOs or content should be presented in an integrated manner.

Integration of curriculum content in the lesson presentation should flow naturally according to the nature, links and overlapping of the content. For example, some content from one SO and LO may strengthen and underpin the content of another. This approach should be applied throughout the three-year curriculum.

It is important that the specific technologies in the teaching plans are revised at regular intervals to phase out old technologies and include new technologies.

3. Main topical areas

The table below illustrates the main topic areas of the EDCR subject.

ELECTRONICS AND DIGITAL CONCEPTS FOR ROBOTICS TOPICAL OVERVIEW		
LEVEL 2	**LEVEL 3**	**LEVEL 4**
• SI units and introduction to atomic theory • Electrical supply systems, Ohm's law, Joule's law and related theoretical aspects • Basic electronic components and semiconductors • Electrical components, symbols, circuit drawings, prototyping and design • Electronic tools and equipment • Digital systems and principles • Workshop ethics, safe use of equipment and operational health and safety	• Magnetism, electromagnetic circuits and related concepts • Electrical supply systems, transformers, DC machines, series-parallel networked circuits • Electronic components and semiconductors • Electrical components, symbols, circuit drawings, prototyping and design • Electronic tools and equipment • Digital systems, PLCs and principles • Functions • Strings • Data structures	• Alternating current theory • Electrical supply systems, DC networks • Electronic components and semiconductors • Electrical components, symbols, circuit drawings, prototyping and design • Digital systems and principles

4. Teaching time and offering type

The instructional offering is presented full-time over two semesters **spanning 24 weeks (not including assessment)**.

This is equivalent to the following:
- 24 × (two × double periods of ± 1 hour 50 minutes each) + 1 (single period of ± 50 minutes)
- 56 hours (± 4,5 hours per week) of which:
  - 36 hours are instructor-led contact hours (which also include practical sessions); and
  - 18 hours are instructor-led contact hours dedicated *to practical tutorials* (on PCs).
- In addition, *a further 10 hours per term* (i.e. ± 1,5 hours per week) are required for students to practice on their own to reinforce and master practical concepts and skills. (This should be accommodated in open labs provided by the college.)

5. Resources

5.1 Physical resources

Well-equipped classrooms and workshops are essential for this practical-orientated subject. If possible, using the facilities of employers in the electrical and electronics field for training is preferred.

5.2 Human resources

Lecturing staff must have appropriate electrical and or electronic engineering-related qualifications and should possess the necessary knowledge, skills and reflective approach. This to ensure that students' learning is kept up to date with the latest technologies and changing trends in their specialist field.

Continuous staff development with exposure to an industrial environment is necessary to acquire new skills and update existing skills where new technologies have been introduced. Lecturers are required to spend a structured and routine period annually in an industrial environment for these purposes.

EDCR requires a trained subject specialist. It is preferred that the EDCR lecturer is an artisan/technician/technical teacher in an electrical-/electronic-/digital-related area. Industry-related experience and workshop management skills are essential and a tertiary qualification in technical teaching is needed.

The following are required of EDCR lecturers:
- Teach the subject content with confidence and flair
- Interact with students in a relaxed but firm manner
- Manage the workshop resourcing, budget and safety
- Manage the teaching environment
- Conduct stocktaking and inventory
- Plan for practical work
- Plan for theory lessons
- Conduct weekly practical sessions
- Maintain and service the workshop as a whole

- Maintain and service the tools and instruments
- Ensure students' safety
- Produce working practical assessment tasks (PATs) and integrated science and technology (ISAT) projects in cooperation with students
- Carry out internal continuous assessment (ICASS)
- Implement innovative methods to keep the subject interesting
- Be self-motivated to keep abreast of the latest technological developments
- Regularly attend skills workshops.

Staff development in terms of updating teaching, learning and assessment skills is required on an ongoing basis, particularly for staff members who have moved from industry into the educational environment of an FET college.

5.3 Other resources

The college should have funding available to provide the following:

- Consumables required to perform practical assignments and examinations
- Maintenance of physical recourses
- Purchasing of new equipment.

In EDCR, students are required to work individually on a computer during contact time and they need access to the Internet.

A particular laboratory environment conducive to the presentation of the robotics/electronic practical content is also required.

5.4 Management plan, infrastructure, equipment and finance

Colleges must have the infrastructure and finances as well as a management plan for the subject to address the following:

- Initial capital layout for setting up a computer and electronics laboratory with the necessary work desks and layout
- Physical resources:
  - Lecture room(s)
  - Training area/Work area
  - Ablution facilities
  - Safe storeroom to be equipped with enough storage space for consumables suitable for storage
  - Funds, from learning provider or funding bodies, need to be made available for the procurement of consumables, tools and equipment to allow the effective operation of a workplace involved in a training programme – students need to be individually equipped with the necessary tools
- LTSM:
  Learning materials must conform to approved training and industrial standard requirements and articulate to higher education. LTSM and resources are needed for both academic and practical aspects of learning, and include the following:
  - Comprehensive texts for student use as well as for supplementary reading
  - Various robotic kits and electronic equipment

  - Learning materials for projection during lectures
  - Facilities to support the promotion of opportunities for research by both students and lecturers
  - Educational tours to relevant learning venues
  - Educational and motivational talks by members of the industry
  - Visual and audio-visual material
  - Relevant workshop manuals and documentation
  - Models and demonstrations
- Budget:
  - Annual running costs:
    - Breakages and maintenance (regular service plan)
    - Insurance
    - Internet connectivity
  - Sustainability plan:
    - To upgrade or replace equipment every four to five years
    - To meet safety standards in terms of electrical points and distribution boards; surge arrestors should be installed and electrical work within the computer lab must carry a certificate of compliance from an appropriate service provider/authority
    - Anti-theft and fire-safety equipment must be installed in the computer lab
    - For network maintenance and management.

5.5 Sustainable support

EDCR is a subject that requires sustained support. The Electrical Technology workshop requires regular resourcing for the purpose of completion of practical work as well as maintenance.

Resourcing could be subdivided into the following categories:
- Safety equipment
- Tools and equipment
- Consumable materials
- PAT and ISAT resources
- LTSM
- Preventative maintenance
- Maintenance.

Management teams at colleges offering EDCR should take note of the implications that the electrical/electronic workshop has on the budget of the college. While it is common practice to provide a working budget for a workshop, it is imperative to note that the budget should be structured not only to cater for the completion of PATs by the students, but also to allow the lecturer to replenish tools and equipment and acquire consumable materials for experiments, demonstrations and simulations.

Apart from the PAT and ISAT resources that are needed, the lecturer must also be allowed to supplement LTSM in the form of posters, models, examples, videos, periodicals and more.

6. Assessment guidelines

This section provides the lecturer with guidelines to develop and implement a coherent, integrated assessment system for the subject Robotics in the National Certificate (Vocational) (NC(V)). It must be read with the National Policy Regarding Further Education and Training Programmes: Approval of the Documents, Policy for the NC(V) Qualifications at levels 2 to 4 on the National Qualifications Framework (NQF). This assessment guideline will be used for NQF levels 2–4.

This section explains the requirements for the internal and external subject assessment. The lecturer must use this document with the Subject Guidelines: Robotics to prepare for and deliver the Robotics subject. Lecturers should use a variety of resources and apply a range of assessment skills in the setting, marking and recording of assessment tasks.

6.1 Assessment in National Certificates (Vocational)

Assessment in the NC(V) is underpinned by the objectives of the NQF.

These objectives aim to:
- create an integrated national framework for learning achievements;
- facilitate access to and progression within education, training and career paths;
- enhance the quality of education and training;
- redress unfair discrimination and past imbalances and thereby accelerate employment opportunities; and
- contribute to the holistic development of the student by addressing the following:
  - social adjustment and responsibility
  - moral accountability and ethical work orientation
  - economic participation
  - nation building.

The principles that drive these objectives are the following:
- Integration – to adopt a unified approach to education and training that will strengthen the human resources development capacity of the nation
- Relevance – to be dynamic and responsive to national development needs
- Credibility – to demonstrate national and international value and recognition of the qualification and acquired competencies and skills
- Coherence – to work within a consistent framework of principles and certification
- Flexibility – to allow for creativity and resourcefulness when achieving learning outcomes, to cater for different learning styles and to use a range of assessment methods, instruments and techniques
- Participation – to enable stakeholders to participate in setting standards and coordinating the achievement of the qualification
- Access – to address barriers to learning at each level to facilitate students' progress
- Progression – to ensure that the qualification framework permits individuals to move through the levels of the national qualification via different, appropriate combinations of the components of the delivery system

- Portability – to enable students to transfer credits of qualifications from one learning institution and/or employer to another institution or employer
- Articulation – to allow vertical and horizontal mobility in the education system when accredited prerequisites have been successfully completed
- Recognition of prior learning – to grant credits for a unit of learning following an assessment or if a student possesses the capabilities specified in the outcomes statement
- Validity of assessments – to ensure that assessment covers the broad range of SKVAs needed to demonstrate applied competency, which is achieved through:
  - clearly stating the outcome to be assessed;
  - selecting the appropriate or suitable evidence;
  - matching the evidence with a compatible or appropriate method of assessment; and
  - selecting and constructing an instrument(s) of assessment
- Reliability – to ensure that assessment practices are consistent so that the same result or judgement is arrived at if the assessment is replicated in the same context; this demands consistency in the interpretation of evidence and therefore careful monitoring of assessment is vital
- Fairness and transparency – to verify that no assessment process or method(s) hinder(s) or unfairly advantage(s) any student; the following could constitute unfairness in assessment:
  - Inequality of opportunities, resources or teaching and learning approaches
  - Bias based on ethnicity, race, gender, age, disability or social class
  - Lack of clarity regarding learning outcome being assessed
  - Comparison of a student's work with that of other students based on learning styles and language
- Practicability and cost-effectiveness – to integrate assessment practices within an outcomes-based education and training system and strive for cost- and time-effective assessment.

6.2 Assessment framework for vocational qualifications

The assessment structure for the NC(V) qualification is as follows:

Internal continuous assessment

SKVAs are assessed throughout the year using assessment instruments such as projects, tests, assignments, investigations, role play and case studies. The ICASS practical component is undertaken in a real workplace, a workshop or a structured environment. This component is moderated internally and externally quality-assured by Umalusi. All ICASS evidence is kept in a portfolio of evidence (PoE) and must be readily available for monitoring, moderation and verification purposes.

Special projects

In addition to the prescribed continuous assessment practicals, fifteen projects have been included in the Facilitator's Guide, and fourteen in the Student Book. According to the *NCV Subject and Assessment Guidelines: Electronics and Digital Concepts for Robotics, NQF Level 2–4, Implementation* *date: January 2023–2025*, page 54, authors should create five projects from the category of prescribed projects. In addition, five original projects and three linked with Robotics are required.

The aim of the projects is to allow students the opportunity to experience first-hand the specific functions of electronic components and enhance their understanding of electrical circuits, particularly how circuits can be designed to achieve desired outcomes. Furthermore, the projects aim to assess students' understanding of the theory covered in this course in a practical way, building on the basic coding skills and circuit design knowledge developed in *NCV2 Fundamentals of Electronics and Digital Concepts for Robotics*.

For further consolidation with the Robotics outcomes for Level 3, the four integrated projects emphasise the link between the two subjects. This opportunity allows students to see how the knowledge and skills acquired in separate subjects can be combined to produce more complex results. Please note that the integrated projects may only be used for assessment purposes in Robotics Level 3.

Refer to Addendum A where the projects are set out. Note that the projects should be assigned according to the abilities and learning experience of the students. The available time and resources should also be considered.

External summative assessment

The external summative assessment (ESASS) is either a single or a set of written papers set to the requirements of the subject learning outcomes. The Department of Higher Education and Training administers the theoretical component according to relevant assessment policies.

A compulsory component of ESASS is the integrated summative assessment task (ISAT). This assessment task draws on the students' cumulative learning throughout the year. The task requires integrated application of competence and is executed under strict assessment conditions. The task should take place in a simulated or structured environment. The ISAT is the most significant test of students' ability to apply their acquired knowledge.

ESASSs will be conducted annually between October and December, with provision made for supplementary sittings.

6.3 Moderation of assessment

Internal moderation

Assessment must be moderated according to the internal moderation policy of the Technical and Vocational Education and Training (TVET) college. Internal college moderation is a continuous process. The moderator's involvement starts with the planning of assessment methods and instruments and follows with continuous collaboration with and support to the assessors. Internal moderation creates common understanding of assessment standards and maintains these across vocational programmes.

External moderation

External moderation is conducted by the Department of Higher Education and Training, Umalusi and, where relevant, an Education and Training Quality

Assurance (ETQA) body according to South African Qualifications Authority (SAQA) and Umalusi standards and requirements.

The external moderator:

- monitors and evaluates the standard of all summative assessments;
- maintains standards by exercising appropriate influence and control over assessors;
- ensures that proper procedures are followed;
- ensures that summative integrated assessments are correctly administered;
- observes a minimum sample of 10 to 25% of summative assessments;
- gives written feedback to the relevant quality assessor; and
- moderates in case of a dispute between an assessor and a student.

Policy on inclusive education requires that assessment procedures for students who experience barriers to learning be customised and supported to enable these students to achieve their maximum potential.

6.4 Period of validity of ICASS

The period of validity of the ICASS mark is determined by the National Policy on the Conduct, Administration and Management of the Assessment of the National Certificates (Vocational). The ICASS must be resubmitted with each examination enrolment for which it constitutes a component.

6.5 Assessor requirements

Assessors must be subject specialists and should ideally be declared competent against the standards set by the Education, Training and Development Practices Sector Education and Training Authority. If the lecturer conducting the assessments has not been declared a competent assessor, an assessor who has been declared competent may be appointed to oversee the assessment process to ensure the quality and integrity of assessments.

6.6 Types of assessment

Assessment benefits the student and the lecturer. It informs students about their progress and helps lecturers make informed decisions at different stages of the learning process. Depending on the intended purpose, different types of assessment can be used.

- **Baseline assessment**
  At the beginning of a level or learning experience, baseline assessment establishes the SKVAs that students bring to the classroom. This knowledge assists lecturers to plan learning programmes and learning activities.
- **Diagnostic assessment**
  This assessment diagnoses the nature and causes of learning barriers experienced by specific students. It is followed by guidance, appropriate support and intervention strategies. This type of assessment is useful to make referrals for students requiring specialist help.

- **Formative assessment**
  This assessment monitors and supports teaching and learning. It determines students' strengths and weaknesses and provides feedback on progress. It determines whether a student is ready for summative assessment.
- **Summative assessment**
  This type of assessment gives an overall picture of students' progress at a given time. It determines whether the student is sufficiently competent to progress to the next level.

6.7 Planning assessment

An assessment plan should cover three main processes:

- **Collecting evidence**
  The assessment plan indicates which subject outcomes and assessment standards will be assessed, what assessment method or activity will be used and when this assessment will be conducted.
- **Recording**
  Recording refers to the assessment instruments or tools with which the assessment will be captured or recorded. Therefore, appropriate assessment instruments must be developed or adapted.
- **Reporting**
  All the evidence is put together in a report to deliver a decision for the subject.

6.8 Methods of assessment

Methods of assessment refer to who carries out the assessment and includes lecturer assessment, self-assessment, peer assessment and group assessment.

LECTURER ASSESSMENT	The lecturer assesses students' performance against given criteria in different contexts, such as individual work, group work, etc.
SELF-ASSESSMENT	Students assess their own performance against given criteria in different contexts, such as individual work, group work, etc.
PEER ASSESSMENT	Students assess another student's or group of students' performances against given criteria in different contexts, such as individual work, group work, etc.
GROUP ASSESSMENT	Students assess the individual performance of other students within a group or the overall performance of a group of students against given criteria.

6.9 Instruments and tools for collecting evidence

All evidence collected for assessment purposes is kept or recorded in the student's PoE.

The table below summarises a variety of methods and instruments for collecting evidence. A method and instrument are chosen to give students ample opportunity to demonstrate that the subject outcome has been attained. This will only be possible if the chosen methods and instruments are appropriate for the target group and the specific outcome being assessed.

	METHODS FOR COLLECTING EVIDENCE		
	OBSERVATION-BASED (LESS STRUCTURED)	TASK-BASED (STRUCTURED)	TEST-BASED (MOST STRUCTURED)
ASSESSMENT INSTRUMENTS	• Observation • Class questions • Lecturer, student, parent discussions	• Assignments or tasks • Projects • Investigations or research • Case studies • Practical exercises • Demonstrations • Role play • Interviews	• Examinations • Class tests • Practical examinations • Oral tests • Open-book tests
ASSESSMENT TOOLS	• Observation sheets • Lecturer's notes • Comments	• Checklists • Rating scales • Rubrics	• Marks (e.g. %) • Rating scales (1–7)
EVIDENCE	• Focus on individual students • Subjective evidence based on lecturer observations and impressions	**Open middle:** Students produce the same evidence but in different ways **Open end:** Students use the same process to achieve different results	Students answer the same questions in the same way, within the same time

6.10 Tests

A test could be a practical test (design- and development-oriented) or a written test. The programme of assessment should reflect a balance between practical and written tests. Tests could include open-book tests.

A test for formal assessment should not comprise a series of small tests, but should cover a substantial amount of content and the duration should be a minimum of 60 minutes.

Open-book tests require students to find information and apply knowledge and skills. Students are tested on understanding and application of learning material and not on rewriting. Open-book tests should not include only short questions. They must include questions/tasks that will encourage thinking and decision making.

For written open-book tests, students are required to write longer reflective answers, such as paragraph-type responses to a given scenario. Paragraphs providing reasons and supporting evidence/arguments are essential.

For practical open-book tests, students are required to apply a combination of a series of procedures and techniques to new situations in order to provide a specific answer or accomplish a specific goal.

Alternative assessment

Alternative assessment is an alternative to standard tests and exams. It provides a true evaluation of what students have learned, going beyond acquired knowledge by looking at their application of this knowledge.

Integrated task/test

An integrated task/test requires students to be able to apply their knowledge and skills in both the theory and the practical work that was covered. Testing these types of scenarios include, for example database theory together with database practical, algorithm with implementation and using a trace table to debug a programme.

Case study

Case studies are investigations of a real-life situation or simulation thereof. Data are gathered from a variety of sources and by using several different methods. A case study requires an in-depth and detailed examination of a scenario, as well as the related contextual conditions.

Each test, open-book test, alternative assessment task and examination must reflect different cognitive levels.

6.11 Tools for assessing student performance

Rating scales are marking systems where a symbol (such as 1 to 7) or a mark (such as 5/10 or 50%) is defined in detail. The detail is as important as the coded score. Traditional marking, assessment and evaluation mostly used rating scales without details such as what was right or wrong, weak or strong, etc.

Task lists and checklists show the student what needs to be done. These consist of short statements describing the expected performance in a particular task. The statements on the checklist can be ticked off when the student has adequately achieved the criterion. Checklists and task lists are useful in peer or group assessment activities.

Rubrics are a hierarchy (graded levels) of criteria with benchmarks that describe the minimum level of acceptable performance or achievement for each criterion. Using rubrics is a different way of assessing and cannot be compared to tests. Each criterion described in the rubric must be assessed separately. Two types of rubrics are mainly used, namely the holistic or the analytical rubric.

6.12 Selecting and/or designing recording and reporting systems

The selection or design of recording and reporting systems depends on the purpose of recording and reporting student achievement. Why particular information is recorded and how it is recorded determine which instrument will be used.

Computer-based systems, for example spreadsheets, are cost- and time-effective. The recording system should be user-friendly, and information should be easily accessed and retrieved.

6.13 Competence descriptions

All assessment should award marks to evaluate specific assessment tasks. However, marks should be awarded against rubrics and not simply be a total of ticks for right answers. Rubrics should explain the competence level descriptors for the SKVAs that a student must demonstrate to achieve each level of the rating scale.

When lecturers or assessors prepare an assessment task or question, they must ensure that the task or question addresses an aspect of a subject outcome. The relevant assessment standard must be used to create the rubric to assess the task or question. The descriptions must clearly indicate the minimum level of attainment for each category on the rating scale.

6.14 Strategies for collecting evidence

A number of different assessment instruments may be used to collect and record evidence. Examples of instruments that can be (adapted and) used in the classroom include the following:

- **Record sheets**
  The lecturer observes students working in a group. These observations are recorded in a summary table at the end of each project. The lecturer can design a record sheet to observe students' interactive and problem-solving skills, attitudes towards group work and involvement in a group activity.
- **Checklists**
  Checklists should have clear categories to ensure that the objectives are effectively met. The categories should describe how the activities are evaluated and against what criteria they are evaluated. Space for comments is essential.

6.15 Schedule of assessment

At NQF levels 2, 3 and 4, lecturers will conduct assessments as well as develop a schedule of formal assessments that will be undertaken in the year. All three levels also have an external examination that accounts for 50% of the total mark. The marks allocated to assessment tasks completed during the year, kept or recorded in a PoE, account for the other 50%.

The PoE and the external assessment include practical and written components. The practical assessment in Principles of Computer Programming must, where necessary, be subjected to external moderation by Umalusi or an appropriate ETQA body, appointed by the Umalusi Council in terms of Section 28(2) of the General and Further Education and Training Quality Assurance Act No. 58 of 2001.

6.16 Recording and reporting

The subject EDCR, as is the case for all the other vocational subjects, is assessed according to five levels of competence. The level descriptions are explained in the following table:

RATING CODE	RATING	MARKS %
5	Outstanding	80–100
4	Highly competent	70–79
3	Competent	50–69

RATING CODE	RATING	MARKS %
2	Not yet competent	40–49
1	Not achieved	0–39

The programme of assessment should be recorded in the lecturer's portfolio of assessment for each subject. The portfolio should at least include the following:

- Contents page
- Formal schedule of assessment
- Requirements for each assessment task
- Tools used for each assessment task
- Recording instrument(s) for each assessment task
- Mark sheet and report for each assessment task.

The college must standardise these documents. The student's PoE must include at least the following:

- Contents page
- Assessment tasks according to the assessment schedule.

6.17 Specifications for external assessment in EDCR

Background

The NC(V) qualification comprises an internal and an external assessment component that both have a weighting of 50%. The internal assessment component is made up of the ICASS tasks only, while the external assessment component is made up of the ISAT and an external examination for vocational subjects.

COMPONENT	WEIGHTING PER COMPONENT	TASK	WEIGHTING PER TASK
Internal assessment	50%	ICASS	50%
External assessment	50%	ISAT	15%
		External examination	35%

Practical assessments form part of both the ICASS and the ISAT tasks of the NC(V) qualification. While the ISAT accounts for 15% of the final subject mark, it is a common standardised practical task, as it is externally set by the Department. The five assessments comprising the ICASS component of the vocational subjects accounting for 50% of the final subject mark are, however, internally set and therefore vary in standard from one institution to the next.

Two of these five ICASS assessments are practical in nature and make up 50% of the ICASS mark, which represents 25% of the final subject mark.

ICASS TASK	QUANTITY	WEIGHTING OF ICASS
Tests	2	10% × 2 = 20%
Practical assessments	2	25% × 2 = 50%
Internal examination	1	30%

In 2017, the two PATs forming part of the ICASS were standardised to ensure a uniform standard across institutions and to improve the chances of employment of NC(V) graduates in the workplace. New subject ISATs were simultaneously introduced in order to facilitate unhindered progression between NC(V) levels in accordance with the NC(V) policy on admission and progression.

The NC(V) policy further requires that assessment tasks must be reviewed on a regular basis to ensure continual relevance, credibility, validity and fairness. The initial PATs have now been reviewed to assess new curriculum content introduced in 2019. The two reviewed practical ICASS assessments as well as the reviewed ISAT contained in this document must be implemented in 2019.

The practical assessments for the ICASS and ISAT tasks are to be implemented as a series of three practical tasks per vocational subject to ensure that the practical competencies prescribed per subject are assessed in an authentic practical context that focuses on applied competence.

TASK NO.	PRACTICAL ASSESSMENT
1	ICASS PAT 1
2	ICASS PAT 2
3	ISAT

Purpose and value of practical assessments to the workplace

The practical ISAT and ICASS assessments play a central role in expressing the vocational nature of the NC(V) qualification, as they require the demonstration of the practical application of theoretical knowledge through the performance of assessment tasks that replicate or simulate a workplace or real-life process and/or product. Performance in these practical assessments is therefore used by industry as a measure to determine readiness of NC(V) graduates to enter the workplace.

Integrated summative assessment task

A compulsory component of the ESASS is the ISAT. The ISAT draws on the students' cumulative learning achieved throughout the year. The task requires integrated application of competence and is executed and recorded in compliance with assessment conditions.

Principles for the conduct of practical assessments

The following principles are applicable to the conduct of practical assessments:

- Each student must be provided with a copy of a subject assessment schedule that includes all three practical assessments (see ICASS guidelines).
- The criteria to be used to assess student performance in a practical assessment must be made available to the students and be explained prior to the conduct of each practical assessment.
- All practical assessments, i.e. performance-based and/or creation of product/artefact, must be undertaken in controlled conditions under the direct supervision of the subject lecturer.

- An internal moderator must moderate at least 10% or a minimum of five performance-based assessments during the actual performance.
- Practical assessments must take place in suitable environments relevant to the task specifications, e.g. workshop, computer laboratory, simulator or actual workplace.

7. National examination

A national examination is conducted annually in October or November by means of a paper(s) set and moderated externally. The following distribution of cognitive application is suggested:

Cognitive and difficulty levels of formal assessments

Formal assessments must cater for a range of cognitive levels and abilities of students, as shown in the table below.

COGNITIVE LEVEL	TAXONOMY	DESCRIPTION
C1	Knowledge, remembering	Recall of factual/process knowledge in isolation, i.e. one step/set of basic steps/instruction/process at a time, e.g. definitions in the theory paper and known procedures/ algorithms in the practical paper. It also presents the knowledge of the various theoretical components and subject content relating to the composition and design of EDCR-based systems. These include: • knowledge about the various components and constituents of a robot; • design-related aspects and considerations; and • knowledge of the applicability and application of formulas.
C2	Understanding, applying	Demonstrates understanding of: • steps/algorithms/processes/ isolatable bits, such as translating from one form of representation to another, e.g. converting a flow chart representation of a program/program segment to a functional program; and • various components and their applications, uses and common properties It also requires using known routines/algorithms/ processes/design constructs and components in a familiar context in order to complete a task, where all of the information required is immediately available to the student.
C3	Analysing, evaluating, creating	Requires reasoning/investigation/developing a plan or sequence of steps/algorithms or electronics-related artefact in the form of a component; has some complexity where students need to see how parts relate to a whole; organising/putting together component parts/elements to form a coherent functional whole/ achieving an overall objective and completing a task could have more than one possible approach. It could also require weighing possibilities, deciding on the most appropriate solution, as well as testing to locate errors/troubleshooting, pattern recognition and generalisation.

COGNITIVE LEVEL	TAXONOMY	DESCRIPTION
C3 *(continued)*		These questions will comprise actions/strategies/ procedures where students are required to create their own solutions to challenges they may encounter. These questions could include analysing questions or data and decision making.

Levels of difficulty (D) are categorised as follows:

D1: Easy for the average student (in relation to the subject levels 2 to 4) to answer

D2: Moderately challenging for the student (in relation to the subject levels 2 to 4) to answer

D3: Difficult for the average student (in relation to the subject levels 2 to 4) to answer

D4: Very difficult for the average student (in relation to the subject levels 2 to 4) to answer. The skills and knowledge required to answer questions at this level should be included to distinguish among high achievers.

Questions in the formal assessment tasks will assess performance at different cognitive levels, critical thinking skills, problem-solving techniques and difficulty, as outlined below.

In judging the level of difficulty of each question, both the demands that each question makes on the cognitive ability of an average EDCR student and the intrinsic level of difficulty of the question or task are considered. In making this judgement, the difficulty or ease of a particular question is identified. A four-category framework for thinking about question or item difficulty adapted from Leong (2006) has been used in this identification process. This framework comprises the following four general categories of difficulty:

- **Content difficulty:** This indexes the difficulty of the subject matter, topic or conceptual knowledge; some content is inherently more difficult than other content.
- **Stimulus difficulty:** This relates to the linguistic features of the question and the challenge that students face in reading, interpreting and understanding the question.
- **Task difficulty:** This refers to the difficulty that students face when trying to formulate or produce an answer.
- **Expected response difficulty:** This refers to difficulties because of the mark scheme or marking guidelines, in other words how marks are to be allocated.

Weighting of cognitive levels and difficulty levels

Papers 1 and 2 will include questions across three cognitive levels. The distribution of cognitive levels in the practical and theory papers is given in the table below.

COGNITIVE LEVEL	DESCRIPTION	PAPER 1 (DESIGN-RELATED)	PAPER 2 (THEORY)
1	Knowledge and remembering	40%	40%
2	Understanding and applying	40%	40%
3	Analysing, evaluating and creating	20%	20%

The estimated percentages for each level of difficulty (D) within each cognitive level (C) are shown in the table below.

	D1	D2	D3	D4	TOTAL
C1	±10%	±10%	±10%	–	**±30%**
C2	±15%	±15%	±8%	±2%	**±40%**
C3	±15%	±7%	±5%	±3%	**±30%**
TOTAL	**±40%**	**±32%**	**±23%**	**±5%**	**100%**

Students are required to investigate and analyse problems in a variety of contexts (such as scientific, technological, environmental and everyday life contexts) in order to solve the described problems effectively, either via design and development of a solution or an EDCR-related artefact in Paper 1 or described proposed solutions in Paper 1/Paper 2.

Weighting of cognitive levels and difficulty levels

PAPER	TYPE
1	Theory
2	Design related

Examinations

LEVEL	PAPER 1 (THEORY)	PAPER 2 (DESIGN-RELATED)
2	100 marks 3 hours	80 marks 3 hours
3	100 marks 3 hours	80 marks 3 hours
4	100 marks 3 hours	80 marks 3 hours

Weighting of the topics for the exams

Level 3

LEVEL 3	PAPER 1 (THEORY)	PAPER 2 (DESIGN-RELATED)
Module 1: Magnetism, electromagnetic circuits and related concepts	15%	5%
Module 2: Electrical supply systems, transformers, DC machines, series-parallel networked circuits	15%	15%
Module 3: Electronic components and semiconductors	20%	25%
Module 4: Electrical components, symbols, circuit drawings, prototyping and design	20%	25%
Module 5: Electronic tools and equipment	15%	5%
Module 6: Digital systems, PLCs and principles	15%	25%

Final exam mark

(Mark for Paper 1 + Paper 2)/(combined paper total) × 100

8. Standardisation and considerations

For educational and training purposes, careful consideration should be given to selecting tools, components, hardware and software across the curriculum for the different levels.

The motivation regarding the use of standardised tools and hardware resides in the following points as it helps ensure:
- fair teaching and learning and setting of fair examination papers, and
- stability/compatibility during examinations.

In addition, other motivational factors are discussed on the next page.

8.1 National exam paper setting

Problems that exam panels can experience if different tools/components/ hardware and software are used with different features and configurations. The complexities to synchronise the different tools and versions when setting practical papers impact on content coverage and cognitive demand and/or time required in answering questions.

8.2 Marking of exams

Not standardising implies that markers need to know each of the available components and if colleges do not standardise, marking could become very difficult.

8.3 Migration of lecturers and students

Students and lecturers moving from one college to another could be faced with challenges if they do not have the necessary prerequisite knowledge or knowledge of the new tools or hardware being used.

8.4 Lecturer support

Good information and communication technology lecturers are very scarce and subject support is very specialised. With standardised tools, lecturer support is less troublesome. This is also true for lecturer training programmes.

8.5 Technical support

This is also made difficult in terms of license agreements, setup, advise, etc.

9. Work schedule

WEEK	MODULE	TOPICS	ACTIVITIES	TIME ALLOCATION
1–2	**Module 1** Magnetism, electromagnetic circuits and related concepts	1.1 Magnetic circuits 1.2 Electromagnetism and electromagnetic induction	Activity 1.1 Activity 1.2 Activity 1.3 Activity 1.4 Activity 1.5 Summative assessment	20 hours
3–6	**Module 2** Electrical supply systems, transformers, DC machines, series-parallel networked circuits	2.1 Transformers 2.2 Calculations relating to transformers 2.3 Calculations using series-parallel network circuits 2.4 Calculations based on the grouping of electrical cells 2.5 Solar cells 2.6 DC machines	Activity 2.1 Activity 2.2 Practical activity 2.1 Activity 2.3 Activity 2.4 Practical activity 2.2 Activity 2.5 Activity 2.6 Summative assessment	40 hours
7–10	**Module 3** Electronic components and semiconductors	3.1 Calculating the resistance of a material 3.2 The characteristics and operation of semiconductor diodes 3.3 Bipolar junction transistors 3.4 The characteristics and application of operational amplifiers (op-Amps) 3.5 Capacitors in series, parallel and series-parallel 3.6 Inductors in series, parallel and series-parallel 3.7 How controllers sense and react to physical conditions	Activity 3.1 Activity 3.2 Activity 3.3 Activity 3.4 Activity 3.5 Activity 3.6 Activity 3.7 Summative assessment	40 hours
11–14	**Module 4** Electrical components, symbols, circuit drawings, prototyping and design	4.1 Revising basic concepts 4.2 Symbols of electric components 4.3 Constructing simple circuits on breadboards and Veroboard	Activity 4.1 Activity 4.2 Activity 4.3 Activity 4.4 Activity 4.5 Activity 4.6	40 hours

WEEK	MODULE	TOPICS	ACTIVITIES	TIME ALLOCATION
		4.4 The composition and design of electric circuits	Activity 4.7 Summative assessment	
15–17	**Module 5** Electronic tools and equipment	5.1 Revision of concepts covered in *NCV2 Fundamentals of Electronic and Digital Concepts for Robotics*		30 hours
		5.2 Using electronic measuring instruments	Practical activity 5.1 Practical activity 5.2 Activity 5.1	
		5.3 Use and care of handheld measuring instruments	Practical activity 5.3 Activity 5.2 Summative assessment	
18–20	**Module 6** Digital systems, PLCs and principles	6.1 The use of logic gates	Activity 6.1	30 hours
		6.2 Explaining and using logic gates	Activity 6.2	
		6.3 Logic design	Activity 6.3 Activity 6.4 Summative assessment	
TOTAL				**200**

Module 1

Magnetism, electromagnetic circuits and related concepts

After students have completed this module, they should be able to:

- state and explain the two fundamental laws of magnetism;
- define the following terms and use the appropriate formulae to perform calculations:
  - magnetic flux
  - magnetic flux density
  - magnetomotive force (mmf)
  - magnetic field strength;
- compare electrical and magnetic quantities;
- explain how magnetic fields are produced by electric currents;
- explain the principles of electromagnetic induction;
- explain the purpose and composition of a solenoid;
- state the laws of electromagnetic induction;
- explain the requirements for sketching magnetic field lines;
- sketch magnetic field lines around bar and horseshoe magnets;
- apply the right-hand grip or screw rule and Fleming's left-hand rule to determine the magnetic field around a current-carrying conductor and a solenoid;
- calculate the emf induced in a conductor;
- determine the direction of the induced current by using Fleming's right-hand rule and Lenz's law;
- list and explain the applications of electromagnets;
- list the factors affecting the force of a current-carrying conductor;
- calculate the magnitude of the force of a current-carrying conductor in a magnetic field;
- calculate the force of attraction or repulsion between two parallel, current-carrying conductors;
- define *ampere*; and
- explain the operation of a simple DC motor.

Introduction

Electricity and magnetism are very closely related. They have a mutually interdependent relationship. Magnetism is a fascinating concept and one of the most important ones to understand, as it is the building block for several electrical components, such as transformers and motors. Students have probably played with magnets. Magnets are easy to use and great fun! One of the most amazing things about magnets is the way in which they attract other magnets (or other magnetic materials) from a distance. Magnets and magnetism are very much part of our lives – round magnets are found in speakers; magnetic resonance imaging (MRI) is a process that allows doctors to "see" inside our bodies; and magnetic strips have long been used to store data. For example, the strip on the back of a credit card stores data to identify your account.

Activity 1.1

SB page 9

1. **Name the TWO poles of a magnet.**

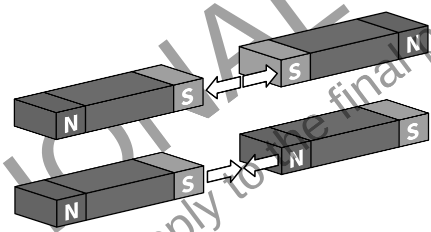
   North pole; South pole

2. **Is the following statement TRUE or FALSE?**

   The greatest attractive force is found at the ends of a magnet.

   True

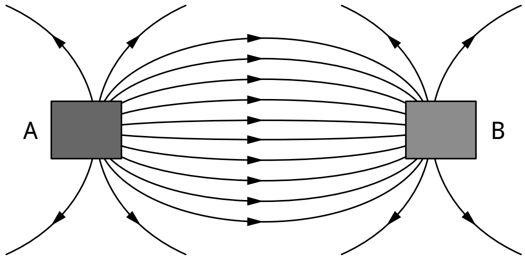
3. **When two magnets are placed near each other, their fields create forces that attract or repel. Make neat, labelled drawings to show these forces.**



4. **Define at least ONE basic law of magnetism.**

   Like poles repel each other; unlike poles attract each other.

5. **The diagram below indicates the magnetic fields between two poles of two bar magnets. Correctly identify the two poles.**



   A = North pole and B = South pole

6. **Write a short definition for *magnetic flux*.**

   Magnetic flux (Φ) refers to the number of magnetic field lines produced by a magnet perpendicular to a given surface.

7. **Write down the formula used to calculate magnetic flux density and state what each symbol represents.**

   $\beta = \frac{\Phi}{A}$

   β = magnetic flux density in tesla (T)

   Φ = magnetic flux in weber (Wb)

   A = area perpendicular to magnetic field in m^2.

   Magnetic flux density is measured in: Weber per square metre ($Wb \cdot m^{-2}$) or tesla (T).

8. **The current flowing through a coil with 125 turns is 25 ampere. Calculate the mmf of the coil.**

   (mmf) $F_m = NI$

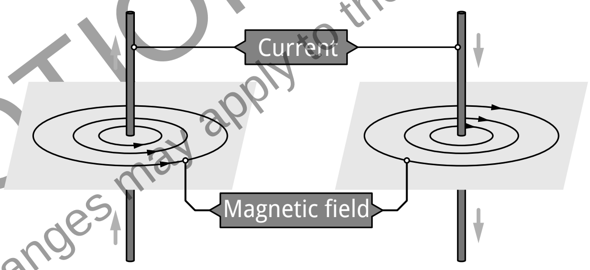
   $= 125 \times 25$

   $= 3\,125$ ampere-turns (At)

9. **When current flows through a conductor, a magnetic field will be created around it. Explain how the right-hand rule can be used to determine the direction of the induced current.**

   Hold the conductor in your right hand so that the fingers wrap around the conductor and your thumb stretches up. Your fingers will indicate the direction of the magnetic field, while the thumb indicates the direction of the current flow.

10. **The diagram below represents the magnetic fields around two current-carrying conductors. In which direction must the currents flow through the conductors to establish the given magnetic fields?**



   The current through the conductor on the left will be from the bottom to the top, and the one on the right will be from top to bottom.

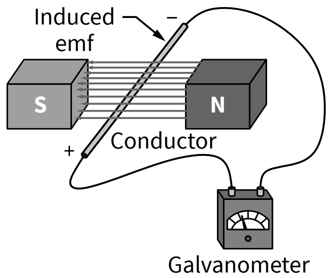
Activity 1.2

SB page 12

1. **Define the term *electromagnetic induction*.**

   Electromagnetic induction is the production of an electromotive force (emf) or voltage across an electrical conductor due to the movement between a conductor and a magnetic field.

2. **The diagram below shows the apparatus used to determine how an emf is generated across a conductor when it is moved through a magnetic field. What do you think the reading will be if the conductor is in the middle of the magnetic field but stationary (not moving)? Give a reason for your answer.**



If there is no movement of the conductor, no emf will be induced. No emf is induced because the conductor is not cutting any magnetic lines.

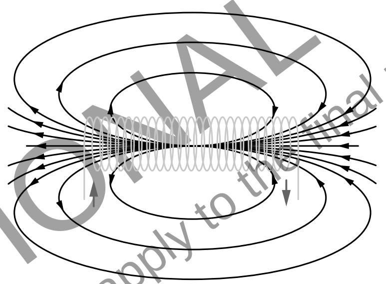
3. **Name TWO factors that will influence the magnitude of the induced emf when a conductor moves through a magnetic field.**

The magnitude of this induced emf will depend on the speed at which we move the conductor up or down through the magnetic field as well as the strength of the magnetic field.

4. **Define a *solenoid*.**

A solenoid is a cylindrical coil of wire.

5. **Make a neat drawing to show the magnetic field around a solenoid.**



6. **Write down Faraday's TWO laws of electromagnetic induction.**

Faraday's two laws of electromagnetic induction may be stated as follow:
- An emf can be induced in a conductor whenever there is a change in the magnetic flux linking with the conductor.
- The magnitude of the induced emf is directly proportional to the rate of change of the magnetic flux linking with the conductor.

Activity 1.3

SB page 22

1. **Name the THREE types of magnets.**

Natural magnets, permanent magnets and electromagnets.

2. **What is the magnetic rock that was discovered by the ancient Greeks called?**

   Magnetite

3. **Briefly explain the term *magnetism*.**

   Magnetism is that strange, invisible force of attraction and repulsion between certain materials.

4. **Explain the difference between the magnetic field around a straight conductor and a solenoid (coil).**

   The magnetic field around the solenoid is much stronger than that of the straight conductor.

5. **Explain the difference between a *permanent magnet* and an *electromagnet*.**

   Permanent magnets: They have all the characteristics of natural magnets but are made of hardened steel and certain alloys of nickel and cobalt. They retain their magnetism indefinitely. Permanent magnets can have different shapes, e.g. round, horseshoe and rectangular.

   Electromagnets: These are magnets that are formed when an electric current is passed through a coil. If current flows, electromagnets will maintain their magnetism, but as soon as the current is switched off, the coil will lose its magnetism.

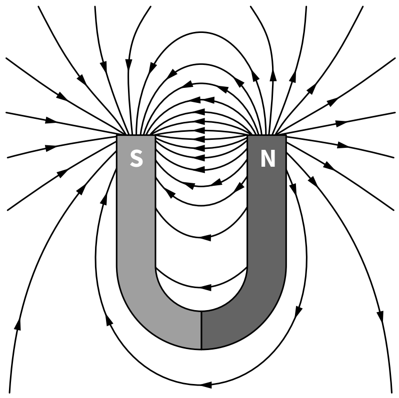
6. **List THREE applications of electromagnets.**

   - Relays and valves
   - Electric motors and transformers
   - Door bells and buzzers
   - Lifting equipment in scrapyards
   - Induction cookers
   - MRI scanners
   - Magnetic locks (Any THREE)

7. **Why are the magnetic field lines more concentrated at the two poles of a magnet?**

   Because the forces of attraction are more concentrated at the poles

8. **Make a neat, labelled drawing showing the magnetic fields around a horseshoe magnet.**



9. Write down your understanding of the term *magnetic field*.

The magnetic field can be referred to the area around a magnet where a magnetic force can be felt.

10. List THREE characteristics of magnetic field lines.

- Magnetic field lines run from the north pole to the south pole.
- Magnetic field lines never cross each other. In other words, the lines running from one pole to the next will always be parallel to each other.
- The stronger the magnetic field, the closer the magnetic lines will be to each other.
- Magnetic field lines are continuous. A magnetic line will run from north to south outside the magnet and the same line will also run from south to north inside the magnet.
- These magnetic field lines are more concentrated at the poles. That is why the forces of attraction are stronger at the poles of the magnets than at the centre. (Any THREE)

11. Define the term *magnetic flux density*.

Magnetic flux density (β) refers to the number of magnetic lines per unit area.

12. Explain how you will determine the polarity of a solenoid by using the right-hand rule.

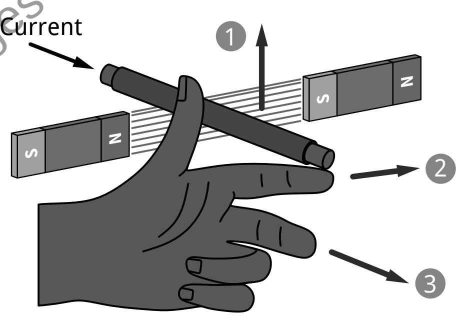
If the solenoid is gripped in the right hand with the fingers pointing in the direction of the current, the outstretched thumb points to the north end of the solenoid.

13. Write down the formula to calculate magnetic field strength.

$H = \frac{Fm}{l}$, where F_m is the magnetomotive force and l is the length of the circuit, or

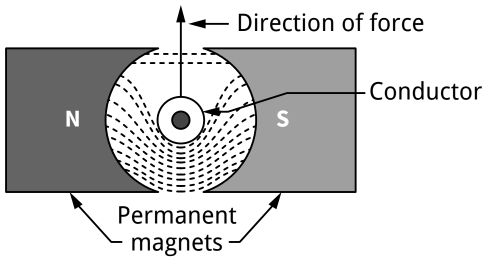
$H = \frac{NI}{l}$, where N is the number of turns, l, the length of the coil and I the current flowing through the circuit.

14. With reference to Fleming's right-hand rule, as indicated in the diagram below, identify what is represented by the three arrows labelled 1, 2 and 3 in the diagram.



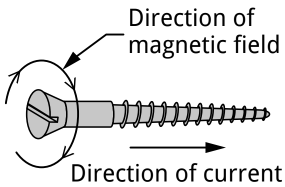
1 = Direction of the force (motion)
2 = Direction of the magnetic field
3 = Direction of the current

15. **With reference to the diagram below, will the current be flowing into the page or out of the page?**



The current will be flowing out of the page through the conductor.

16. **The screw rule can be used to determine the direction of the magnetic field around a straight current-carrying conductor. Redraw the given diagram and use an arrowhead to indicate the direction of the magnetic field.**



The magnetic field will be clockwise.

17. **With reference to a coil (solenoid), briefly explain the right-hand grip rule.**

If the solenoid is gripped in the right hand with the fingers pointing in the direction of the current, the outstretched thumb points to the north end of the solenoid.

Activity 1.4

SB page 27

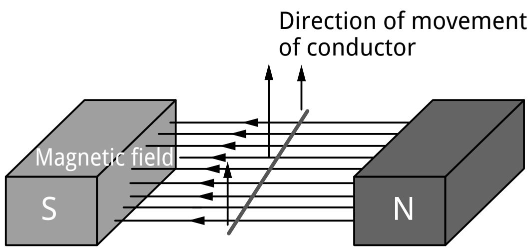
1. **A conductor of 1,25 m in length is moved perpendicular to a uniform magnetic field of 0,36 T at a rate of 12 m/s. Calculate the induced emf in the conductor.**

emf = $\frac{\beta}{\nu}$

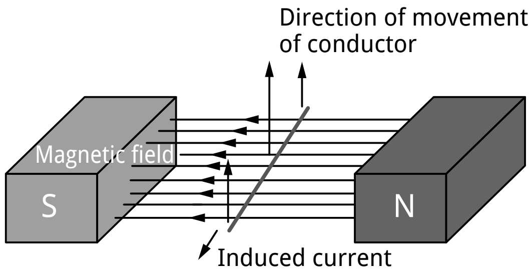
= 0,36 × 1,25 × 12

= 5,4 Volt (V)

2. **With reference to the following diagram, and by making use of Flemings's right-hand rule, determine the direction of the induced current in the conductor.**



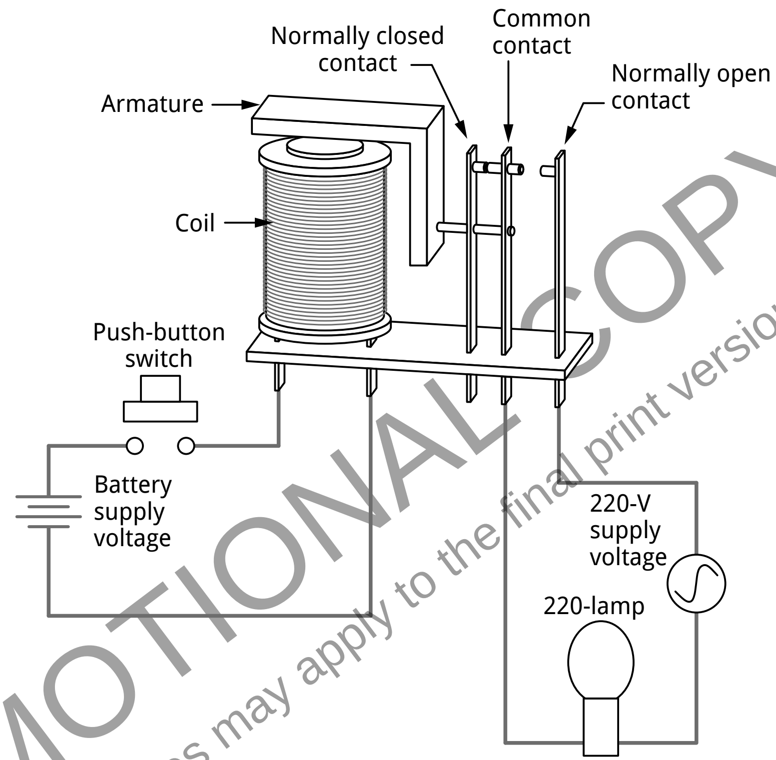
The direction of the current flow will be out of the page.



3. **Define** ***Lenz's law*****.**

Lenz's law states that: The direction of the induced current is such that it tends to set up a current opposing the motion that produced it.

4. **With reference to the following diagram, explain the basic operation of a relay.**



- As soon as the switch is closed, current will flow through the circuit energising the coil.
- The energised coil will now attract the L-shaped armature.
- As the armature is pulled in, it will open and close the switches of the relay – the normally open switch will close, and the normally closed switch will open.

5. **Give ONE advantage of using relays in circuits.**

A relay will allow one circuit to switch a second circuit which can be separate from the first, e.g. a low-voltage battery circuit can use a relay to switch a 230-V AC mains circuit.

6. **Give ONE application of a lifting magnet.**

   Lifting magnets are temporary magnets most used in scrapyards and recycling plants to move metallic objects from one place to another.

Activity 1.5

SB page 33

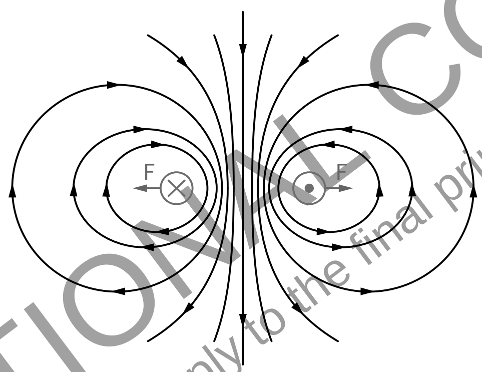
1. **How would you increase the force on a current-carrying conductor?**

   - Increase the strength of the magnetic field.
   - Increase the current flow.
   - Increase the length of the conductor.

2. **A conductor that is 1,5 m long and carrying 5-A current is placed perpendicular to a uniform magnetic field of 2 T. Calculate the magnitude of the magnetic force on the wire.**

   $F = I\,l\,\beta \sin\theta$
   $= 5 \times 1{,}5 \times 2 \times \sin(90)$
   $= 5 \times 1{,}5 \times 2 \times 1$
   $= 15$ N

3. **Make a neat, labelled drawing to show the magnetic field around two parallel current-carrying conductors where the currents are flowing in opposite directions.**



4. **Explain why there will be an attractive force between two parallel current-carrying conductors if the current through them flows in the same direction.**

   The magnetic field between the two wires flows in the same direction, hence creating an attractive force between the two current-carrying conductors, pulling them closer to each other.

5. **Calculate the force between two parallel current-carrying conductors, placed 350 cm apart, each carrying a current of 25 A in opposite directions. The length of each conductor is 2,5 m. Take the permeability of free space to be $4\pi \times 10^{-7}$ H/m.**

   $F = \frac{\mu_{0.L.I1I2}}{2\pi r}$

   $= \frac{4\pi \times 10^{-7} \times 2{,}5 \times 25 \times 25}{2\pi \times 3{,}5}$

   $= \frac{2 \times 10^{-7} \times 2{,}5 \times 25 \times 25}{3{,}5}$

   $= 8{,}929\ 10^{-5}$ N (repulsive force)

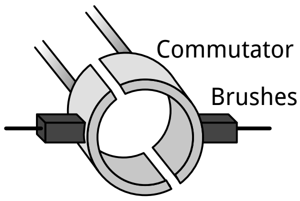
6. Define the term *ampere*.

If two long parallel wires are 1 m apart and each carries a current of 1 A, then the force per unit length on each wire is 2×10^{-7} N/m.

7. Name the FOUR main parts of a DC motor.

- Armature/Rotor
- Stator (permanent magnets)
- Commutator
- Brushes

8. The diagram below shows a commutator and brushes. Explain the functions of each part.



Commutator: The commutator reverses the current flow within a coil winding when the shaft turns.

Brushes: They connect the DC supply to the armature/rotor/coil ensuring that current flows from the supply via the commutator to the coil winding.

9. Name THREE applications of the DC motor.

- Toys
- Electric cars
- Robots
- Pumps
- Power tools
- Printer
- Electric aircraft
- Elevators, etc. (Any THREE)

Summative assessment

SB page 34

1. When two magnets are placed near each other, their fields create forces that attract or repel. What will happen when magnets of like poles approach each other?

Like poles will repel. (1)

2. Write down a detailed definition for *magnetic flux density*.

Magnetic flux density (β) refers to the number of magnetic lines per unit area.

Magnetic flux density is a vector quantity and is measured in weber per square metre ($Wb{\cdot}m^{-2}$) or tesla (T). (3)

3. **The flux density of 35 Wb/m² (tesla) is measured over an area of 0,00025 m². Calculate the value of the total flux in this area.**

$\Phi = \frac{\beta}{A}$

$= 35 \times 0{,}00025$

$= 8{,}75 \times 10^{-3}$ Wb or 8,75 mWb (3)

4. **Calculate the flux density if the magnetic flux in the poles of an electric motor is 0,4 weber, with an area of 0,02 square metres.**

$\Phi = \frac{\beta}{A}$

$\beta = \frac{0{,}4}{0{,}02}$

= 20 tesla (T) or (Wb/m^2) (3)

5. **A current of 4,5 ampere is flowing through a coil with 350 turns. Calculate the mmf developed in the coil.**

(mmf) $F_m = NI$

$= 350 \times 4{,}5$

= 1 575 ampere-turns (At) (3)

6. **The soft iron core of an electromagnet is 600 mm long. If the current of 3,5 ampere flows through 500 turns, calculate:**

6.1 **The mmf produced**

(mmf) $F_m = NI$

$= 500 \times 3{,}5$

= 1 750 ampere-turns (At) (3)

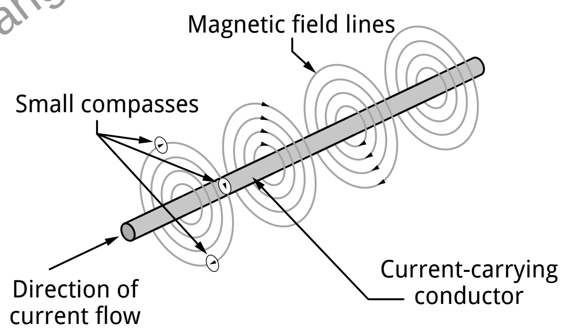
6.2 **The magnetic field strength of the circuit.**

$H = \frac{NI}{l}$

$= \frac{500 \times 3{,}5}{0{,}6}$

= 2 916,67 ampere/meters (A/m) (3)

7. **Make a neat, labelled drawing to show the magnetic fields around a current-carrying conductor. Indicate the magnetic field direction as well as the current direction.**



(4)

8. Name THREE factors which have an influence on the magnitude of an induced emf.

- The speed at which the conductor is moved up or down through the magnetic field
- The strength of the magnetic field
- The active length of the conductor (3)

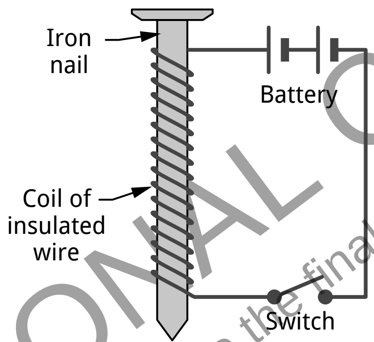
9. What can be done to strengthen the magnetic field of a solenoid?

The field strength can be increased by increasing the number of turns in the coil or by increasing the current through the coil. Wrapping the coils around a soft iron core will also increase the magnetic field strength. (2)

10. Explain the rule used to determine the north pole of a solenoid/coil.

The polarity of a magnetic field around a solenoid/coil may be determined by the right-hand rule. If the solenoid/coil is gripped in your right hand with your fingers pointing in the direction of the current, the outstretched thumb points to the north end of the solenoid/coil. (4)

11. Make a drawing of a simple electromagnet, and briefly explain its operation.



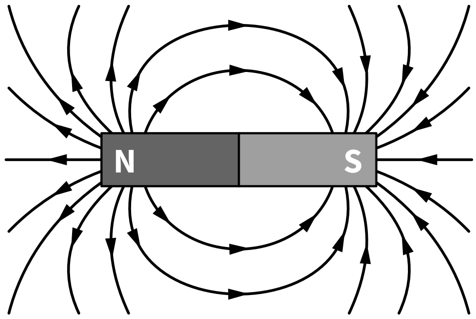
As soon as current is flowing through the circuit, the soft iron core (the nail) will be magnetised and will act as a temporary magnet. When the current stops flowing, the core loses its magnetic characteristics. (8)

12. Give THREE applications of an electromagnet.

- Relays and valves
- Electric motors and transformers
- Doorbells and buzzers
- Lifting equipment used in scrapyards
- Induction cookers
- MRI scanners
- Magnetic locks, etc. (Any THREE)

(3)

13. Make a neat, labelled drawing of the magnetic field around a bar magnet.



(4)

14. Define *Lenz's law*.

Lenz's law states that the direction of the induced current is such that it tends to set up a current opposing the motion that produced it. (3)

15. Explain how the screw rule helps one to determine the direction of the magnetic field around a conductor.

The direction of current flow and magnetic field lines can also be determined by comparing it to the action of turning a screw into wood. The direction of travel represents the direction of conventional current flow and the direction of turning represents the direction of the magnetic flux. (3)

16. Calculate the induced emf in a straight conductor, 40 cm long, moving through a magnetic field of 0,75 tesla at a velocity of 500 cm/s.

$\text{emf} = \frac{\beta}{\nu}$

$= 0{,}75 \times 0{,}4 \times 5$

$= 1{,}5$ volt (V) (3)

17. A conductor that is 25 cm long moves at a velocity of 150 cm/s through a magnetic field to produce an induced emf of 75 volt. Calculate the flux density of the magnetic field.

$B = \frac{\text{emf}}{l \times V}$

$= \frac{75}{0{,}25 \times 1{,}5}$

$= 200$ T (3)

18. Briefly explain how a lifting magnet works.

When current starts to flow through the coils of the lifting magnet, magnetic fields are formed around it, changing it into a magnet and allowing it to pick up metallic objects.

When current stop flowing through the circuit, the lifting magnet will be switched off, thus losing its magnetic characteristics and dropping the metallic objects. (4)

19. Calculate the force between two parallel current-carrying conductors, placed 0,025 m apart, each carrying a current of 125 A in opposite directions. The length of each conductor is 1,5 m. Take the permeability of free space to be $4\pi \times 10^{-7}$ H/m.

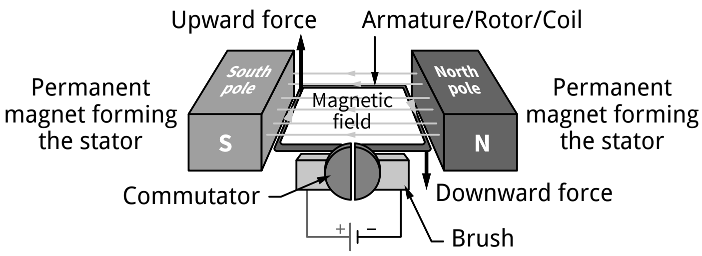
$$F = \frac{\mu_{0.L.I1I2}}{2\pi r}$$

$$= \frac{4\pi \times 10^{-7} \times 1{,}5 \times 125 \times 125}{2\pi \times 0{,}025}$$

$$= \frac{2 \times 10^{-7} \times 1{,}5 \times 125 \times 125}{0{,}025}$$

= 0,1875 N (repulsive) (3)

20. With reference to the given sketch, briefly explain the basic operation of a DC motor.



A DC motors requires a magnetic field and a current-carrying conductor. According to Fleming's left-hand rule, the conductor on the left always experiences a force in an upward direction, while the conductor on the right experiences a downward force. In other words, the DC motor spins due to the interaction between the magnetic field of the permanent magnet and the magnetic field of the current-carrying conductor. Hence, a unidirectional torque is achieved in DC motors. The direction of rotation of a DC motor can be changed by simply changing around the polarity of the supply. (8)

TOTAL: 74

Module 2

Electrical supply systems, transformers, DC machines, series-parallel networked circuits

After students have completed this module, they should be able to:

- explain the principle of operation of a *transformer*;
- explain the rating of a transformer;
- list the advantages, disadvantages and applications of autotransformers;
- distinguish between different types of transformers and explain related terminology;
- explain, with examples, the following electrical supply systems:
  - single-phase supply systems;
  - three-phase supply systems;
- sketch sine wave voltage waveforms with different amplitudes and frequencies;
- explain and sketch phase angle displacement in three-phase supplies;
- explain, with examples, the use of different electrical supply systems in South Africa;
- explain the advantages and disadvantages of different electrical supply systems;
- use the ideal transformer equation to perform calculations (single-phase);
- list losses in a transformer and calculate efficiency;
- explain how three-phase transformers are constructed;
- sketch the different transformer connections and identify their uses;
- use transformer equations to perform calculations (three-phase);
- list and explain the methods of cooling used in dry-type and oil-immersed type transformers;
- explain the function of the conservator, breather and Buchholz relay of a transformer;
- calculate total resistance, current and voltage drop for given circuits using different methods;
- apply Kirchhoff's laws in electric circuit calculations;
- conduct a practical circuit experiment to verify calculations within the range;
- demonstrate an understanding of the concept of *potential difference (PD)*;
- explain the difference between emf and PD;
- demonstrate an understanding of *internal resistance*;
- explain the concepts of *voltage drop* and *current drain* due to overload;
- determine how long a battery will be able to deliver current to a load;
- demonstrate an understanding regarding the concept of *ampere hours* using calculations;

- explain concepts such as *emf of cells, internal resistance, terminal voltage* and *grouping of cells*;
- perform calculations for typical circuits involving the grouping of cells given practical examples;
- explain the difference between primary cells and secondary cells;
- list examples and applications of primary cells and secondary cells;
- sketch and explain different types of batteries;
- differentiate between *renewable* and *non-renewable energies*;
- explain how solar energy is converted into electrical energy;
- outline the benefits and disadvantages of solar energy;
- differentiate between different types of solar cells;
- outline the advantages and disadvantages of photovoltaic cells;
- compare conventional energy sources to solar energy;
- demonstrate how solar panels can be configured as a power source;
- explain the term *charge controller*;
- explain the term *voltage regulator*;
- explain how solar panels are rated;
- discuss how the position of the sun affects the amount of solar energy that can be concentrated and stored;
- explain the purpose and use of an inverter;
- discuss the concepts of *kilowatt hour* and *daylight hour*;
- explain the purpose of a voltage regulator as part of a solar project;
- perform basic calculations to determine how the use of solar cells combined with other power sources can be used in projects;
- design and build a simple project incorporating solar cells and other sources of power;
- explain the functions of a *motor* and a *generator*;
- explain the construction of a DC machine;
- distinguish between *lap winding* and *wave winding*;
- explain *armature reaction*;
- list and discuss types of DC generators;
- calculate terminal voltage and generated emf of a generator;
- list and discuss types of DC motors;
- list losses in DC machines;
- list the characteristics and applications of DC motors;
- explain the purpose of a DC motor starter; and
- explain how the speed of DC motors can be controlled.

Introduction

When dealing with the distribution of electrical energy, we split the system into three parts. The first part deals with electricity generation, the second with how the electrical energy is transmitted via high-voltage cables (called transmission lines), and the third part focuses on how the electrical energy is distributed to the electricity consumers. The consumers require electricity to run their machines and equipment, which could either be connected in series, parallel or a combination of the two.

Activity 2.1

SB page 50

1. **What is the principle of operation of any transformer?**

   Electromagnetism

2. **Describe the basic operation of a transformer.**

   A varying current in the first (or primary) winding creates a continually changing magnetic field around that coil and hence in the core of the transformer. This changing magnetic field cuts the secondary winding, inducing a varying electromotive force (emf), or voltage, in the secondary winding. This effect is called *mutual induction*.

3. **What is meant by the *classification* of a transformer?**

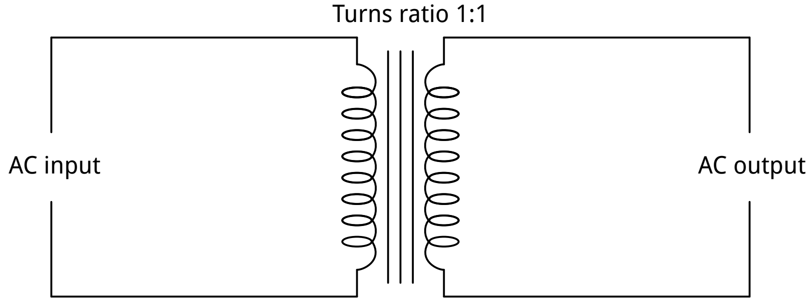
   Transformers are adapted to numerous engineering applications and may be classified as follows:

   - by power level (from fraction of a watt to many megawatts);
   - by application (power supply, impedance matching, circuit isolation);
   - by frequency range (power, audio, RF);
   - by voltage class (a few volts to about 750 kilovolts);
   - by cooling type (air-cooled, oil-filled, fan-cooled, water-cooled, etc.);
   - by purpose (rectifier, arc furnace, amplifier output, etc.); and
   - by ratio of the number of turns in the coils.

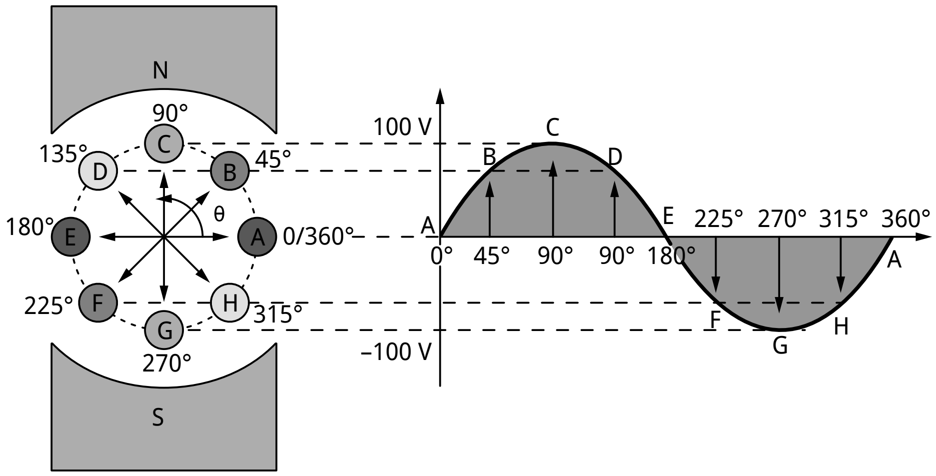
4. **Explain, by means of an example, the difference in construction between a step-up and step-down transformer.**

   There is no difference in construction. Take a transformer with a turns ratio of 50:3. If it is used with 50 windings on the primary and three on secondary, it is a step-down transformer. If it is used with three windings on the primary and 50 on the secondary, it is a step-up transformer.

5. **Draw a neat, fully labelled sketch of an isolation transformer.**



6. **Explain, with the aid of a sketch, how a single-phase AC supply is generated.**

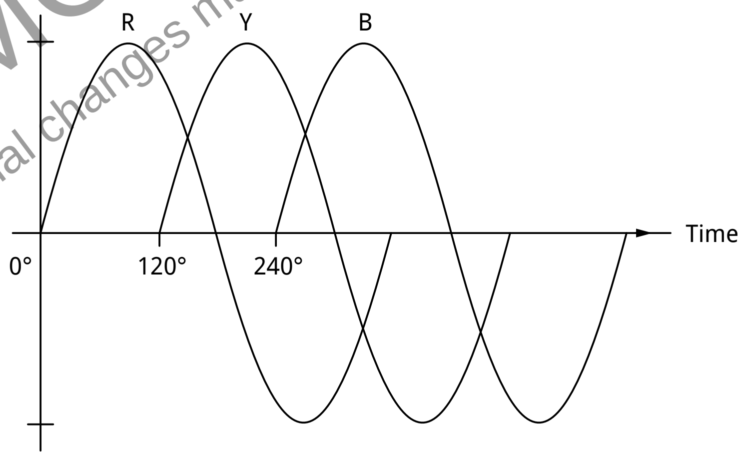


- At 0° the conductor moves parallel with respect to the magnetic field and no current is induced.
- At 45° the conductor moves at an angle with respect to the magnetic field and some current is induced.
- At 90° the conductor moves perpendicular with respect to the magnetic field and maximum current induced.
- At 180° the conductor moves parallel with respect to the magnetic field again and no current is induced.
- At 270° the conductor moves perpendicular with respect to the magnetic field but in the opposite direction. Maximum current induced, but it flows in the opposite direction.
- At 360° the conductor moves parallel with respect to the magnetic field and no current is induced.
- This completes one cycle of the generated AC wave.

7. **What is the phase displacement between the phases in a three-phase generator?**

   120°

8. **Draw the basic waveform of a three-phase generated wave.**



9. **Explain the difference between *amplitude*, *frequency* and *period*.**

   Amplitude is the value of the induced voltage or current from the *x*-axis to the highest point of the wave. It is also referred to as the peak value.

   Frequency is the number of complete waves that pass a fixed point in one second.

   Period is the time that it takes to complete one cycle.

10. **What does the term *PEN* stand for?**

    Protected earthed neutral

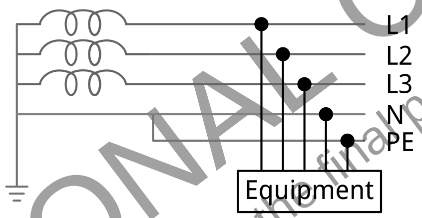
11. **Name the THREE basic power systems as defined by the IEC.**

    TT system, TN system, and IT system

12. **Name the advantages of the TNS system.**

    - The TNS power-supply system is safe and reliable, suitable for low-voltage power-supply systems such as industrial and civil buildings.
    - It can be used before construction works begin.
    - When the system is running normally, there is no current on the dedicated protection line.
    - There is no voltage on the PE line to the ground, so the zero protection of the metal shell of the electrical equipment is connected to the special protection line PE, which is safe and reliable.

13. **Draw a neat, labelled sketch of the TNC-S system.**



Activity 2.2

SB page 63

1. **A single-phase transformer has 690 turns on the primary winding, which is connected to a 230-V AC supply. The voltage and current on the secondary side are 24 V and 3 A, respectively. Determine:**

   1.1 **The number of turns on the secondary side**

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$N_p = \frac{N_p.V_s}{V_p}$$

$$= \frac{690 \times 24}{230}$$

$$= 72 \text{ turns}$$

1.2 The value of the primary current

$$\frac{I_p}{I_s} = \frac{V_s}{V_p}$$

$$I_p = \frac{I_s \times V_s}{V_p}$$

$$= \frac{3 \times 24}{230}$$

$$= 313{,}07 \text{ mA}$$

1.3 The turns ratio

$$\frac{N_p}{N_s} = \frac{690}{72}$$ Ratio is 10 :1

1.4 The voltage per turn on the primary side.

Voltage per turn = $\frac{690}{230}$ = 3 V per turn

2. **A single-phase transformer with a turns ratio of 50:2 is connected to a 240-V AC supply. A 2-kΩ load is connected to the secondary side. Determine:**

2.1 The secondary voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = \frac{V_p N_s}{N_p}$$

$$= \frac{240 \times 2}{50}$$

$$= 9{,}6 \text{ V}$$

2.2 The value of the secondary current

$$I_{sec} = \frac{V_s}{RL} = \frac{9{,}6}{2\ 000} = 4{,}8 \text{ mA}$$

2.3 The primary current

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

$$I_p = \frac{I_s \times N_s}{N_p}$$

$$= \frac{4{,}8 \text{ mA} \times 2}{50}$$

$$= 319\ \mu\text{A}$$

2.4 The power rating of the transformer

$P = I_p V_p = 319 \text{ mA} \times 240 = 46 \text{ mW}$

OR: $P = I_s V_s = 4{,}8 \text{ mA} \times 9{,}6 = 46 \text{ mW}$

3. **List the FOUR losses that occur in transformers and briefly explain what is meant by each type of loss.**

- *Copper losses*: These are losses due to the resistance of the copper wires
- *Iron losses*: Occur due to resistance and hysteresis of the laminated iron core
- *Dielectric losses*: If the insulated lacquer layer around windings is damaged or not sufficient, a small leakage current will flow
- *Stray losses*: The magnetic fields cut the surrounding metal parts of the transformer casing

4. **Calculate the efficiency of a transformer if the input power is 5 kVA and the output power is 4,7 kVA.**

$$\eta = \frac{P_{output}}{P_{input}} \times 100$$

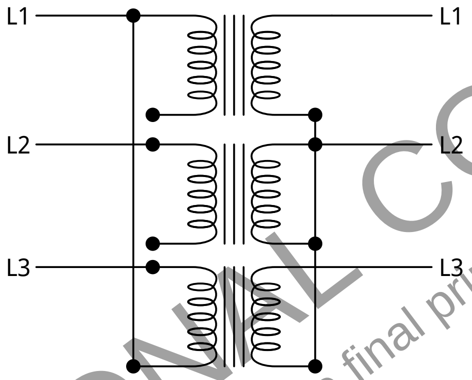
$$= \frac{4\,700}{5\,000} \times 100$$

$$= 94\%$$

5. **Explain the difference between the core- and the shell-type transformer.**

CORE	SHELL
Core is enclosed	Windings are enclosed
Three limbs	Five limbs
Less weight	More weight
Less expensive	Higher cost
Low-voltage transformer	High-voltage transformer
Coils are easily removed	Coils are difficult to remove

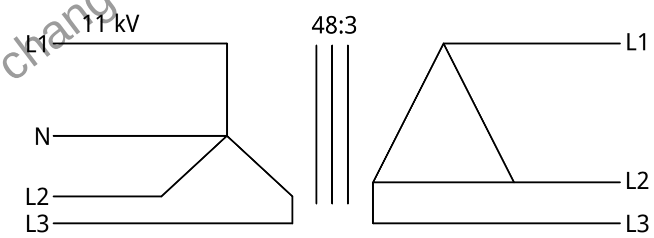
6. **Identify the type of three-phase transformer connection shown below.**



Delta-star

7. **Consider a single three-phase transformer with a turns ratio of 84:5 that is connected to an 11-kV supply voltage. The transformer is connected in star-delta.**

   7.1 Represent the system by means of a neat fully labelled sketch.



7.2 Calculate the secondary line voltage.

$$V_{PH} = \frac{VL}{\sqrt{3}}$$

$$= \frac{22\,000}{\sqrt{3}}$$

$$= 6{,}35 \text{ kV (Star)}$$

$$\frac{V_{sec(ph)}}{V_{prim(ph)}} = \frac{N_s}{N_p}$$

$$V_{sec} = \frac{(6\,350{,}85)(5)}{84}$$

$$= 378{,}03 \text{ V}$$

$$V_{L(sec)} = V_{PH(sec)}$$

$$= 378{,}03 \text{ V}$$

8. What do we call the cooling method used when a transformer is submerged in oil and a fan is used to cool it further?

Oil-cooled, air-blast method

9. Give TWO reasons for the use of a conservator tank in transformers.

It provides space for the oil that expands due to heat, so pressure does not build up inside the tank. It also serves as a reservoir to ensure there is more than enough oil in to keep the transformer cool.

10. The Buchholz relay provides two types of protection. Briefly explain this statement.

Signalling faults – As excess currents flow through the the transformer, they cause heat in the windings. This heats up the oil, causing air bubbles. Some bubbles will accumulate in the top of the Buchholz relay, causing a float at the top of the relay to drop. Once sufficient air is trapped in the relay it will activate the top mercury tilt switch and sound an alarm.

Short-circuit faults – When a short circuit occurs, the sudden increase in current will cause an excess of bubbles to be formed. This rush of bubbles will move at high speed towards the relay and activate the bottom mercury tilt switch. This in turn will activate the mechanism that disconnects the supply from the transformer.

Practical activity 2.1 (SB page 71) **INDIVIDUAL ACTIVITY**

Objective:
Conduct a practical circuit experiment to verify calculations. Use a breadboard to build a series circuit to test Kirchoff's laws.

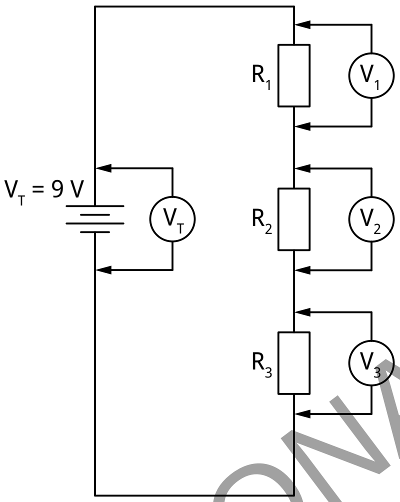
You will need:
- Three resistors with R_1 = 100 Ω, R_2 = 220 Ω and R_3 = 270 Ω
- 9-V DC supply
- Breadboard
- Connecting wires
- Multimeter with appropriate voltage and current scales. (If you have access to more ammeters and voltmeters, it will make the process a little easier. One good meter will do. It will just take a little longer.)

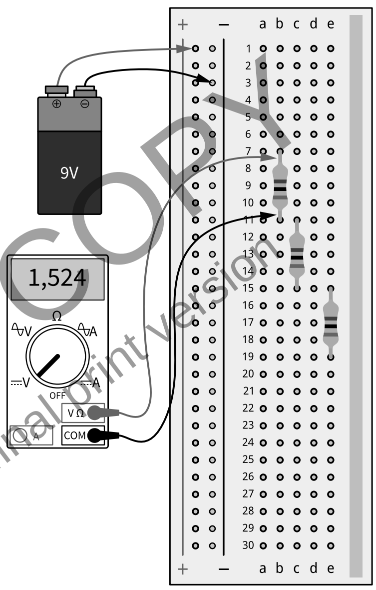
Practical activity 2.1 (continued)

The experiment will be conducted in two steps. After each step the results will be compared to Kirchoff's laws. In the first step all the voltages will be measured and in the second step all the currents will be measured.

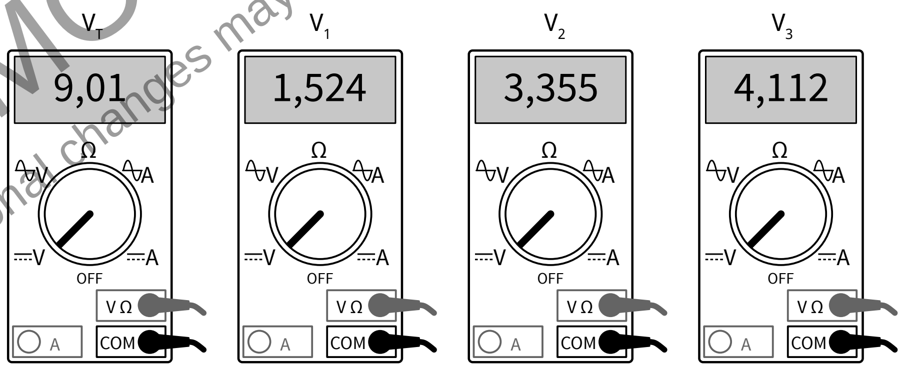
Instructions:
Step 1:

- Construct the series circuit on the breadboard.
- Connect the power supply.
- Set the multimeter to the DC scale. Use whatever setting is suitable on your meter, as long as the voltage setting is higher than 9 V.
- Record all the voltage readings.
- Check whether the voltage drops around the circuit add up to the supply voltage. Allow for small variances as all experiments have inconsistencies due to the tolerance of the resistors, resistance of connecting wires and resistance of all points where wires join components.





Our recorded readings were as follows:



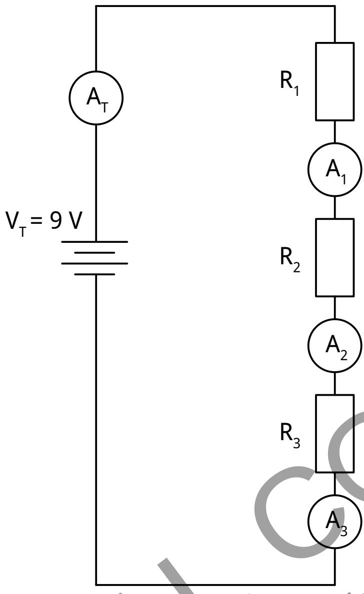
This proves Kirchoff's law that the voltage drops around the circuit add up to the supply voltage.

$V_T = V_1 + V_2 + V_3$ = 1,524 + 3,355 + 4,112 = 8,991 V ~ 9 V
(There is a small variance of 0,009 V.)

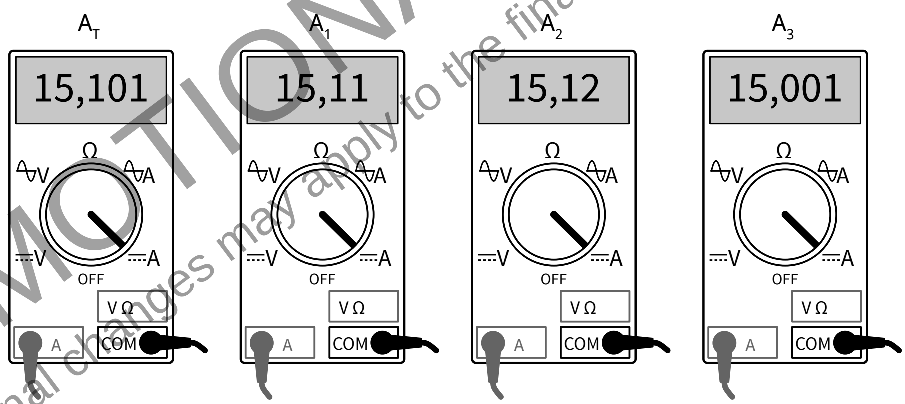
Practical activity 2.1 (continued)

Step 2:

- Set the multimeter to the current scale. The meter should be able to measure mA.
- Remember that, in order to measure current, the wires in the circuit will have to be disconnected and rewired to allow the ammeter to be inserted.
- Record all the current readings.
- Check whether the currents around the circuit are all equal. Once again, allow for small variances.



Our recorded current readings were as follows:



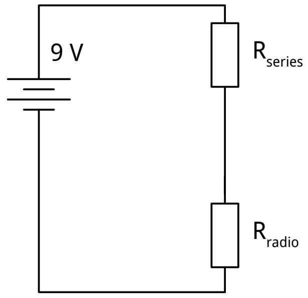
This proves Kirchoff's law that the current flowing in a circuit is the same everywhere.

$I_T = I_1 = I_2 = I_3 = 15{,}101$ mA

Activity 2.3

SB page 77

1. **You want to listen to the weather report on a 6-V radio. The radio has a total internal resistance of 50 Ω. Unfortunately, the only supply that is available is a 9-V battery. Use your knowledge of Kirchoff's laws to determine the value of the series resistor that will cause the correct voltage dividing network so that the radio can operate without being damaged by a 9-V supply. Supply a working circuit diagram.**

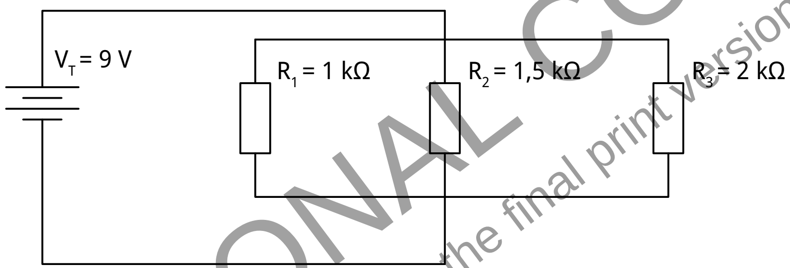


$V_{series} = V_T - V_{radio} = 9 - 3 = 3\text{ V}$

$I_T = \frac{V_{radio}}{R_{radio}} = \frac{6}{50} = 120\text{ mA}$ (Current is the same everywhere in a series circuit)

$R_{series} = \frac{V_{series}}{I} = \frac{3}{120\text{ mA}} = 25\ \Omega$

2. **The following parallel circuit is given. Calculate:**



2.1 The total resistance of the circuit

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$= \frac{1}{1\,000} + \frac{1}{1\,500} + \frac{1}{2\,000}$

$R_T = 461{,}54\ \Omega$ (Remember, the total value is always smaller than the smallest value.)

2.2 The total current flowing in the circuit

$I = \frac{V_T}{R_T} = \frac{9}{461{,}54} = 19{,}5\text{ mA}$

2.3 The current flowing through each resistor.

$I_1 = \frac{V_1}{R_1} = \frac{9}{1\,000} = 9\text{ mA}$

$I_2 = \frac{V_2}{R_2} = \frac{9}{1\,500} = 6\text{ mA}$

$I_3 = \frac{V_3}{R_3} = \frac{9}{2\,000} = 4{,}5\text{ mA}$

$I_T = I_1 + I_2 + I_3$
$= 9\text{ mA} + 6\text{ mA} + 4{,}5\text{ mA}$
$= 19{,}5\text{ mA}$

3. **State Kirchoff's two laws for a parallel circuit.**
   - The voltage drops across all branches are the same
   - The current entering a point is the same as the current leaving a point

4. **A battery's voltage is measured with a digital multimeter. The first measurement is taken across the terminals of just the battery. Then a lamp is connected, and the terminal voltage is measured again. Explain the difference between the two measurements taken.**

Just the battery	emf	no load voltage (V)
With the lamp	pd	load voltage (V)

5. **Why is the voltage drop across the internal resistance of a battery zero when you measure the emf of the battery?**

   No current will flow, therefore $V_{int} = I \times R_{int} = 0 \times R_{int} = 0\text{ V}$

6. **Determine (theoretically) how long a 105-AH battery will be able to deliver current to a load at a constant rate of 2,34 A.**

   $\text{Time} = \frac{\text{rating}}{I} = \frac{105}{2{,}34} = 44{,}87\text{ hours}$

Activity 2.4

SB page 91

1. **Three cells are connected in series. Each cell has an emf of 1,5 V and an internal resistance of 0,4 Ω. This new combination is connected to a 10-Ω load resistor. Calculate the following:**

   1.1 The emf of the battery

   $E = e_1 + e_2 + e_3 = 1{,}5 + 1{,}5 + 1{,}5 = 4{,}5\text{ V}$

   1.2 The total internal resistance

   $R_{int} = r_{int\ 1} + r_{int\ 2} + r_{int\ 3}$
   $= 0{,}4 + 0{,}4 + 0{,}4$
   $= 1{,}2\ \Omega$

   1.3 The total current that will flow through the resistor

   $I = \frac{E}{RL + R_{int}} = \frac{4{,}5}{10 + 1{,}2} = 401{,}79\text{ mA}$

   1.4 The internal voltage drop

   $V_{int} = I \times R_{int} = 401{,}79\text{ mA} \times 1{,}2 = 0{,}48\text{ V}$

   1.5 The terminal voltage of the battery with the resistor connected.

   $V = I \times R_L = 401{,}79\text{ mA} \times 10 = 4{,}02\text{ V}$

2. Three cells are connected in parallel. Each cell has an emf of 1,5 V and an internal resistance of 0,5 Ω.

2.1 Determine the emf of the battery.

$E = e_1 = e_2 = e_3 = 1{,}5\ V$

2.2 Calculate the total internal resistance.

$R_{int} = \frac{R_{int\ 1}}{2} = \frac{0{,}5}{3} = 0{,}17\ \Omega$

3. What is the main difference between a primary and a secondary cell?

Primary: Cannot be recharged
Secondary: Can be recharged

4. Name THREE advantages of a mercury (button) cell.

Any THREE of the following:

- Voltage is very constant until discharged
- Good for low-current applications
- Large capacity for its size
- Long shelf life

5. Name TWO application for lithium-ion batteries.

Any TWO:
Laptop computers, power tool, inverter batteries, etc.

6. What is the part of the lead-acid battery called that prevents the plates from touching each other and causing internal short circuits?

Separators

7. Name TWO advantages of the lead-acid battery.

Any TWO of the following:

- Low cost
- Reliable; over 140 years of development
- Robust; tolerant to abuse
- Tolerant to overcharging
- Low internal impedance
- Can deliver very high currents
- Indefinite shelf life if stored without electrolyte
- Can be left on trickle or float charge for prolonged periods
- Wide range of sizes and capacities available
- Many suppliers worldwide
- The world's most recycled product.

8. Why should lead-acid batteries never be discharged to lower than 80% of their total capacity?

It reduces their lifespan drastically.

9. What is a hydrometer and what is it used for?

A hydrometer is used to test the ratio of the mass of a unit volume of electrolyte to the mass of the same volume of water. This is also known as testing the relative density or specific gravity of the electrolyte.

10. Name THREE tests that should be carried out on any lead-acid battery.

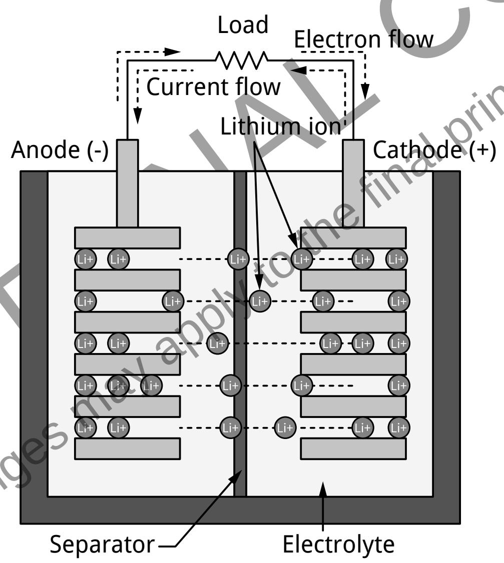
- Density test
- Open-circuit voltage test
- Load tests

11. Name the materials of which the two electrodes of a lithium-ion battery are made.

- The positive electrode is typically made of a chemical compound called lithium-cobalt oxide ($LiCoO_2$).
- The negative electrode is generally made of carbon (graphite).

12. With the aid of a diagram, explain the *discharging cycle* of the lithium-ion battery.

During discharging, the ions flow back through the electrolyte from the negative electrode to the positive electrode through the outer circuit, powering your cell phone, laptop, MP3 player, etc. When the ions and electrons combine at the positive electrode, lithium is deposited there. When all the ions have moved back, the battery is fully discharged and needs charging again.



(During discharging)

13. List THREE advantages and THREE disadvantages of lithium-ion batteries.

Any THREE of the following advantages:

- Very lightweight
- High energy density
- Hold charge for long periods
- Can handle hundreds of charge/discharge cycles

- No maintenance needed (sealed battery)
- A variety of shapes and sizes is available
- No memory effect (can be charged even if not fully discharged)
- Contain relatively low levels of toxic heavy metals (environmentally friendly)

Disadvantages – any THREE:

- Need protective circuitry against overcharge
- Start degrading as soon as they leave the factory (two- to three-year lifespan)
- Reasonably expensive
- Are ruined if completely discharged
- Extremely sensitive to high temperatures

14. Care and maintenance of a lithium-ion battery are important to improve its lifespan. Describe the care and maintenance of these batteries.

- Keep the batteries at room temperature.
- For extended storage, discharge a lithium-ion battery to about 40% and store it in a cool place.
- Use partial-discharge cycles occasionally to prolong battery life. (Allow the battery to run down to 5% once every 30 days.)
- Charge the battery often, rather than letting it run all the way down. (If the battery runs too low, it may die completely.
- Use a battery charger that is made for lithium-ion batteries. (When a lithium-ion battery is fully charged, the charger will adjust to reduce the flow of the current.)
- There is no harm in leaving lithium battery-powered devices, such as laptops or phones, plugged into their chargers, as the charger automatically adjusts to a trickle charge.
- Keep the battery and device away from moisture. The batteries can absorb moisture, which will eventually damage them

15. How would you know if a lithium-ion battery is damaged or about to catch fire?

- Heat
- Swelling
- Noise
- Odour
- Smoke

Practical activity 2.2 (SB page 109) **PAIR ACTIVITY**

Objective:
Set up a simple circuit to power LED lights using solar chargers.

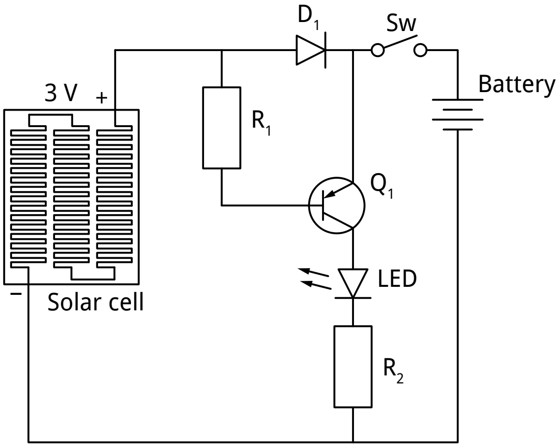
You will need:

- Soldering iron
- Solder
- Stand for soldering iron

Practical activity 2.2 (continued)

You will need (*continued*):

- End-cutting nippers (or side cutters)
- Connecting wires
- Container (box) to mount the circuit in (waterproof)
- Battery holder
- Breadboard for testing and modifications
- Components listed below



COMPONENT LIST	
D_1	Diode (1N5817)
R_1	Resistor (5,6 kΩ)
R_2	Resistor (100 Ω)
Switch	SPST
Q_1	PNP transistor (S8550)
Battery	AA rechargable
LED	High-bright 5 mm
3-V solar cell	

Instructions:

1. **Use the breadboard to connect the components.**
2. **Test the operation of the circuit at different times of the day and night.**

Activity 2.5

SB page 110

1. **What is the difference between *renewable* and *non-renewable* energy sources?**

   Non-renewable sources will eventually be depleted. There will be no more coal, uranium, natural gas or oil to take out of the earth. In contrast, there is an unlimited supply of renewable energy sources, like tidal, sun and wind power.

2. **Name THREE advantages of solar energy.**

   Any THREE correct answers

   - Saving costs
   - Guaranteed supply
   - Clean power
   - Employment opportunities
   - Peace of mind
   - No installation limitations

3. **Name FOUR advantages and FOUR disadvantages of PV cells.**

ADVANTAGES:	DISADVANTAGES:
High reliability	High start-up cost
High durability	Weather conditions determine the amount of energy converted
Low maintenance costs	Energy-storage equipment, such as batteries and inverters, are expensive

ADVANTAGES:	DISADVANTAGES:
Zero fuel consumption	Low efficiency
Zero noise pollution	Lack of knowledge and skills among installers
Environmentally friendly	Toxic chemicals are used
No constant attention required	Inefficient transmission over long distances
Independence from national power grid	Panels are fragile
Space efficient	
Locally available	

4. **Explain the difference between a *charge controller* and a *voltage regulator*.**

   Charge controller: It monitors the output of the solar panels and compares it to the battery voltage. The controller continually adjusts the voltage value to ensure that the battery receives the maximum current without overcharging it.

   Voltage regulator: It allows the charging of the battery at a fixed voltage and allows a very small variance over a wide range of load and input conditions.

5. **What is meant by *peak sun hour*?**

   A peak sun hour is equal to one hour in which the sun's solar irradiance (sunlight) produces an average of 1 000 W per square metre.

6. **Determine how many solar panels of 1,7 m × 1 m (consult table for power ratings) would be required to supply a South-African household with a daily energy consumption of 28 kWh.**

SIZE	AREA	CELLS	WATTAGE
1,7 m × 1 m	1,7 m^2	120 HC cells	300–400 W
2,1 m × 1 m	2,1 m^2	144 HC cells	350–450 W
2,3 m × 1,1 m	2,53 m^2	132 or 156 HC cells	450–560 W
2,4 m × 1,3 m	3,12 m^2	132 or 156 HC cells	560–680 W

   If you require 28 kWh daily use:

   Sunlight hours: $\frac{28\,000}{5,5}$ = 5 090,91 W per hour

   This means we would need $\frac{5\,090,91}{300}$ = 16,96

   Thus, 17 panels required

Activity 2.6

SB page 126

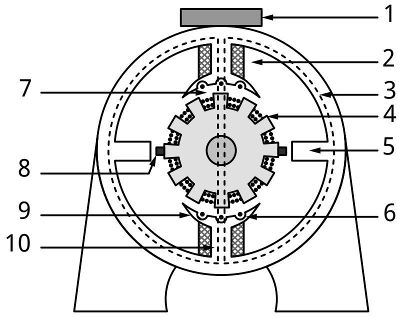
1. **State the functions of motors and generators in terms of energy conversion.**

   An electric motor converts electrical energy into mechanical energy, while a generator converts mechanical energy into electrical energy.

2. **Name the THREE parts of a DC machine.**

   - Stator or the yoke
   - The rotor
   - The commutator

3. Label the parts numbered 1 to 10 in the illustration below.



1	Terminal box
2	Field winding
3	Yokes or stator
4	Armature windings
5	Interpole
6	Compensating windings
7	Air gap
8	Brush
9	Pole shoes
10	Main pole

4. Explain the difference in construction between *lap* and *wave windings*.

In lap winding, the end of the armature coil is connected to the adjacent commutator segment, whereas in wave winding the end of the armature coil is placed in the commutator segment which is some distance apart.

5. Compare the voltage and power ratings of *lap* and *wave winding*.

Lap winding is used on low-voltage, medium power (50 to 500 kW) machines and high-power machines with power ratings above 500 kW. Wave winding is used for high-voltage and low-current machines with power rating of less than 50 kW.

6. Briefly explain the *demagnetising* and *cross-magnetising* effect that armature reaction has on motors.

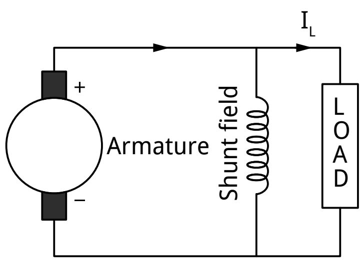
Armature reaction has two effects on the motor:

- Demagnetising effect: It reduces the strength of the main flux
- Cross-magnetising effect: It bends/distorts the main flux line along the conductor

7. Name the TWO main types of DC generators.

Separately excited and self-excited

8. Draw a circuit diagram for a shunt generator.



9. Name TWO applications of a shunt generator.

Any TWO of the following:

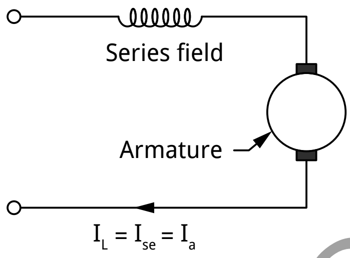
- Battery charging, because it gives the correct voltage according to the condition (even when the direction of the current through the battery is reversed, its polarity does not change)
- As an accelerator for the secretion motor and the generator
- Electroplating and other types of electrolysis
- Constant-speed lathe machines

10. A separately excited generator has an armature resistance of 0,15 Ω and supplies 5 kW at an emf of 240 V. Calculate the current drawn as well as the terminal voltage (potential difference) across the load.

$I = \frac{P}{V} = \frac{5\,000}{240} = 20{,}83$ A

$V = E - I_aR_a = 240 - (20{,}83 \times 0{,}15) = 236{,}88$ V

11. Draw a labelled circuit diagram for a series motor.



12. What are the TWO main characteristics of a series motor?

At no load or at light loads, the armature current, and therefore also the field current, is weak. This results in a dangerously high speed and a series motor should therefore be positively coupled to the load.

13. Compare the starting torque of *shunt* and *series motors*.

Shunt motor: does not have a high starting torque

Series motor: has a high starting torque

14. Compare the load characteristics of shunt, series and compound motors.

Shunt motor: The speed remains relatively constant between no-load and full-load conditions.

Series motor: At no or light loads, the speed of the motor is dangerously high and it should therefore be positively coupled to the load.

Compound motor: The load-torque characteristics are somewhere between those of a shunt motor and a series motor.

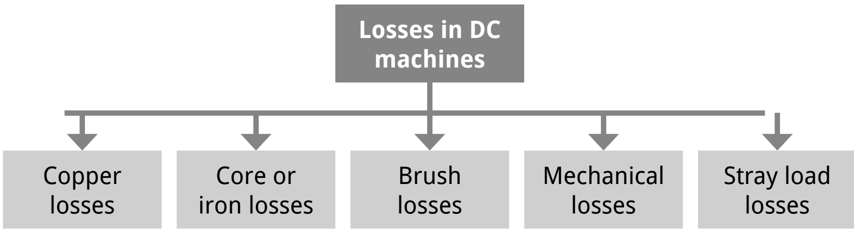
15. A 240-V DC motor has an armature resistance of 0,85 Ω. It is drawing an armature current of 25 A while driving a certain load. Calculate the induced emf in the motor under these conditions.

$E_{back} = V - I_aR_a = 240 - (25)(0{,}85) = 218{,}75$ V

16. A DC motor has lap-connected armature winding. When connected to a 220-V DC supply it draws an armature current of 32 A. Calculate the back emf with which the motor is running. Assume the armature resistance is 0,7 Ω.

$E_{back} = V - I_aR_a = 220 - (32)(0{,}7) = 197{,}6$ V

17. Briefly discuss each of the losses of a DC motor shown below.



Copper or ohmic losses are losses due to the resistance of the copper wires used for the windings. As current flows it causes heat and the losses due to this heat are known as copper losses.

The *core losses* are the hysteresis and eddy-current losses. These losses are considered almost constant as the machines are usually operated at constant flux density and constant speed. These losses make up about 20 per cent of the full-load losses.

Eddy-current losses are caused by the flow of circulating currents induced in the steel core due to the flow of magnetic flux in the core. The current induced in the core of the transformer is dependent on the core material. These losses can be reduced by using laminated plates.

Hysteresis loss is a heat loss caused by the magnetic properties of the core. This is caused by the repeated reversal of the magnetic field in the core of a transformer. Choosing proper core material that has a low hysteresis coefficient and high permeability can minimise hysteresis losses.

Brush losses are the losses that occur between the commutator and the carbon brushes. It is the power loss at the brush contact point. As the commutator turns and moves past the brushes, it causes friction. The brush drop depends upon the brush contact voltage drop and the armature current.

Mechanical losses are losses that take place because of the mechanical operation of the machines. Mechanical losses are divided into bearing-friction loss (occur as the rotor turns in the bearings) and windage losses in the moving parts of the machine and the air circulating in the machine.

Stray losses are varied. The following factors are considered in stray load losses.

- The distortion of flux because of the armature reaction
- Short circuit currents in the coil, undergoing commutation.

These losses are very difficult to determine. For most machines, stray losses are taken to be one per cent of the full-load output power.

18. Name TWO applications for each of the following DC motors.

18.1 Shunt excited

Where a constant speed is required, as in lathes, or where a low starting torque features, as in fans

18.2 Series excited

For starting motor-vehicle engines, and driving cranes, trains, hoists, lifts, trolley buses and other electric vehicles

18.3 Compound motors

They are particularly suitable for applications with fluctuating loads, such as steel rolling mills, guillotines, punch machines and shearing machines. The practical use of a differential compound motor is limited.

19. Which THREE factors determine the speed of a DC motor?

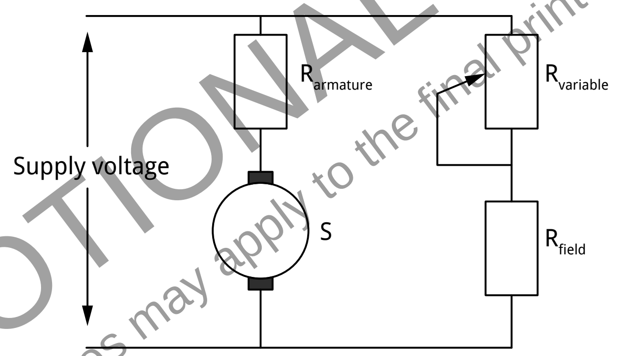
- The speed of the motor is directly proportional to supply voltage.
- The speed of the motor is inversely proportional to armature voltage drop.
- The motor speed is inversely proportional to the flux per pole generated in the field windings.

20. The speed of a DC motor can be controlled by:

- **varying the flux and the current through field winding;**
- **varying the armature voltage and the armature resistance;**
- **varying the supply voltage.**

Briefly discuss the first method. Support your explanation by means of a sketch.

Due to the field winding, the magnetic flux varies in order to vary the speed of the motor. As the magnetic flux depends on the current flowing through the field winding, it can be changed by varying the current through the field-winding. This can be achieved by using a variable resistor in a series with the field-winding resistor.



Initially, when the variable resistor is kept at its minimum position, the rated current flows through the field winding due to a rated supply voltage. As a result, the speed is kept normal. When the resistance increases gradually, the current through the field winding decreases. This in turn decreases the flux produced. Thus, the speed of the motor increases beyond its normal value.

NOTE TO FACILITATOR: PROJECTS

The following projects, included in Addendum A, may be considered:

- *1.6 Air-freshener dispenser with a DC motor;*
- *2.3 A 9-V to 240-V inverter; and*
- *3.2 Robot-controlled electromagnet*

Summative assessment

SB page 127

1. **What is meant by the *kVA rating* of a transformer?**

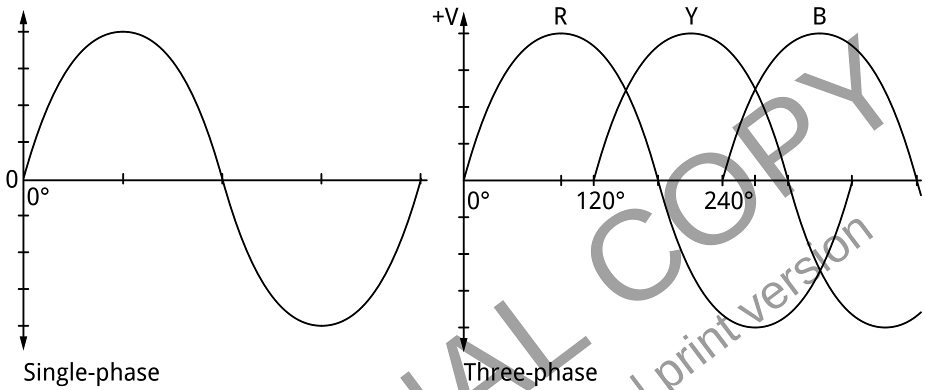
   It refers to how much current the transformer can supply at a certain voltage. (2)

2. **Name THREE advantages of an autotransformer over a conventional transformer.**

   Any THREE correct answers:
   - Only one winding
   - Less copper required
   - Cheaper
   - Lighter
   - Smaller
   - More efficient for the same VA rating
   - Better voltage regulation

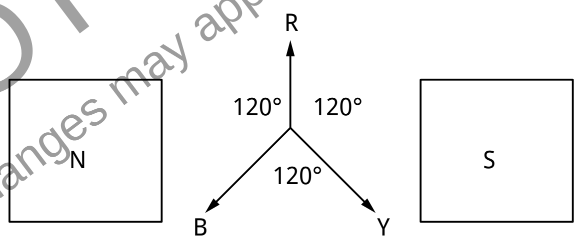
   (3)

3. **Draw TWO simple waveforms to show the difference between *single-phase* and *three-phase* electrical power. Indicate the phase illustrated by each drawing.**



(2)

4. **Three conductors are rotated within a permanent magnetic field to generate a three-phase supply. Determine the induced emf at the angles of rotation given in the table.**



PHASE	ANGLE ROTATION	INDUCED EMF
Red	**180°**	0 V
Yellow	**120°**	0 V
Blue	**240°**	0 V
Red	**270°**	Max negative
Yellow	**210°**	Max positive
Red	**90°**	Max positive

(6)

5. **Use the waveform shown below to answer the following questions:**

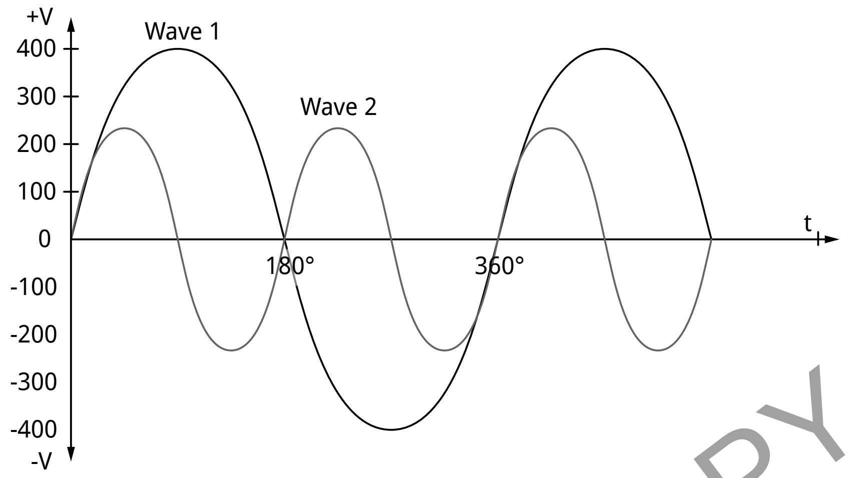
   5.1 **What is the peak voltage for wave 1 and wave 2, respectively?**

   Wave 1 = 400 V Wave 2 = 233 V (2)

   5.2 **What is the peak-peak voltage for wave 1 and wave 2, respectively?**

   Wave 1 = 800 V Wave 2 = 466 V (2)

   5.3 **What is the period of sine wave 1 and 2, respectively?**



   Wave 1 = 360° Wave 2 = 180° (2)

6. **The electrical supply systems used in South Africa are described in the table below. Provide the missing information.**

SYSTEM	VOLTAGE	MEANING
TNC	230 V/400 V	**The neutral conductor and the protective earth are combined throughout the network in a single conductor, the PEN conductor (four-conductor system).**
TNC-S	**230 V/400 V**	The earth and neutral can be separated at the back rear of the distribution box.
TNS	**230 V/400 V**	**The system strictly separates the working neutral N from the dedicated earth line (five-conductor system).**
TT	**230 V/400 V**	**One point is earthed directly (operational earth). The exposed conductive parts of the electrical installation are connected to earth lines separate from the operational earth.**
IT	230 V/400 V/600 V	**This indicates that the power-supply side has no working ground. The exposed conductive parts of the installation are earthed.**

(5)

7. **A transformer connected to a supply and a load is shown below. Calculate the following:**

   7.1 **The turns ratio**

   Turns ratio $\frac{N_p}{N_s} = \frac{10\ 000}{200} = \frac{50}{1}$

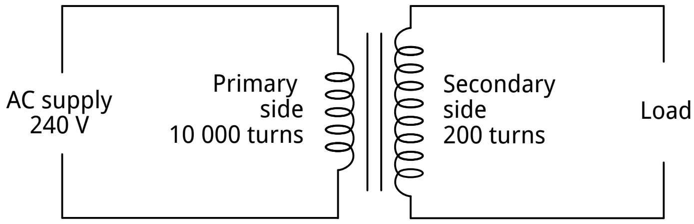
   Therefore the ratio is 50:1 (2)

7.2 The secondary voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(240)(1)}{50} = 4{,}8\ \text{V}$$ (3)

7.3 The secondary current if the load has a resistance of 200 Ω.



$$I_{sec} = \frac{V_{sec}}{R_{load}} = \frac{4{,}8}{200} = 24\ \text{mA}$$ (3)

8. A transformer with a rating of 10 kVA and a windings ratio of 50:3 delivers a secondary voltage of 240 V. Calculate:

8.1 The primary voltage

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p = \frac{V_s N_p}{N_s}$$

$$= \frac{240 \times 50}{3}$$

$$= 4\ \text{kV}$$ (3)

8.2 The current

$$I_p = \frac{P_p}{V_p} = \frac{10\ \text{kVA}}{4\ \text{kV}} = 2{,}5\ \text{A}$$ (3)

8.3 The secondary current.

$$I_s = \frac{P_s}{V_s} = \frac{10\ \text{kVA}}{240} = 41{,}67\ \text{A}$$ (3)

9. Calculate the efficiency of a transformer if the input power is 10 kVA. The copper and iron losses amount to 190 VA.

$$P_{out} = P_{in} - \text{losses}$$

$$= 10\,000 - 190$$

$$= 9\,810\ \text{VA}$$

$$\eta = \frac{P_{output}}{P_{input}} \times 100$$

$$= \frac{9\,810}{10\,000} \times 100$$

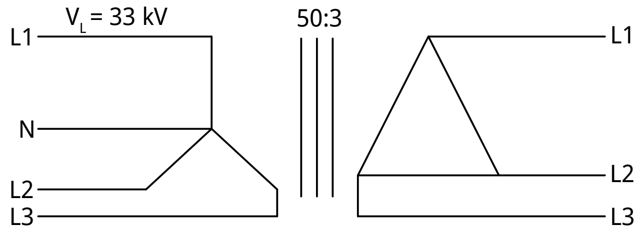
$$= 98{,}1\%$$ (5)

10. Name the FOUR types of three-phase tranformer conenctions.

- Star-star
- Delta-delta
- Star-delta
- Delta-star (4)

11. A single three-phase transformer with a turns ratio of 50:3 is connected to a 33-kV supply voltage. The transformer is connected in star delta.

11.1 Represent this information by means of a neat schematic diagram.



(3)

11.2 Calculate the line voltage on the secondary side.

$V_{PH} = \frac{VL}{\sqrt{3}} = \frac{33\ 000}{\sqrt{3}} = 19{,}05 \text{ kV}$

$\frac{V_{sec(ph)}}{V_{prim(ph)}} = \frac{N_s}{N_p}$

$V_{sec} = \frac{(19{,}05 \text{ kV})(3)}{50}$

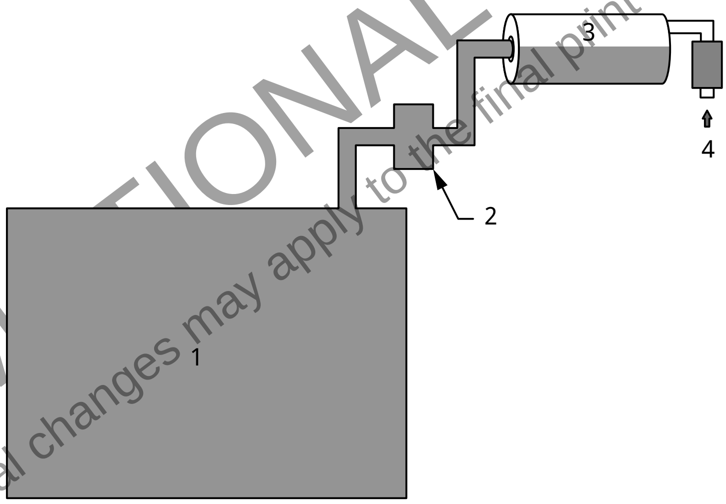
$= 1{,}14 \text{ kV}$

$V_L = V_{PH} = 1{,}14 \text{ kV}$ (6)

12. Which type of protection device used in transformers is triggered when too many gas bubbles are released due to excessive heating?

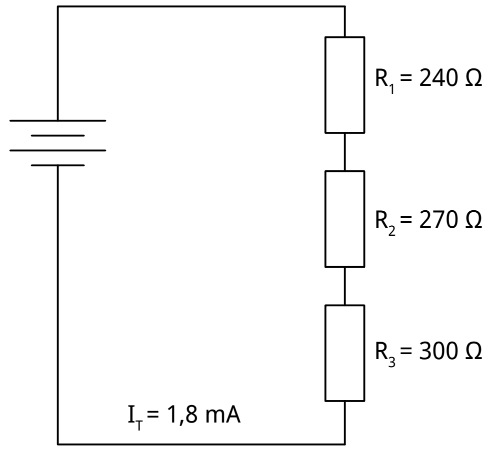
Buchholz relay (1)

13. Name the parts of the transformer numbered 1 to 4 in the diagram below.



1. Main oil tank
2. Buchholz relay
3. Conservator tank
4. Breather (4)

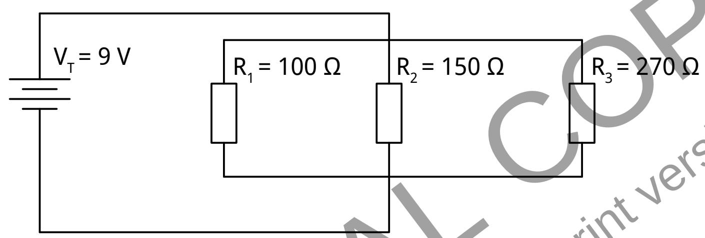
14. Calculate the voltage drop across each resistor as well as the supply voltage for the series circuit shown below.



$V_1 = I \times R_1 = (1{,}8 \text{ mA})(240) = 432 \text{ mV}$
$V_2 = I \times R_2 = (1{,}8 \text{ mA})(270) = 486 \text{ mV}$
$V_3 = I \times R_3 = (1{,}8 \text{ mA})(300) = 540 \text{ mV}$

$V_T = V_1 + V_2 + V_3$
$= 432 \text{ mV} + 486 \text{ mV} + 540 \text{ mV}$
$= 1{,}46 \text{ V}$ (8)

15. Use the information provided in the circuit diagram below and calculate the following:



15.1 The total resistance of the circuit

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{100} + \frac{1}{150} + \frac{1}{270}$$

$R_T = 49{,}09\ \Omega$ (3)

15.2 The total current flowing in the circuit

$$I = \frac{V_T}{R_T} = \frac{9}{49{,}09} = 183{,}34 \text{ mA}$$ (2)

15.3 The current flowing through each resistor.

$I_1 = \frac{V_1}{R_1} = \frac{9}{100} = 90 \text{ mA}$

$I_2 = \frac{V_2}{R_2} = \frac{9}{150} = 60 \text{ mA}$

$I_3 = \frac{V_3}{R_3} = \frac{9}{270} = 33{,}33 \text{ mA}$

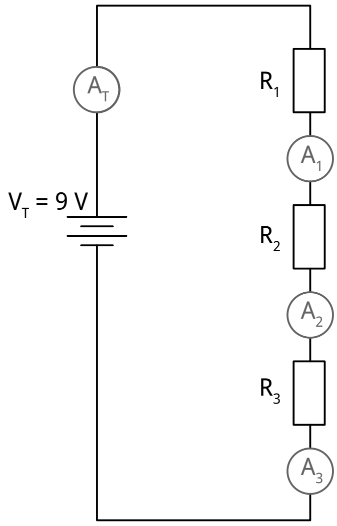
$I_T = I_1 + I_2 + I_3$
$= 90 \text{ mA} + 60 \text{ mA} + 33{,}33 \text{ mA}$
$= 183{,}33 \text{ mA}$ (8)

16. Define Kirchoff's TWO laws for a series circuit.

- The current flowing in a series circuit is the same everywhere.
- Voltage drops around the circuit add up to the supply voltage. (2)

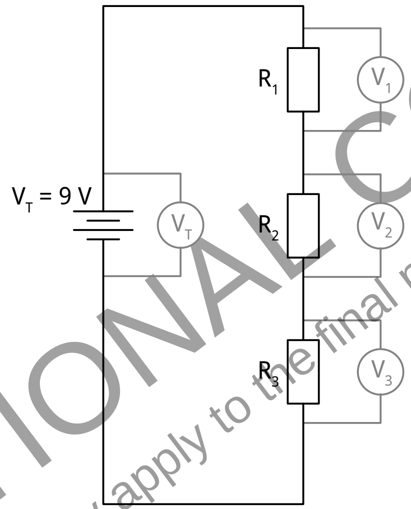
17. **Draw a neat circuit with THREE resistors in series.**

17.1 Show how one would connect ammeters to measure the current flowing everywhere in the circuit.



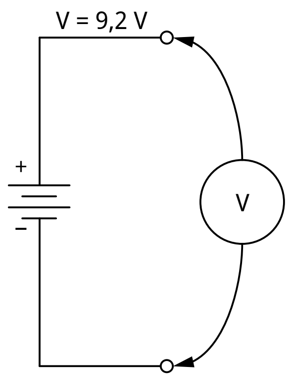
(4)

17.2 Show how one would connect voltmeters in the circuit to measure the voltage drop across each resistor.



(4)

18. **What type of voltage is measured in the circuit below? Explain your answer.** (2)



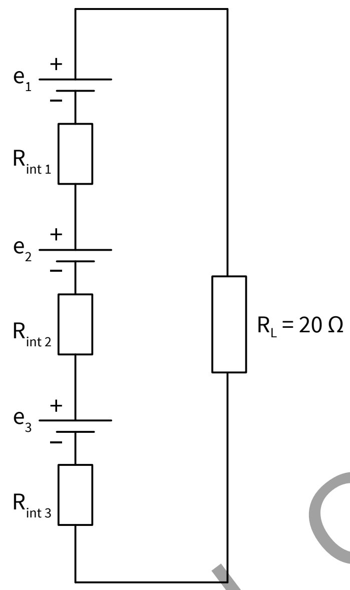
Open-circuit voltage. No load is connected to the battery.

19. What contributes to the internal resistance of a battery?

- Internal connections between cells
- Internal resistances of the connecting wires to the terminals
- The resistance of the electrolyte between electrodes. (3)

20. 20.1 Represent the following circuit by means of a neat sketch: Three cells, each with an open circuit terminal voltage of 1,6 V and an internal resistance of 0,25 Ω, are connected in series. The system is connected to a 20-Ω load.

20.2 Using the information given in 20.1, calculate the following:



(2)

(a) Open-circuit terminal voltage

$E = e_1 + e_2 + e_3 = 1{,}6 + 1{,}6 + 1{,}6 = 4{,}8$ V (2)

(b) The total resistance of the battery

$R_{int} = r_{int\,1} + r_{int\,2} + r_{int\,3}$

$= 0{,}25 + 0{,}25 + 0{,}25 = 0{,}75\ \Omega$ (2)

(c) The current that will flow through the load

$I = \frac{E}{R_L + R_{int}} = \frac{4{,}8}{20 + 0{,}75} = 0{,}23$ A or 231,32 mA (3)

(d) The voltage drop across the internal resistances

$V_{int} = I \times R_{int} = 231{,}32$ mA $\times 0{,}75 = 0{,}17$ V (3)

(e) The closed-terminal voltage.

$V = I \times R_L = 231{,}32$ mA $\times 20 = 4{,}63$ V (3)

21. A battery that cannot be recharged is classified as a … battery.

primary (1)

22. Give two applications of each of the following type of batteries.

22.1 Mercury

Watches, calculators, cameras, hearing aids, etc.

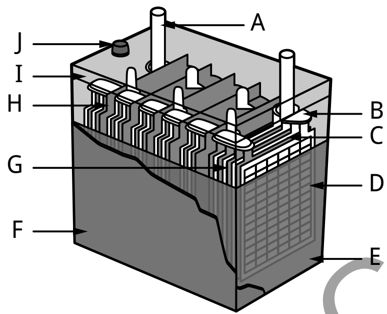
22.2 Alkaline

Radios, calculators, camera flashes, etc.

22.3 Carbon-zinc

Torches, radios, etc. (6)

23. The sketch of a lead-acid car battery is shown below. Name the parts labelled A to J.



A – Terminal posts
B – Cell connectors
C – Cells
D – Plates
E – Electrolyte
F – Seperators
G – Case
H – Partitions
I – Cover
J – Vent caps (5)

24. Name THREE disadvantages of the lead-acid battery.

Any THREE correct answers:

- Very heavy and bulky
- Danger of overheating during charging
- Not suitable for fast charging
- Typical cycle life is 300 to 500 cycles
- Must be stored in a charged state once the electrolyte has been introduced to avoid deterioration of the active chemicals. (3)

25. Why do consumers generally prefer a sealed lead-acid (SLA) battery?

This construction is designed to prevent electrolyte loss through evaporation, spillage and gassing, and this in turn prolongs the life of the battery and eases maintenance. Instead of simple vent caps on the cells to let gas escape, SLA batteries have pressure valves that open only under extreme conditions. (2)

26. Which instrument is used to test the relative density or specific gravity of the electrolyte in lead-acid batteries?

Hydrometer (1)

27. What is meant by an *open-circuit test* for batteries?

An open-circuit voltage test entails measuring the voltage across the terminals of the battery when no load is connected to the battery. The purpose of the open-circuit voltage test is to identify the electrical potential capability of the battery. (2)

28. Why should lithium-ion batteries not be disposed of in household rubbish bins?

Lithium-ion batteries contain metals such as cobalt, nickel and manganese, which are toxic and can contaminate water supplies and ecosystems if they leak out of landfills. Additionally, fires in landfills or battery-recycling facilities have been attributed to inappropriate disposal of lithium-ion batteries. (2)

29. Draw a table to compare the advantages of renewable energy to non-renewable energy.

RENEWABLE RESOURCES	NON-RENEWABLE RESOURCES
Cannot be depleted over time	Will be depleted over time
Sunlight, wind, tidal, geothermal, hydro	Coal, natural gas, uranium (nuclear) and oil
Low carbon footprint	High carbon footprint
The upfront cost is very high	The upfront cost is low
Infrastructure required is expensive initially	Infrastructure required is more cost-effective
Sometimes require large area of land (wind and solar farms)	Comparatively less land area is needed

(4)

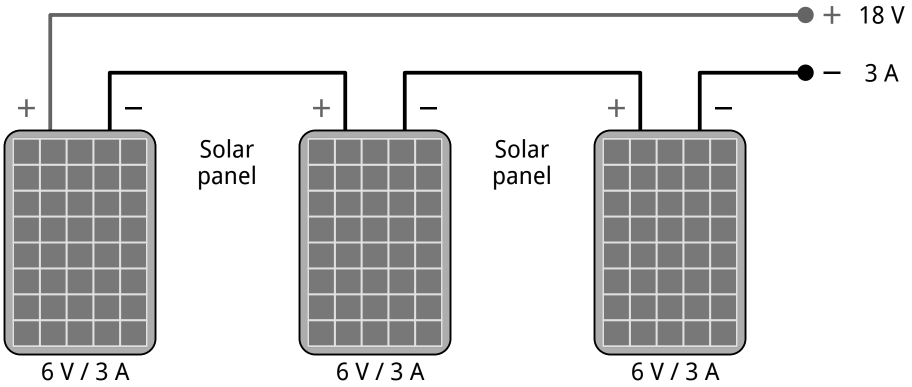
30. Explain how solar energy is converted into electrical energy.

When the sun shines onto the panel, energy from the sunlight is absorbed by the photovoltaic cells in the panel. This energy releases electrons that move in response to an internal electrical field in the cell, causing electricity to flow. (2)

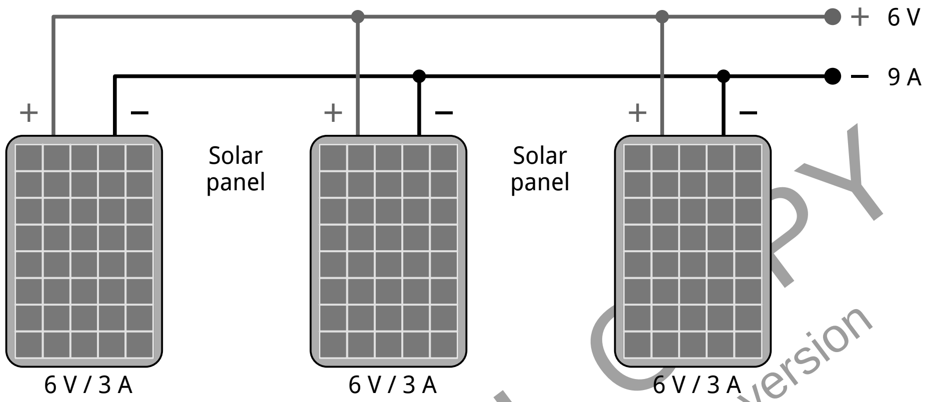
31. Explain the difference between *monocrystalline* and *polycrystalline* cells.

Monocrystalline: Made using thin slices of single crystals (called wafers)
Polycrystalline: Made of different silicon crystals that are melted and poured together (2)

32. Show, by means of a simple sketch, how PV panels can be connected in *series* and in *parallel*, respectively, to match load requirements. Name each sketch.



Solar panels connected in series



Solar panels connected in parallel (4)

33. Discuss how the position of the sun affects the amount of solar energy that can be concentrated and stored in panels.

Maximum efficiency is achieved when the sun is at 90°, i.e. perpendicular to the panels. But as the sun moves across the sky, the angle changes and the efficiency decreases. It would be perfect if we could "track" the sun and adjust the positioning of the panel so that they are always perpendicular to the sun, but that would be very expensive. In South Africa a north-facing house not surrounded by trees will have a better chance of efficient energy conversions, depending on the angle of the roof. (4)

34. 34.1 What is an *inverter*?

An inverter is an electronic device that converts the DC power from the battery into 240-V AC power.

34.2 Name TWO different types of inverters?

Modified sine-wave and the pure sine-wave inverters (3)

35. Determine how many solar panels of 2,4 m × 1,3 m (consult table for power ratings) would be required to supply a South-African household with a daily energy consumption of 28 kWh.

SIZE	AREA	CELLS	WATTAGE
1,7 m × 1 m	1,7 m²	120 HC cells	300–400 W
2,1 m × 1 m	2,1 m²	144 HC cells	350–450 W
2,3 m × 1,1 m	2,53 m²	132 or 156 HC cells	450–560 W
2,4 m × 1,3 m	3,12 m²	132 or 156 HC cells	560–680 W

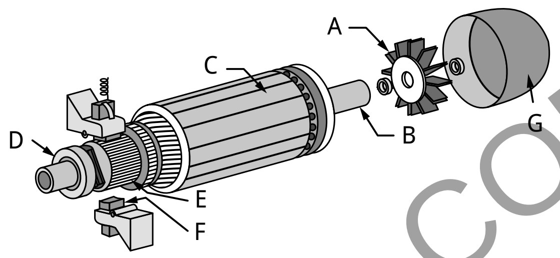
If you require 28 kWh daily use:

Sunlight hours: $\frac{28\,000}{5,5}$ = 5 090,91 W per hour

This means you would need: $\frac{5\,090,91}{560}$ = 9,09

Thus 10 panels are required (4)

36. Identify the parts labelled A to G in the sketch of the rotor below.



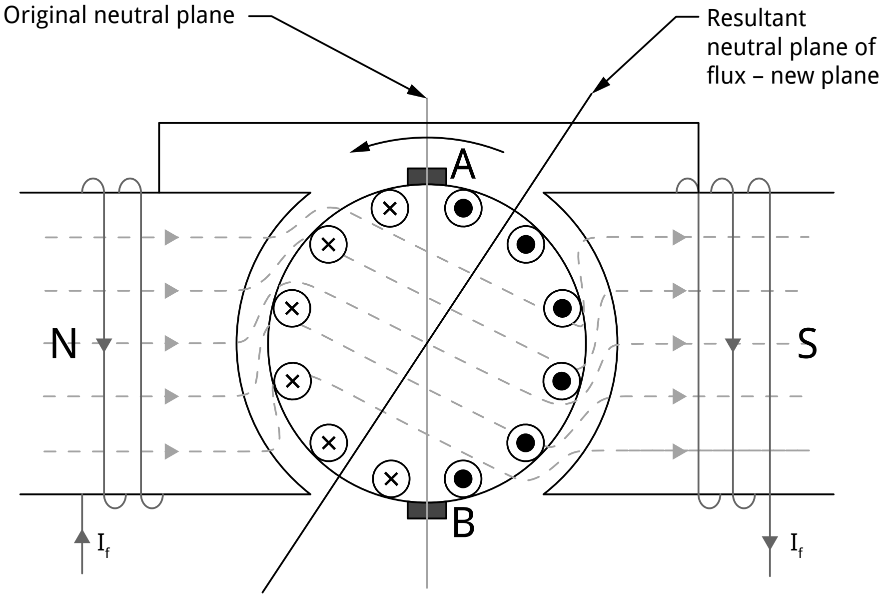
A – Fan
B – Shaft
C – Armature
D – Bearing
E – Commutator
F – Carbon brush
G – Fan cover (7)

37. Fill in the missing detail to complete the table below. Write down the letter followed by the missing information.

BASIS FOR COMPARISON	A – LAP WINDING	WAVE WINDING
Definition	**The coil is lapped back to the following coil.**	B – The coil of the winding forms the shape of a wave
Connection	**The end of the armature coil is connected to an adjacent segment on the commutators.**	**The end of the armature coil is connected to commutator segments some distance apart.**
Parallel path	C – The number of parallel paths is equal to the total of number poles.	**The number of parallel paths is two.**
Other name	**Parallel winding or mulitiple winding**	**Two-circuit or series winding**
emf	**Less**	D – More

(4)

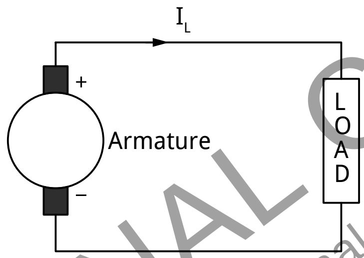
38. By means of a simple sketch, show the shift in the neutral plane due to armature reaction.



(4)

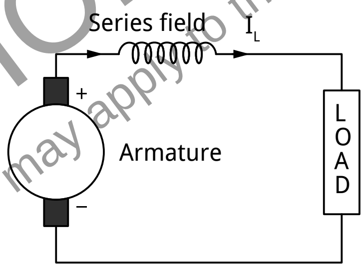
39. Make use of THREE simple sketches to show the difference in connection between the following types of generators:

39.1 Separately excited generator



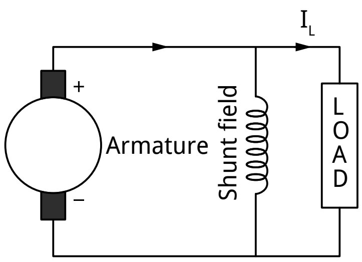
(2)

39.2 Series generator



(2)

39.3 Shunt generator.



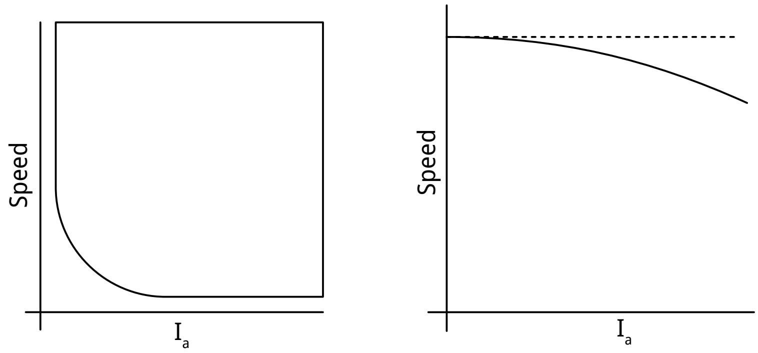
(2)

40. A separately excited generator has an armature resistance of 0,15 Ω and supplies 5 kW at an emf of 240 V. Calculate the terminal voltage (potential difference) across the load.

$I = \frac{P}{V} = \frac{5\,000}{240} = 20{,}83$ A

$V = E - I_aR_a = 240 - (20{,}83 \times 0{,}15) = 236{,}88$ V (6)

41. Draw a neat current-versus-speed graph to show the difference in characteristics between a *series motor* and a *shunt motor*. Name each graph.



Series Shunt (4)

42. A DC motor has lap-connected armature winding. When connected to a 240-V DC supply, it draws an armature current of 35 A. Calculate the back emf at which the motor is running. Assume the armature resistance is 0,8 Ω.

$E_{back} = V - I_aR_a = 240 - (35)(0{,}8) = 212$ V (3)

43. The table below shows the differences in applications for shunt, series and compound motors. Match the application in COLUMN B with the relevant motor in COLUMN A.

COLUMN A	COLUMN B
43.1 Shunt excited	**A** Particularly suitable for applications with fluctuating loads such as steel rolling mills, guillotines, punch machines and shearing machines. The practical use of these motors are limited.
43.2 Series exited	**B** Is used where a constant speed is required, as with lathes, or where a low starting torque features, as with fans.
43.3 Compound	**C** It is used for starting motor vehicle engines, driving cranes, trains, hoists, lifts, trolley buses and other electric vehicles.

43.1 B 43.2 C 43.3 A (3)

44. DC variable-speed drives have a number of benefits compared to conventional speed control using gears and pulleys. Name THREE advantages.

Any THREE of the following:

- Increased energy efficiency and cost savings
- Eliminating the need for expensive mechanical drive components
- Increased motor longevity
- Minimised risk of motor damage during motor start-up
- Reduced opportunity for power-line disturbances that can lead to motor damage. (3)

TOTAL: 200

Module 3

Electronic components and semiconductors

After students have completed this module, they should be able to:

- explain *resistivity*;
- state the factors that influence the resistance of a material and perform calculations;
- explain the temperature coefficient of resistance;
- distinguish between positive, negative and low temperature coefficients of resistance;
- perform calculations to determine resistance;
- explain the operation of diodes and their applications;
- explain the effect of temperature on diode characteristics;
- compare the characteristic curve of various semiconductor diode materials;
- use diode specification sheets;
- describe the basic structure and operation of bipolar junction transistors;
- calculate the current of a bipolar junction transistor;
- explain the circuit configuration of bipolar junction transistors;
- indicate the rating of the components by means of the physical markings on them;
- use bipolar junction transistor specification sheets;
- describe the operation of a bipolar junction transistor as an amplifier;
- explain the concept, composition, functioning and purpose of an op-amp;
- sketch the circuit symbol of an op-amp;
- identify the different types of op-amp packages;
- list the important parameters of an op-amp;
- list and explain the applications of op-amps;
- describe a capacitor in terms of its related properties;
- explain how a capacitor can store charge;
- list common types of capacitors;
- explain and calculate capacitance, charge, electric field strength and energy stored in a capacitor;
- calculate total capacitance as well as the charge on and potential difference across each capacitor when capacitors are connected in series, parallel and series-parallel circuits;
- explain *inductance*, *self-inductance* and *mutual inductance*;
- calculate energy stored in a magnetic circuit;
- calculate the value of emf induced in a coil;
- list the factors that affect the inductance in an inductor;

- calculate total inductance in series, parallel and series-parallel circuits;
- explain the concept and purpose of electronic controllers;
- list examples of controllers and their purpose;
- differentiate between a *controller* and a *transducer*;
- list the requirements when selecting a transducer; and
- identify and explain how instruments can be modified to act as sensors for an electronic controller.

Introduction

In this module students will continue to learn about electronic components and semiconductors. These components are vital to the functioning of many devices commonly used today and to the development of robots and robotics.

Activity 3.1

SB page 139

1. **Which FOUR factors determine the resistance of any material?**

   - Its length: the longer the conductor, the higher its resistance
   - Its cross-sectional area: the thicker a conductor, the lower its resistance and the thinner the conductor, the higher its resistance
   - The material of which it is made (specific resistance): different conductors have different resistivity values, hence their resistance will change accordingly
   - Its temperature: the hotter it is, the higher the resistance, and the colder it is, the less the resistance.

2. **Calculate the resistance of a copper conductor that has a cross-sectional area of 20 mm² and a length of 1 km. Consult the table for the specific resistance of copper.**

   $\ell = 1 \text{ km} = 1\ 000 \text{ m}$ and $A = 20 \text{ mm}^2 = 20 \times 10^{-6} \text{m}^2$

   $\rho = \frac{RA}{\ell} = \frac{(1{,}72 \times 10^{-8})(1\ 000)}{20 \times 10^{-6}} = 0{,}86\ \Omega$

3. **Explain the terms *PTC* and *NTC*.**

   PTC: Abbreviation for *positive temperature coefficient*; as the temperature increases, so does resistance (directly proportional)
   NTC: Abbreviation for *negative temperature coefficient*; as the temperature increases, resistance decreases (inversely proportional)

4. **A copper conductor has a resistance of 12,6 Ω at room temperature (20 °C). Calculate the resistance of the copper wire at 115 °C.**

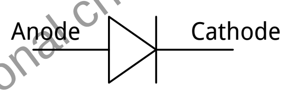
   $\triangle T = T2 - T1 = 115 - 20 = 95\ °C$
   $R_T = R_1 (1 + \alpha \triangle T) = 12{,}6 (1 + 0{,}00386 \times 95) = 17{,}22\ \Omega$

Activity 3.2

SB page 149

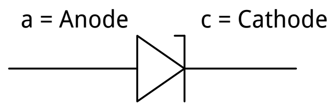
1. **Identify the following components:**

1.1



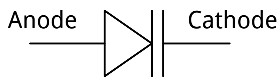
P-N diode

1.2



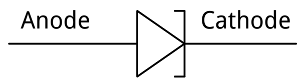
Zener diode

1.3



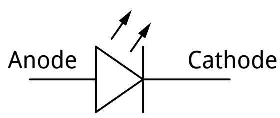
Varactor

1.4



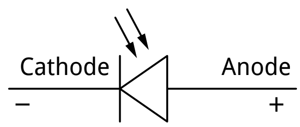
Tunnel diode

1.5



Light-emitting diode (LED)

1.6



Photodiode

2. **Name THREE applications of a varactor diode.**

   Any THREE of the following:
   - RF (radio-frequency) circuits
   - Tuning filters
   - Voltage-controlled oscillators (VCOs)
   - Frequency multipliers
   - Parametric amplifiers

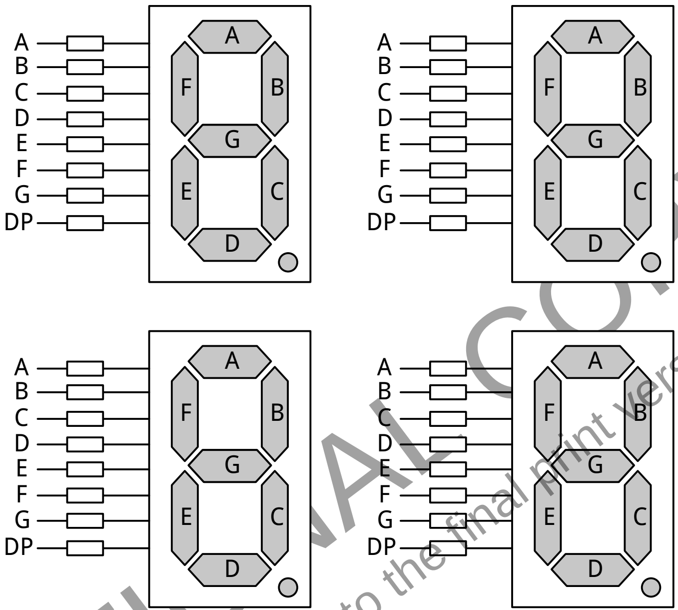
3. **Which diode can be used to regulate the output voltage of a power supply?**

   Zener diode

4. **What does the abbreviation *LCD* mean?**

   Liquid-crystal display

5. **Which segments in each of the illustrations below must be illuminated to represent the number 27,5?**



1st display	A, B, G, E, D	3rd display	DP
2nd display	A, B, C	4th display	A, F, G, C, D

6. **Give THREE applications of seven-segment displays.**

   Any THREE of the following:
   - Digital clocks
   - Electronic meters
   - Basic calculators
   - Microwaves
   - Virtually any electronic devices that display numerical information.

7. **What is the purpose of a photodiode?**

   Photodiodes convert light energy into electrical energy.

8. **Explain the term *thermal runaway*.**

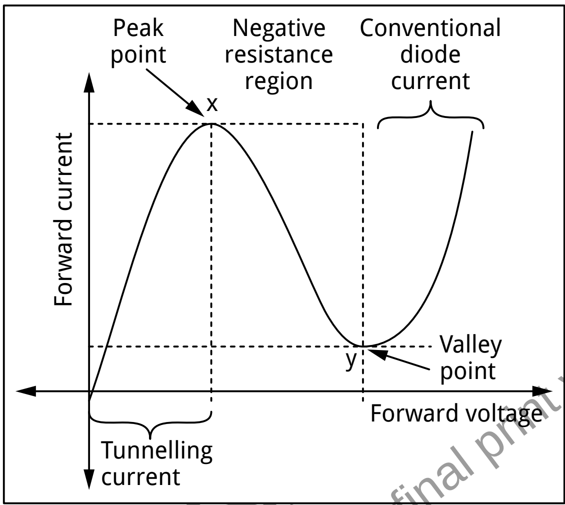
   In semiconductors, heat causes more electron-hole pairs to be generated, which in turn increase current flow. This increase in current generates more heat and the cycle repeats itself until the diode draws excessive current.

9. Name TWO safety precautions to follow when working with diodes.

Any TWO of the following:

- Never remove or insert a diode into a circuit with the voltage applied.
- Never use force to loosen them from their circuits.
- Always be careful when soldering to ensure that excessive heat is not applied to the diode.
- When testing a diode, ensure that the test voltage does not exceed the maximum allowable voltage.
- Be careful when you handle a signal diode because the static charge from your body could cause a short.
- Always replace a diode with one of the same type.
- Ensure a replacement diode is connected into a circuit in the correct direction.

10. Identify the diode based on the characteristic curve shown below.



Tunnel diode

11. Use the data sheet for Zener diodes shown below to answer the questions that follow.

ELECTRICAL CHARACTERISTICS (AT 25 °C, UNLESS OTHERWISE SPECIFIED)									
PART NUMBER	ZENER VOLTAGE	TEST CURRENT		REVERSE LEAKAGE CURRENT		DYNAMIC RESISTANCE f = 1 KHZ		SURGE CURRENT	REGULATOR CURRENT
	V_Z @ I_{ZT1}	I_{ZT1}	I_{ZT2}	I_R @ V_R		Z_{ZT} @ I_{ZT1}	Z_{ZK} @ I_{ZT2}	I_R	I_{ZM}
	V	mA	mA	µA	V	Ω		mA	mA
	NOM.			MAX.		TYP.	MAX.		MAX.
1N4728A	3,3	76	1	100	1	10	400	1380	276
1N4729A	3,3	69	1	50	1	10	400	1260	252
1N4730A	3,9	64	1	10	1	9	400	1190	234
1N4731A	4,3	58	1	10	1	9	400	1070	217
1N4732A	4,7	53	1	10	1	8	500	970	193

11.1 Select a Zener diode that will regulate a 4,3-V output voltage.

1N4731A

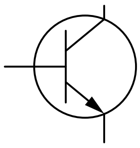
11.2 What is the maximum allowable surge current that a 1N4729A can handle?

1 260 mA or 1,26 A

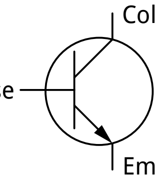
Activity 3.3

SB page 163

1. **Copy the transistor shown below.**



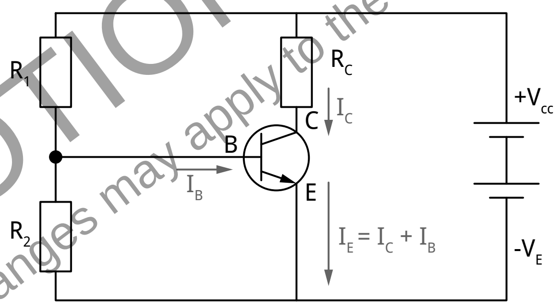
1.1 Label all the terminals.



1.2 State the type of transistor.

NPN

2. **Copy the circuit diagram shown below and indicate the direction of the collector, emitter and base currents.**



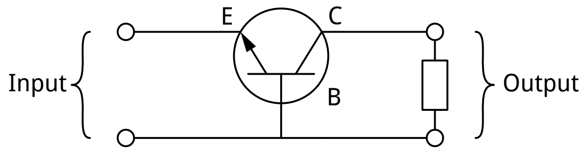
3. **The current flow in the emitter of a transistor is 100 mA and that causes a current flow of 1,28 mA in the base of the transistor. Determine the size of the collector current.**

$I_E = I_B + I_C$

$I_C = I_E - I_B = (100 \times 10^{-3}) - (1,28 \times 10^{-3}) = 98,72$ mA

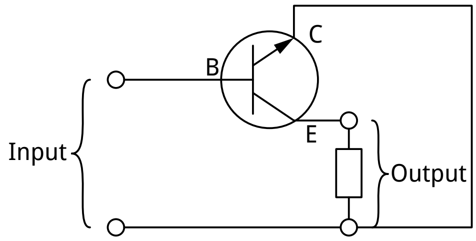
4. Identify the THREE transistor configurations shown below. Motivate your answers.

4.1



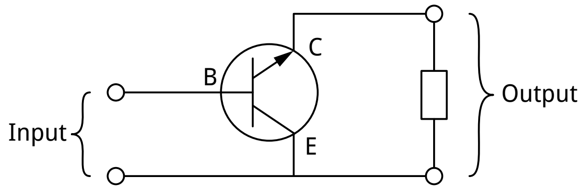
Common base:
The base terminal is common to the input as well as the output

4.2



Common emitter:
The emitter terminal is common to the input as well as the output

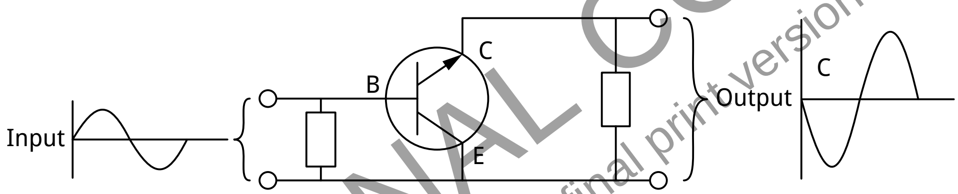
4.3



Common collector:
The collector terminal is common to the input as well as the output

5. Draw the concept circuit diagram, as well as the input and output waveforms, for the common emitter configuration.

Common emitter input and output waves:



6. Give ONE application for each of the following types of amplifiers:

6.1 Common emitter

Any ONE of the following:

- Class-A low-noise amplifiers
- Low-frequency voltage amplifiers
- Linear amplifier applications
- Radio-frequency circuits (for example to amplify faint signals received by an antenna)
- Amplifiers for power amplification

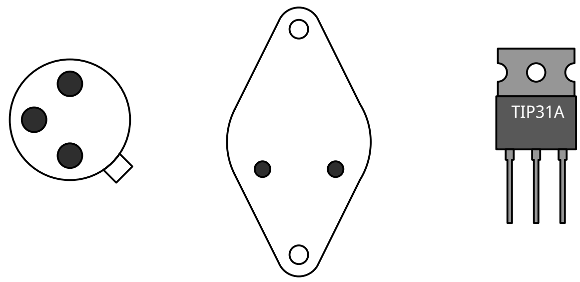
6.2 Common base

This amplifier is used for high-frequency applications (RF amplifiers) because the base separates the input and the output, minimising oscillations at high frequencies.

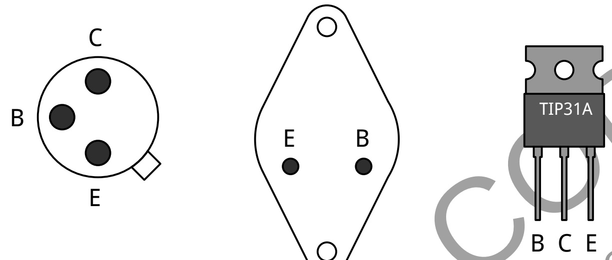
6.3 Common collector

- As an emitter follower
- An impedance-matching device
- Buffers as used in digital circuits with basic logic gates
- Current amplifier in power amps
- Isolation amplifier

7. Copy the transistors and label the terminals.



TO18 TO39 | TO3 | TO218 TO220

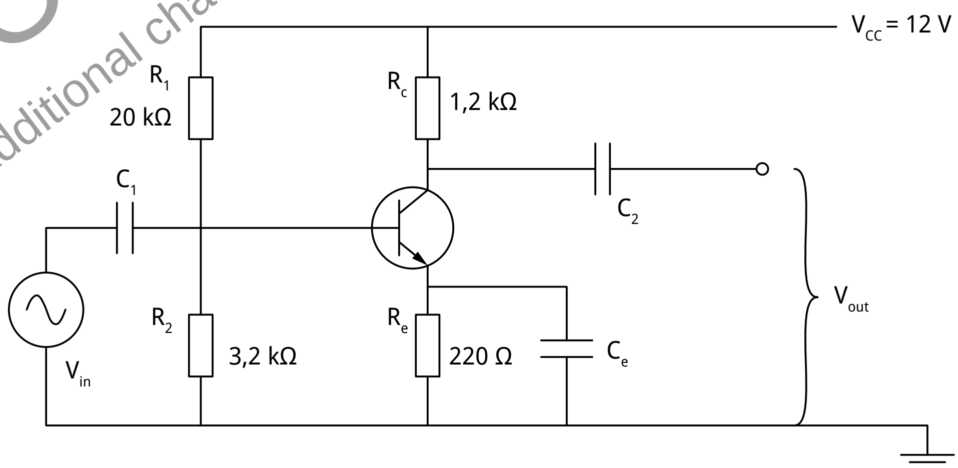


TO18 TO39 | TO3 | TO218 TO220

8. From the data sheet for transistors (Figure 3.20), identify a PNP transistor that would be able to handle a collector current of 100 mA. For safety, allow twice the maximum amount of the current given as a safety margin. If the required transistor is not available, identify a possible substitute.

BC178 or BC478

9. Draw a neat circuit for a single-stage transistor-amplifier circuit. Clearly show where the input is applied and where the output can be taken from.



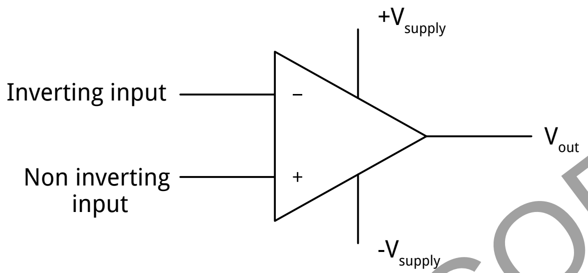
10. Explain the purpose of each of the components in the circuit drawn in answer to in Question 9.

- R_1 and R_2 – voltage dividers to bias the transistor's V_{be}
- R_c – limit current flowing through the transistor. (The value of R_c determines the maximum current flowing through it.)
- R_e and C_e – controls thermal runaway so that the transistor does not burn out due to an increase in current flowing through the transistor.
- Transistor – to amplify the input signal
- C_1 – blocks the DC from $+V_{CC}$ so that it does not reach the input and interfere with the input signal.
- C_2 – blocks the DC from $+V_{CC}$ so it does not reach the output and interfere with the output signal.

Activity 3.4

SB page 170

1. Draw the IEC symbol for an operational amplifier.



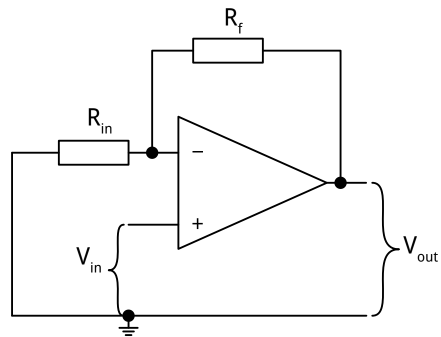
2. Name THREE operational amplifier packages.

Dual-supply, single-supply and rail-to-rail packages

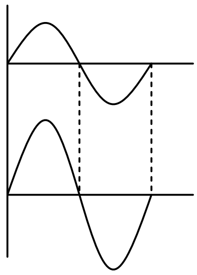
3. Name THREE characteristics of an ideal op-amp.

Any THREE of the following:
- Infinite open-loop gain (AV = ∞)
- Infinite input impedance (Zin = ∞)
- Zero output impedance (Z_{out} = 0)
- Infinite common-mode rejection ration (CMRR= ∞)
- Very high stability
- Slew rate is infinite
- Infinite bandwidth (amplifies both AC and DC signals without any loss in gain).

4. Identify the op-amp configuration shown below and draw the input and output waveforms. Clearly show the phase relationship between them.



Non-inverting op-amp



5. **Which op-amp configuration should be used to mix a number of inputs to produce a single output?**

   Summing amplifier

6. **Discuss the shape of the input and output waves for a differentiator.**

   The input wave is a saw-tooth wave and it it is converted into a square/rectangular wave.

Activity 3.5

SB page 180

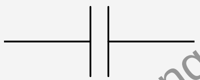
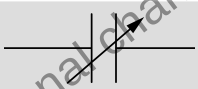
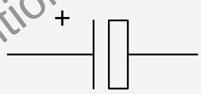
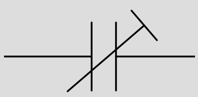
1. **Why is a capacitor referred to as a *passive component*?**

   It relies on current flowing through the circuit. If it is not charged by an external source, it cannot generate current.

2. **What determines the amount of charge a capacitor can store?**

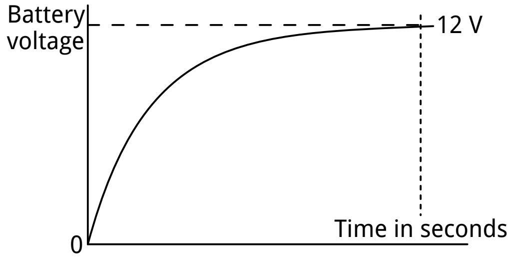
   - The size of the parallel plates (the bigger the plates, the bigger the charge)
   - The distance between the plates (the bigger the distance between plates, the smaller the charge stored)
   - The type of dielectric.

3. **Copy the table below and then complete it by identifying each of the components.**

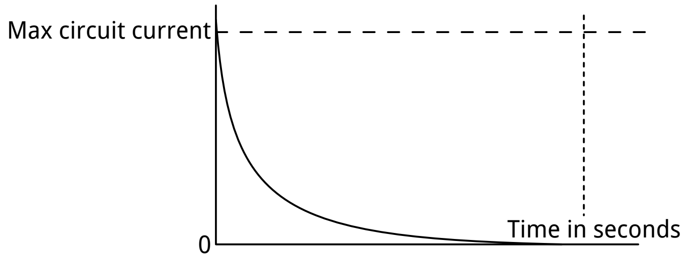
CAPACITOR SYMBOL	COMPONENT IDENTIFICATION
	Unpolarised
	Variable
	Polarised
	Preset

4. **With reference to capacitors, explain what the graphs shown below represent.**

4.1



4.2



The graphs represent a capacitor being charged.

4.1 The graph shows the voltage. Over a period the voltage increases. It starts charging rapidly and then it gradually levels out until the voltage of the capacitor equals the supply voltage.

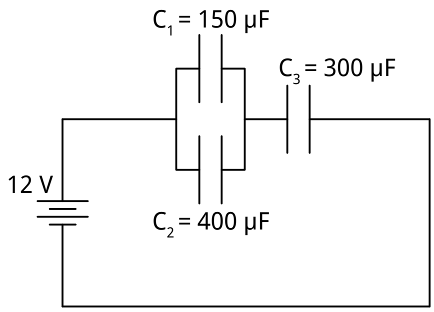
4.2 Current spikes to maximum and then, as the capacitor charge reaches maximum, current decreases. When the capacitor is fully charged, zero current flows.

5. **Briefly explain the difference between the following capacitor types: ceramic, electrolytic, plastic film, silver-mica, tantalum.**

- Ceramic – uses a ceramic dielectric, has a low loss factor and a reasonable level of stability
- Electrolytic – highest levels of capacitance for a given volume; uses electrolyte-soaked paper as a dielectric; used in polarised capacitors
- Plastic-film capacitors – different types, e.g. polycarbonate, polyester and polystyrene; normally non-polar
- Silver-mica – manufactured by plating silver electrodes directly onto the mica film dielectric using several layers
- Tantalum – very small; uses a film of oxide on tantalum; low working voltages (35 V is normally the maximum) and some even have values of around one volt; polarised.

6. **Three capacitors are connected as follows: C_1 and C_2 are connected in parallel, and this combination is then connected in series with C_3. The combination is connected across a 12-V supply. Answer the following questions if the capacitor values are: C_1 = 150 μF, C_2 = 400 μF and C_3 = 300 μF.**

6.1 **Represent the circuit by means of a neat sketch.**



6.2 Calculate the total capacitance.

$C_{E1} = C_1 + C_2 = (150 \times 10^{-6}) + (400 \times 10^{-6}) = 550\ \mu F$

$C_T = \frac{C_{e1} \times C_3}{C_{e1} + C_3} = \frac{550\ \mu F \times 300\ \mu F}{550\ \mu F + 300\ \mu F} = 194{,}12\ \mu F$

6.3 Calculate the total charge the combination can store.

$Q_T = C_T V_T = 194{,}12\ \mu F \times 12 = 2{,}33\ mC$

Activity 3.6

SB page 185

1. **Define Lenz's law of electromagnetism.**

   The induced current always opposes the applied current.

2. **What is the difference between *self-inductance* and *mutual inductance*?**

   Self inductance – when the magnetic field of the coil cuts the coil itself, thereby inducing a current

   Mutual inductance – when the magnetic field around one coil cuts a second coil, inducing a current in that coil

3. **Which factors would influence the inductance of an inductor?**

   - The number of turns in the winding
   - Cross-sectional area of the wire (thickness)
   - The core material

4. **Three inductors are connected in parallel. The values of the inductors are 100 mH, 450 mH and 220 mH, respectively. Calculate the total inductance of the combination.**

   $\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} = \frac{1}{100 \times 10^{-3}} + \frac{1}{450 \times 10^{-3}} + \frac{1}{220 \times 10^{-3}}$

   $L_T = 59{,}64\ mH$

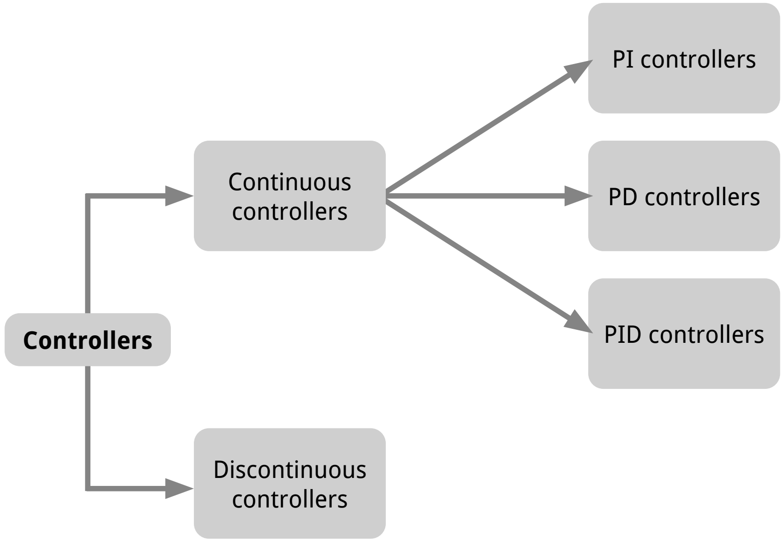
Activity 3.7

SB page 191

1. **What is a *controller*?**

   An electronic device that uses electrical signals to perform receptive, comparative and corrective functions

2. **Copy the block diagram and label all the blocks to show the different types of controllers.**



3. **Give TWO examples of controllers used in industry today.**

   Any TWO of the following:
   - PLC (programmable logic controller)
   - Cruise control in vehicles
   - Variable speed drives
   - Refrigeration systems
   - Washing machines
   - Automatic traffic-light system

4. **Explain the basic working principal of a transducer by following the given block diagram.**

   The input device will receive a quantity, normally non-electrical. This is converted to an electrical quantity and passed on to the process device. The process device will then modify the quantity to an acceptable format for display purposes.

5. **Name THREE resistive transducers.**

   Any THREE of the following:

   Resistance strain gauge, resistance thermometer, thermistor, resistance hygrometer, photoconductive cell

6. **Give THREE applications of capacitive transducers.**

   Any THREE of the following:

   Displacement or pressure, music, noise or speech, liquid levels and thickness gauging

7. **What type of transducer would the following be?**

   7.1 **Differential transformer**

   Passive-inductive transducers

   7.2 **Photoemissive cell**

   Passive-photosensitive transducers

8. **On what principle does a crystal transducer work? Explain this basic principle.**

   It works on the piezoelectric effect. The electric voltage produced by the piezoelectric transducer is linearly varied to applied stress or force. If the ends are squashed together, a potential will appear across the terminal, and if the ends are pulled in opposite directions, the polarity will reverse.

NOTE TO FACILITATOR: PROJECTS

The following projects, included in Addendum A, may be considered:

- *1.1 Fading LED lights;*
- *1.5 Simple cell-phone detector using an op-amp; and*
- *2.1 Continuity tester.*

Summative assessment

SB page 192

1. **Explain how current flow is affected in a good conductor and a poor conductor, respectively.**

   - Good conductor: Low resistance, therefore high current flow
   - Poor conductor: High resistance, therefore low current flow (2)

2. **What is meant by the term *rho*?**

   It is the Greek letter ρ and is used to express the resistivity of a conductor. To ensure a standard, each material is assigned a specific resistance by comparing a unit cube of each material (1 m × 1 m × 1 m) and it is expressed in ohms per metre cubed (Ω/m^3) (3)

3. **Why is copper most commonly used in electrical cables if it is not the best conductor available to us?**

   Silver is the best conductor, but it is expensive. Copper is far easier to mine and produce, and it costs much less. (1)

4. **An aluminium conductor is 400 m long and has a diameter of 10 mm. The resistivity of aluminium is 2,83 × 10⁻⁸. Calculate the resistance of the cable.**

   $A = \pi r^2 = \pi(5)^2 = 78{,}54\ mm^2 = 78{,}54 \times 10^{-6}\ m^2$

   $R = \frac{\rho l}{A} = \frac{(2{,}83 \times 10^{-8})(400)}{78{,}54 \times 10^{-6}} = 0{,}14\ \Omega$ (5)

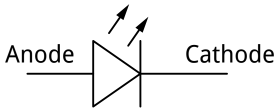
5. **A tungsten conductor has a resistance of 15,2 Ω at room temperature (20 °C). Calculate the resistance of the conductor at 120 °C.**

   $\triangle T = T_2 - T_1 = 120 - 20 = 100\ °C$

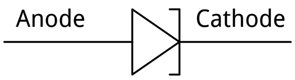
   $R_T = R_1 (1 + \alpha \triangle T) = 15{,}2 (1 + 0{,}00495 \times 100) = 22{,}72\ \Omega$ (4)

6. **Draw neat IEC symbols for the following diodes.**

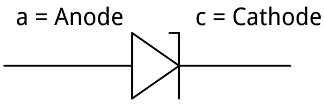
   6.1 **LED**



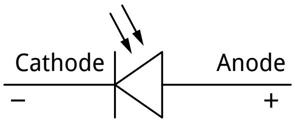
   6.2 **Tunnel diode**



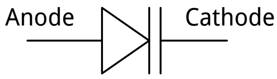
   6.3 **Zener diode**



   6.4 **Photodiode**



   6.5 **Varactor**



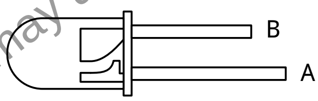
(5)

7. **Match the diode in COLUMN A to its most correct purpose in COLUMN B. Write only the question number and the matching letter.**

COLUMN A	COLUMN B
7.1 LED	**A. Regulation of power supplies**
7.2 Zener	**B. Bridge rectifiers**
7.3 Varactor	**C. Power indicators**
7.4 Photodiode	**D. Voltage-controlled oscillators**
7.5 P-N diode	**E. Light detectors**

7.1 C 7.2 A 7.3 D 7.4 E 7.5 B (5)

8. **Identify the component and the terminals labelled A and B in the figure below.**



LED
A: Anode
B: Cathode (3)

9. **Consider the abbreviation *LCD*.**

   9.1 **What does the abbreviation stand for?**

   Liquid-crystal display (1)

   9.2 **Name the advantages of the component.**

   They are thin, light and draw little power. (2)

10. Name THREE applications of the seven-segment display.

Any THREE of the following:

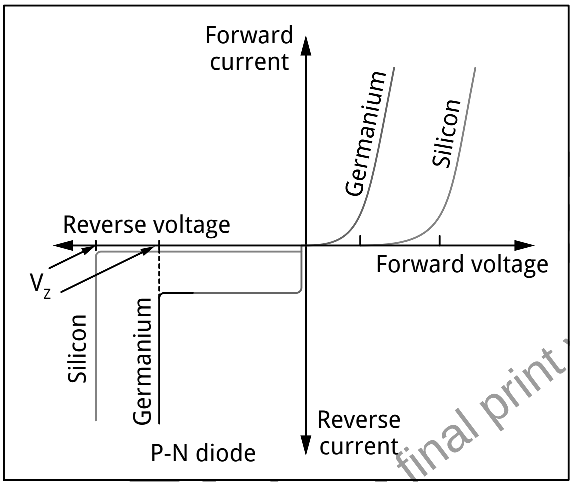
- Digital clocks
- Electronic meters
- Basic calculators
- Microwaves
- Virtually any electronic device that displays numerical information. (3)

11. Explain *thermal runaway* with reference to transistors.

Heat causes more electron-hole pairs to be generated, which in turn increase current flow. This increase in current generates more heat, and the cycle repeats itself until the diode draws excessive current. (4)

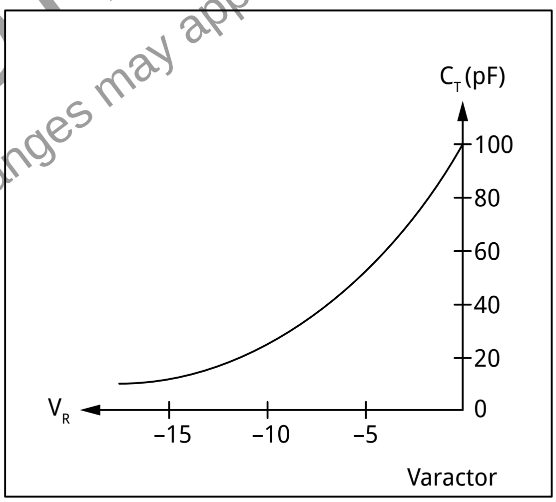
12. Draw a neat current-versus-voltage characteristic curve to show the difference between the following:

12.1 Silicon-germanium P-N diode



Silicon-germanium P-N diode

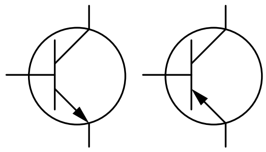
12.2 Varactor diode

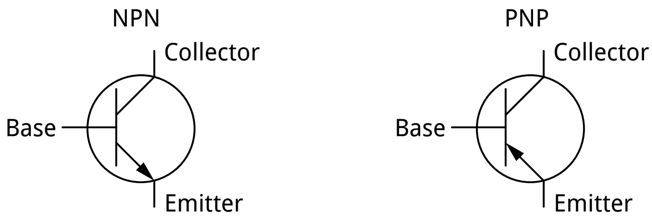


Varactor

(4)

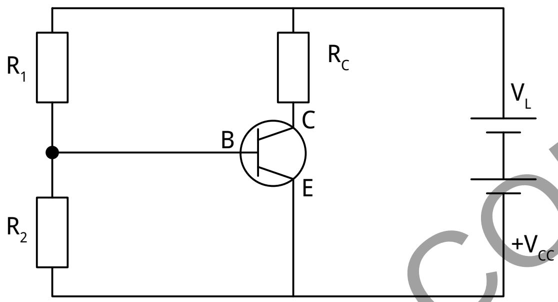
13. Redraw the symbols for the following NPN and the PNP transistors and label the terminals correctly.

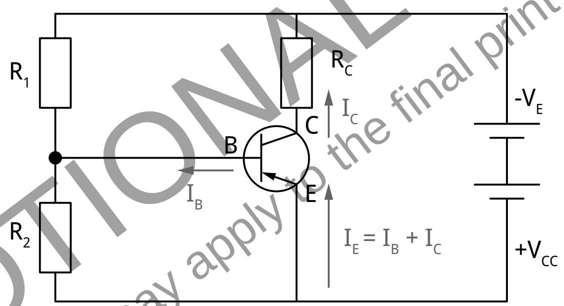




(2)

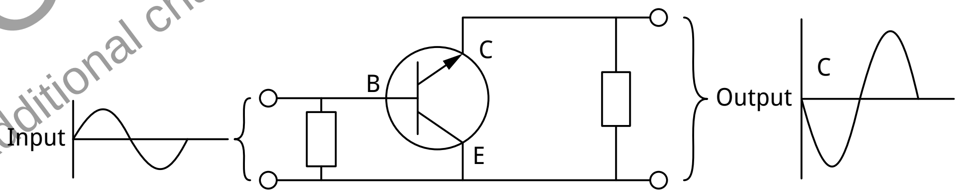
14. Copy the circuit diagram shown below and indicate the direction of the collector, emitter and base currents.





(3)

15. Draw a neat concept circuit for a common-emitter transistor circuit clearly showing the input and output waveforms.



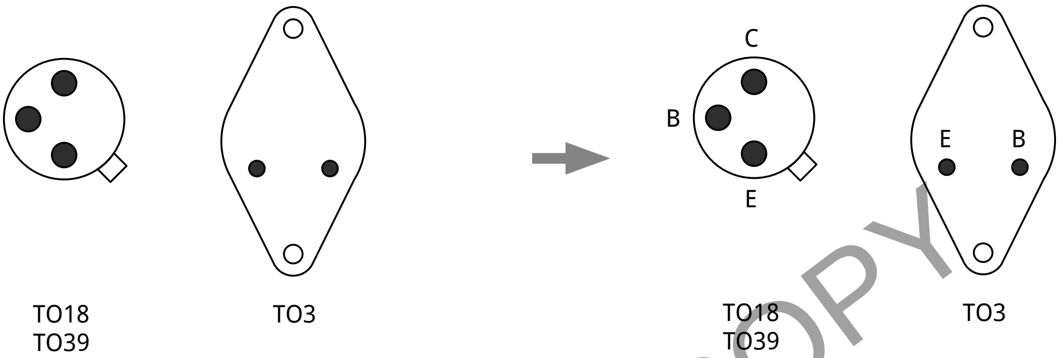
(4)

16. Name the THREE characteristics of the common-emitter transistor configuration drawn in answer to question 15.

Any THREE of the following characteristics:

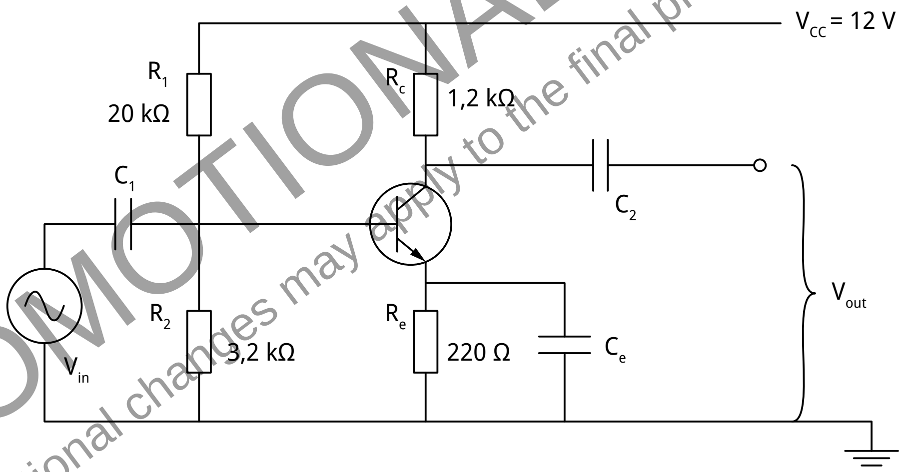
- Average input impedance (±1 kΩ)
- High output impedance (±10 kΩ)
- High voltage gain (±300)
- High current gain (±100)
- Very high power gain (±30 000)
- Phase shift between output and input is 180° (output wave is out of phase with input wave). (3)

17. Copy the two common transistor packages shown below and label the terminals correctly.



(2)

18. The circuit diagram for a biased, single-stage class A transistor amplifier is shown below.



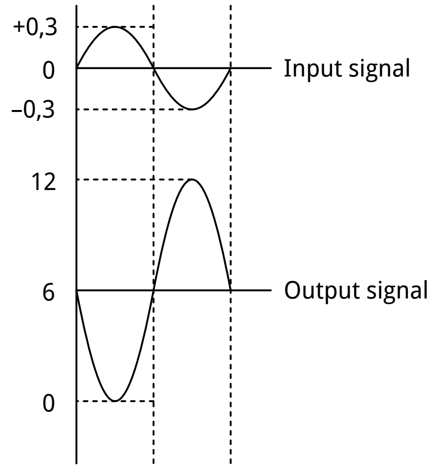
18.1 Explain the operation of the circuit for the *positive half cycle* only.

During the positive half cycle:

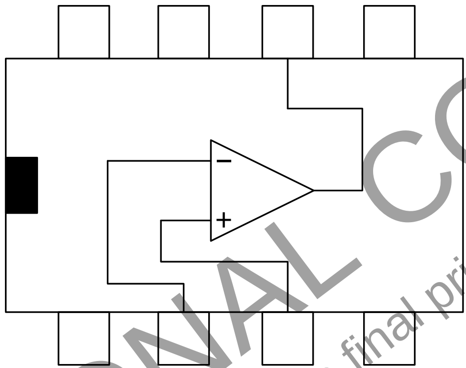
- The input signal is superimposed on V_2 (the voltage across R_2). Superimposed means "to put on top of ", so 0,3 V on top of 0,9 V will add up to 1,2 V.
- V_2 increases.
- V_{be} increases (because V_2 is parallel to V_{be}).

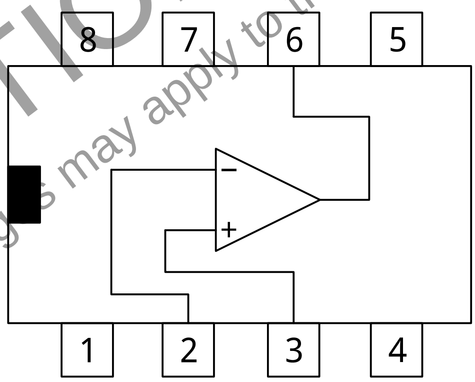
- The transistor becomes more switched on, so it becomes more like a closed switch.
- The output voltage decreases, so it will drop from 6 V to 0 V. (4)

18.2 Draw the input and output waveforms for the amplifier to show the phase relationship between them. (2)



19. Copy the eight-pin IC given below and then number all the legs.





(2)

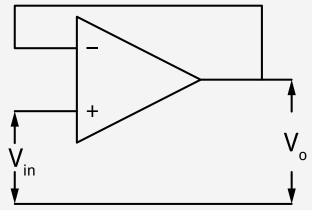
20. What type of supply does an op-amp use if it has the ability to operate normally even if the input voltage swings from V_{ee} to V_{cc}? In other words, it can operate over the full supply voltage range.

Rail-to-rail supply (1)

21. Identify each operational-amplifier circuit shown below and match it to the correct input and output waveforms. You can simply match the numbers and letters, e.g. 1 D.

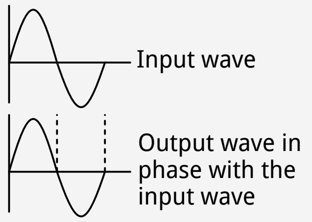
<table>
<tr><th>CIRCUIT DIAGRAM</th><th>INPUT VERSUS OUTPUT WAVEFORMS</th></tr>
<tr><td>

21.1



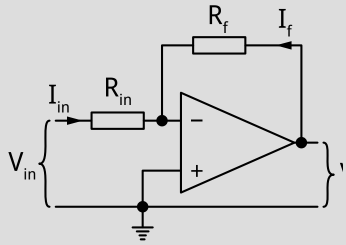
</td><td>

A



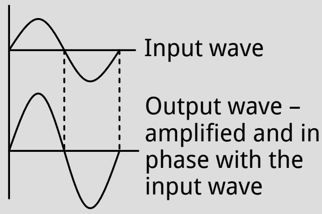
</td></tr>
<tr><td>

21.2



</td><td>

B



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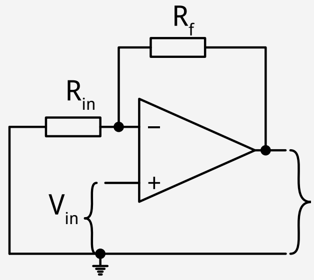
<tr><td>

21.3



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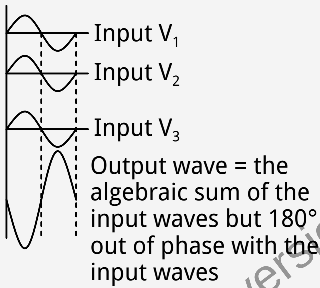
C



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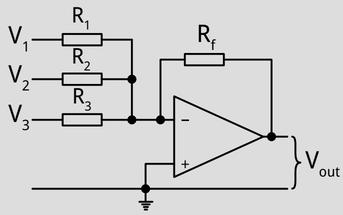
21.4



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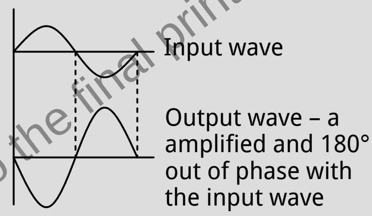
D



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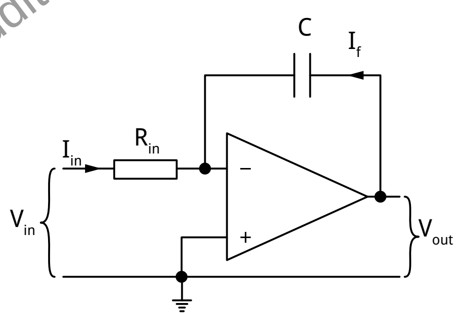
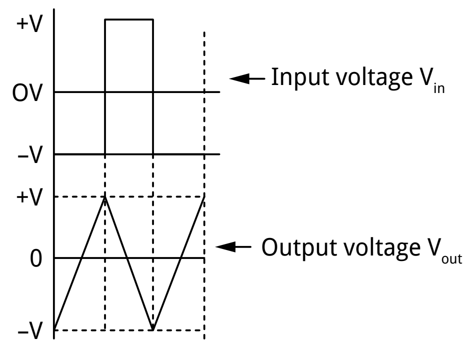
21.1 A Voltage follower
21.2 D Inverting amplifier
21.3 B Non-inverting amplifier
21.4 C Summing amplifier (8)

22. Draw a neat concept circuit diagram of an operational amplifier used as an integrator. Show the input and output waveforms.



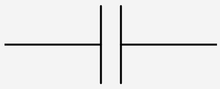
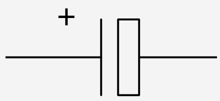
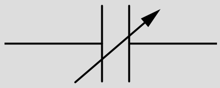
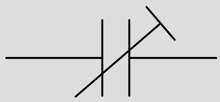


(6)

23. What is a *parallel-plate capacitor*?

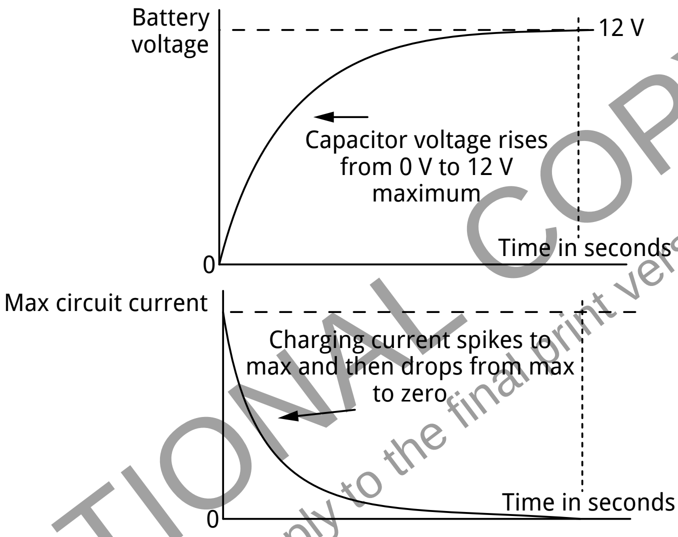
A capacitor consisting of two parallel conductive plates that are separated by an insulator material called the dielectric. The dielectric material prevents the flow of current between the two plates. (2)

24. Copy and complete the table below by drawing the IEC symbols for each capacitor.

CAPACITOR SYMBOL	CAPACITOR IDENTIFICATION	CAPACITOR SYMBOL	CAPACITOR IDENTIFICATION
Unpolarised		Polarised	
Variable		Preset	

(4)

25. Draw TWO neat graphs to show the relationship between voltage and current in a capacitor.



(2)

26. Explain the difference between the *charge of a capacitor* and its *electric field strength*.

- Charge: Charge (Q) stored in a capacitor is the product of its capacitance (C) and the voltage (V) applied to it. The capacitance of a capacitor should always be a constant, known value. So, we can adjust voltage to increase or decrease the capacitor charge. (Q = CV).
- Electric field strength: The ability of a capacitor to store energy in the form of an electric field (and consequently to oppose changes in voltage) is called capacitance. It is measured in the unit of farad (F). A voltage applied between two conductive plates creates a uniform electric field between those plates. The electric field strength in a capacitor is directly proportional to the voltage applied and inversely proportional to the distance between the plates. (4)

27. Three capacitors are connected as follows: C_1 and C_2 are connected in parallel, and this combination is then connected in series with C_3. The combination is connected across a 24-V supply.

27.1 Determine the total capacitance if C_1 = 100 μF, C_2 = 200 μF and C_3 = 400 μF.

$C_{E1} = C_1 + C_2 = (100 \times 10^{-6}) + (200 \times 10^{-6}) = 300\ \mu F$

$C_T = \frac{C_{e1} \times C_3}{C_{e1} + C_3} = \frac{300\ \mu F \times 400\ \mu F}{300\ \mu F + 400\ \mu F} = 171{,}43\ \mu F$ (6)

27.2 Determine the total charge this combination can store.

$Q_T = C_T V_T = 171{,}43\ \mu F \times 24 = 4{,}11\ mC$ (3)

28. Give THREE other names for an *inductor*.

Coil; choke; reactor (3)

29. Why can mutual inductance not take place if the primary winding is connected to a DC supply?

It needs a continually changing magnetic field to cut the secondary windings and induce a current. A DC supply creates a constant magnetic field, which means no field lines are cutting the secondary winding, therefore not inducing any current. (2)

30. Inductor one has a value of 50 mH, inductor two has a value of 120 mH and inductor three has a value of 80 mH. Calculate the total inductance if they are connected in:

30.1 Series

$L_T = L_1 + L_2 + L_3 = 50\ mH + 120\ mH + 80\ mH = 250\ mH$ (3)

30.2 Parallel.

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} = \frac{1}{50 \times 10^{-3}} + \frac{1}{120 \times 10^{-3}} + \frac{1}{80 \times 10^{-3}}$

$L_T = 24{,}49\ mH$ (3)

31. Which electronic device uses electrical signals to perform receptive, comparative and corrective functions?

A controller (1)

32. Controllers are divided into two categories. Name them. (2)

- Continuous
- Discontinuous (2)

33. Explain the difference between a *controller* and a *transducer*.

- Controller: An electronic device that receives various electrical inputs and performs an instruction based on how it has been programmed.
- Transducer: An electronic device that converts energy from one form to another. The process of converting energy from one form to another is known as transduction. (2)

34. Draw a block diagram to represent a typical processing system.

(3)

35. A table for passive transducers is shown below. Complete the table by providing the missing details.

RESISTIVE TYPE TRANSDUCERS – PASSIVE TYPES		
TYPE OF TRANSDUCER	**OPERATING PRINCIPAL**	**APPLICATION**
Resistance-strain gauge	**35.1** Resistance of wire changes when subjected to elongation or compression due to external stress being applied	**Measurement of force, torque or displacement.**
Resistance thermometer	**Resistance wire with a high positive temperature coefficient; changes with a variance in temperature**	**35.2** Measurement of temperature and radiant heat
35.3 Thermistor	**Resistance of certain metal oxides with a negative temperature coefficient changes with a variance in temperature**	**Measurement of temperature**
Resistance hygrometer	**Resistance of conductive material changes with a variance in moisture content**	**35.4** Relative humidity
Photoconductive cell	**35.5** Resistance of cell changes with a variance in incident light	**Photosensitive relay**

(5)

36. Explain the difference between a *photo-emissive* cell and a *photomultiplier* cell.

- Photo-emissive cell: Electron emission will occur due to incident light on photo-emmissive surface.
- Photomultiplier: Secondary electron emission will occur due to incident light on photo-emmissive surface. (2)

37. Name the effect described below.

If the ends of a crystal are squashed together, a potential will appear across the terminal, and if the ends are pulled in opposite directions, the polarity will reverse.

Piezoelectric effect (1)

TOTAL: 125

Module 4

Electrical components, symbols, circuit drawings, prototyping and design

After students have completed this module, they should be able to:

- read and draw the symbols of the following electronic components:
  - resistors and potentiometers
  - capacitors (polarised and non-polarised)
  - inductors
  - transformers
  - relays
  - diodes (rectifier, high-speed, Zener, light-emitting),
  - integrated circuits (regulators, analogue op-amps)
  - transducers/sensors
  - op-amps
  - transistors
  - DC motors;
- sketch, label and interpret elementary circuits;
- build simple series and parallel circuits on breadboards and Veroboards as per design, using basic soldering techniques;
- calculate the outcomes of the built circuits;
- verify the outcomes using appropriate meters;
- mount a given range of components onto a breadboard and connect them to a circuit;
- describe different electric circuit combinations using various components and configurations within the given range;
- explain the principles of operation for a combination of resistors;
- sketch circuit diagrams based on the information supplied, using IEC symbols;
- use appropriate formulae to calculate voltages, total resistance and currents in all the circuit branches;
- apply Kirchhoff's laws in electric circuit calculations; and
- conduct practical circuit experiments to verify calculations.

Introduction

To work in the field of electricity and electronics, you must be familiar with the different electrical components, their symbols and their applications. You will encounter many circuit diagrams. From time to time, you might also be required to build circuits on a breadboard, Veroboard or printed circuit boards (PCB). It is therefore important that you can read and understand these diagrams. In this module, you will encounter many of the concepts covered in *NCV2 Fundamentals of Electronics and Digital Concepts for Robotics* as we return to the building blocks of the subject. New concepts will also be introduced. You have already revised the calculation of voltage, resistance and current in circuits in Module 2. Here you will again practise these basic calculations and build circuits to verify the solutions.

Activity 4.1

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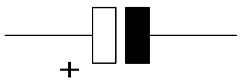
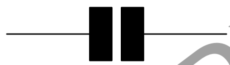
The aim of this activity is to test your knowledge regarding the work covered previously.

1. **Sketch the symbol used to indicate each of the following electrical components:**

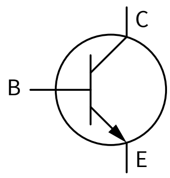
1.1 polarised resistor



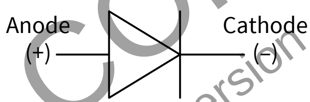
1.2 non-polarised resistor



1.3 NPN transistor

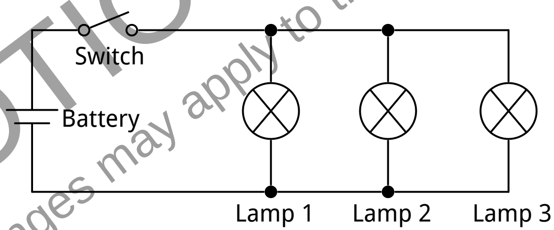


1.4 general-purpose diode

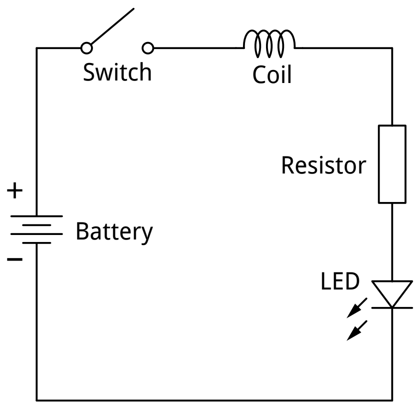


2. **Make a neat, labelled drawing of each of the following circuits:**

2.1 Three lamps connected in parallel to an open switch and a battery



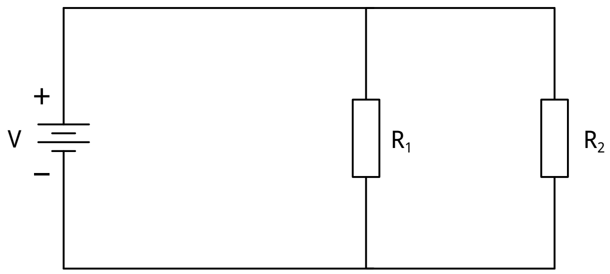
2.2 Series circuit consisting of a coil, LED, resistor, open switch and battery



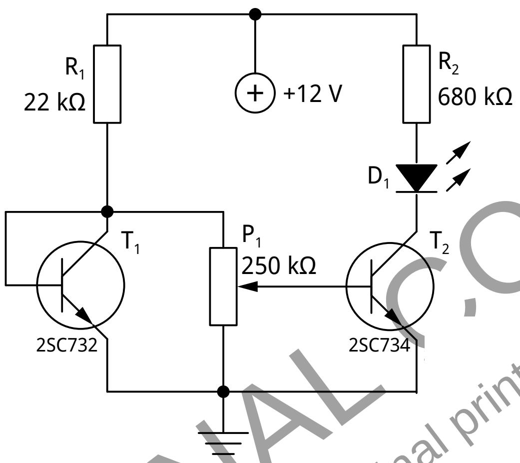
3. **Give a short description of an *electric circuit*.**

An electric circuit can be described as a combination of various components connected together to form a continuous path allowing current to flow through it.

4. **By drawing a simple circuit, show how two resistors in parallel can be connected to a battery.**

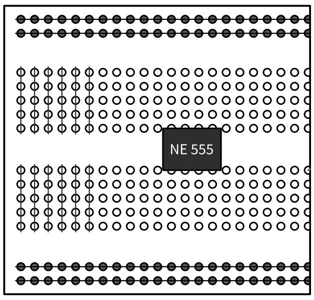


5. **With reference to the circuit in the figure below, identify all the components used.**



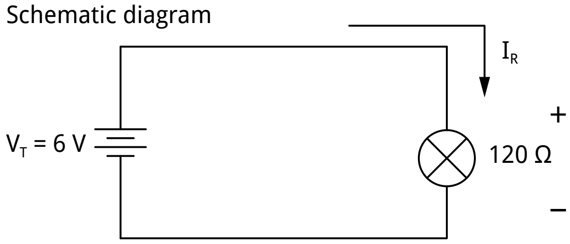
- 2 × NPN transistors
- 1 × potentiometer
- 1 × LED
- 2 × resistors

6. **Describe why an IC has to be connected as indicated in the figure below.**



ICs must always be connected across the centre open piece – one row of IC pins on one side and the other row on the other side. It will prevent the IC pins from shorting out.

7. **A flashlight uses a 6-V battery and its bulb has a resistance of 120 Ω. Calculate the amount of current that will be drawn from the battery when the flashlight is switched on.**



$I = \frac{V}{R}$

$= \frac{6}{120}$

$= 0{,}05$ A

8. **Calculate the total resistance of a circuit when three resistors are connected in parallel. The resistors have a value of 100 Ω each.**

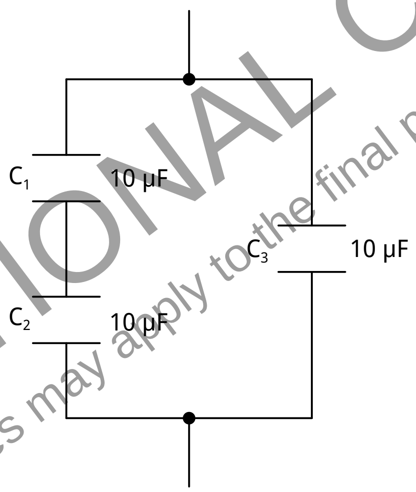
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$\frac{1}{100} + \frac{1}{100} + \frac{1}{100}$

$= 0{,}03$

$R_T = 33{,}33\ \Omega$

9. **Calculate the total capacitance of the circuit in the figure below.**



$\frac{1}{C_{12}} = \frac{1}{C_1} + \frac{1}{C_2}$

$= \frac{1}{10} + \frac{1}{10}$

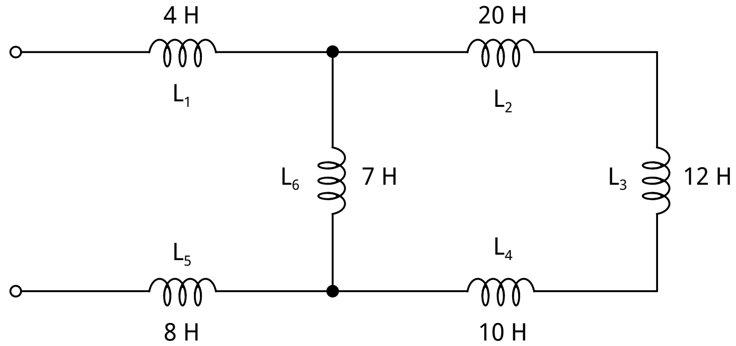
$C_{12} = 5\ \mu F$

So: $C_T = C_{12} + C_3$

$= 5 + 10$

$= 15\ \mu F$

10. With reference to the figure below, calculate the total inductance of the circuit.



$$L_{234} = L_2 + L_3 + L_4$$
$$= 20 + 12 + 10$$
$$= 42\ \text{H}$$

Then

$$\frac{1}{L_{2346}} = \frac{1}{L_{234}} + \frac{1}{L_6}$$
$$= \frac{1}{42} + \frac{1}{7}$$
$$= 0{,}167$$
$$L_{2346} = 6\ \text{H}$$

and

$$L_T = L_{2346} + L_1 + L_5$$
$$= 6 + 4 + 8$$
$$= 18\ \text{H}$$

11. Three resistors of 5 Ω, 6 Ω and 13 Ω, respectively, are connected in series across a 12-V supply. Calculate:

11.1 The total resistance of the circuit

$$R_T = R_1 + R_2 + R_3$$
$$= 5 + 6 + 13$$
$$= 24\ \Omega$$

11.2 The current drawn from the supply

$$R_T = R_1 + R_2 + R_3$$
$$= 4 + 12 + 15$$
$$= 31\ \Omega$$

12. Define ***Kirchhoff's voltage law*.**

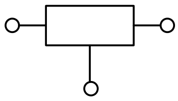
Kirchhoff's voltage law states that the sum of the voltage drops across the resistances of a closed circuit equals the total voltage applied to the circuit.

Activity 4.2

SB page 205

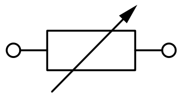
1. Identify each of the electrical components according to the IEE symbol used to indicate it in an electrical circuit:

1.1



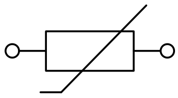
Potentiometer

1.2



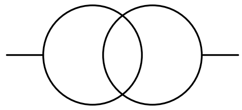
Variable resistor/rheostat

1.3



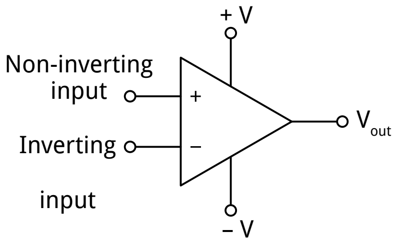
PTC-thermistor

1.4



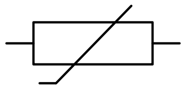
Transformer

1.5



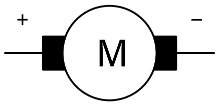
Op-amp

1.6



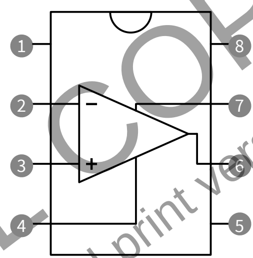
Inductor (fixed)

1.7



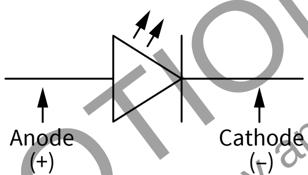
DC motor

1.8



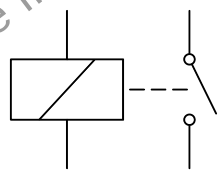
IC

1.9



LED

1.10

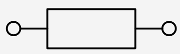
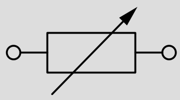


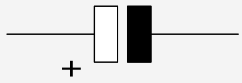
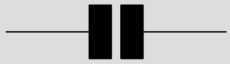
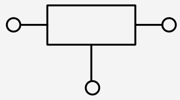
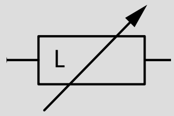
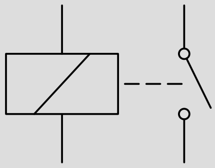
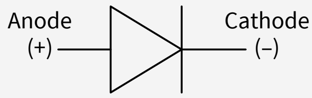
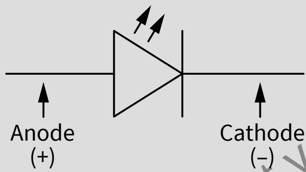
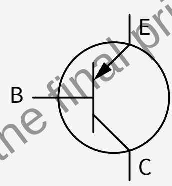
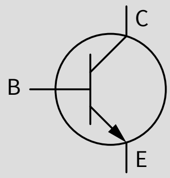
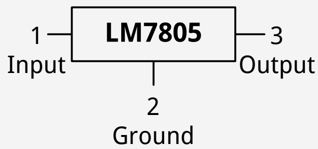
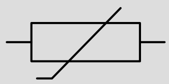
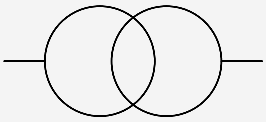
Relay

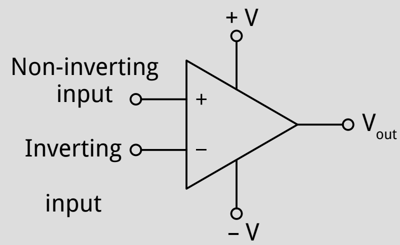
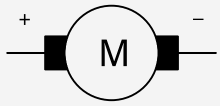
Activity 4.3

SB page 205

Complete the table below by providing a neat drawing of the IEC symbol that is used for each of the listed components.

COMPONENT	SYMBOL
E.g. Capacitor (non-polarised)	
Fixed resistor	
Variable resistor	

COMPONENT	SYMBOL
Polarised capacitor	
Non-polarised capacitor	
Potentiometer	
Variable inductor	
Fixed inductor	
Relay	
General-purpose diode	
LED	
PNP transistor	
NPN transistor	
IC-regulator	
Thermistor	
Transformer	

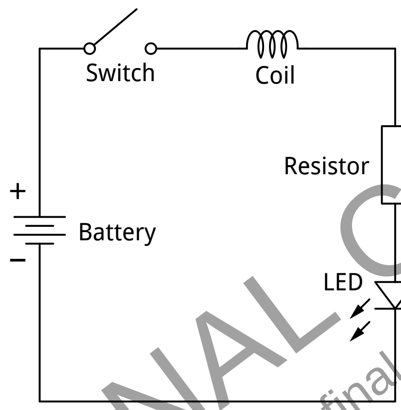
COMPONENT	SYMBOL
Op-amp	
DC motor	

Activity 4.4

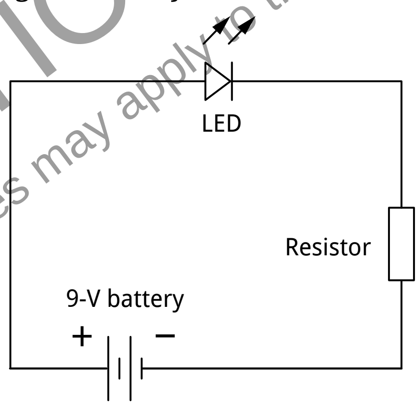
SB page 210

1. **Draw the following circuits using the correct symbols for all the listed components:**

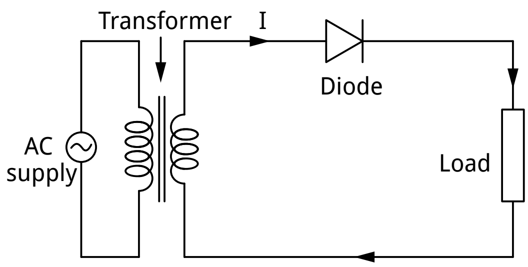
   1.1 Series circuit consisting of a coil, LED, resistor, open switch, and a battery



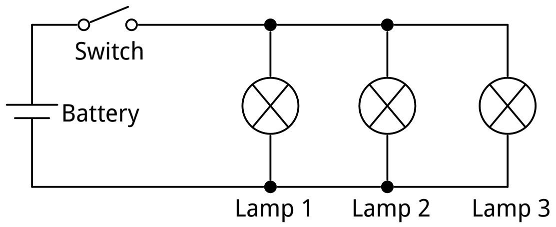
   1.2 Circuit consisting of a battery, resistor and LED connected in series



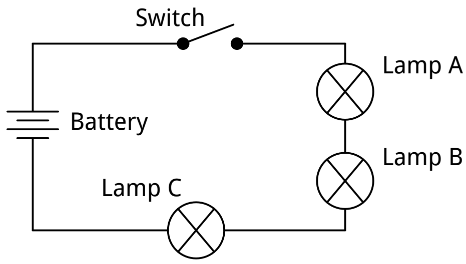
   1.3 Simple power supply consisting of an AC supply, a transformer, a diode, and a resistive load



1.4 Circuit consisting of three lamps connected in parallel to an open switch and a battery



1.5 Circuit consisting of three lamps, an open switch and a battery connected in series

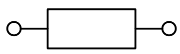


Activity 4.5

SB page 210

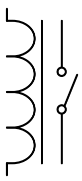
1. **Draw the IEC symbol for each of the following electronic components:**

1.1 Fixed resistor

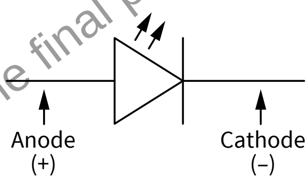


1.2 Polarised capacitor

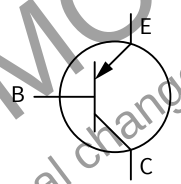
1.3 Relay



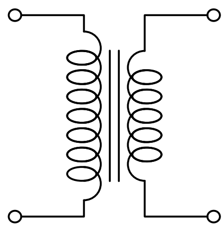
1.4 LED



1.5 PNP transistor



1.6 Transformer

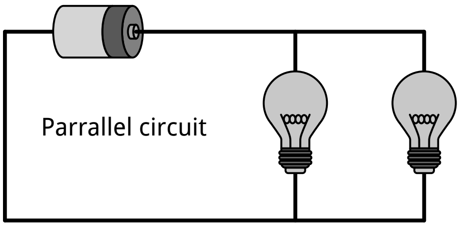


2. **Electric circuits can be divided into five main groups. Name them.**

- Open-circuits
- Closed circuits
- Short circuits
- Series circuits
- Parallel circuits

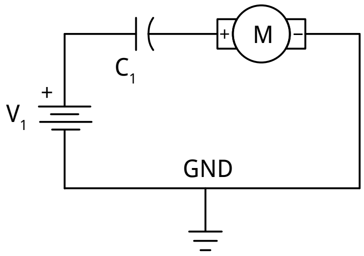
3. **Write down the three main components of a basic circuit.**
   - Energy source;
   - Electrical components; and
   - Continuous current.

4. **Make a simple drawing of a parallel circuit.**



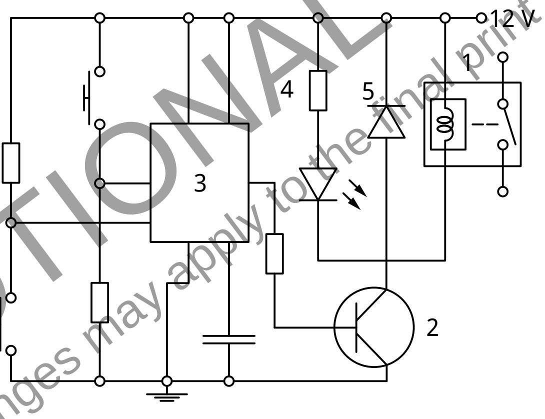
(Any correct representation of a parallel circuit)

5. **Identify all the components used in the following circuit.**



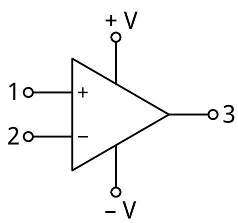
1 × DC motor   1 × non-polarised capacitor   1 × battery

6. **Identify the components numbered 1–5 in the circuit diagram below.**



1. Relay   **2.** NPN transistor   **3.** 8-pin IC (integrated circuit)
4. Resistor   **5.** Diode

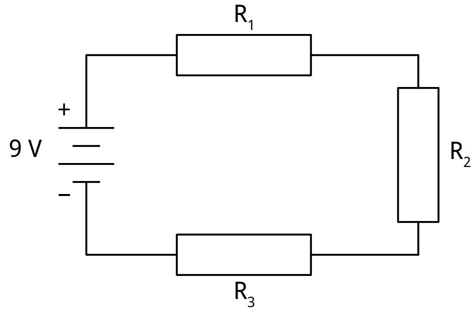
7. **The following symbol represents an op-amp. Name the parts labelled 1–3.**



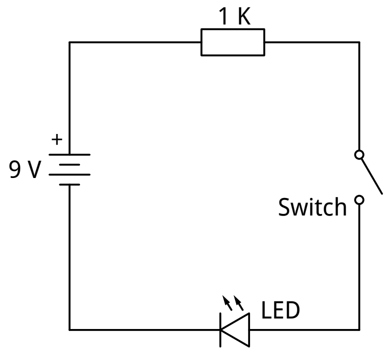
1. Non-inverting input   **2.** Inverting input   **3.** Output

8. Make a neat, labelled drawing of the following circuits:

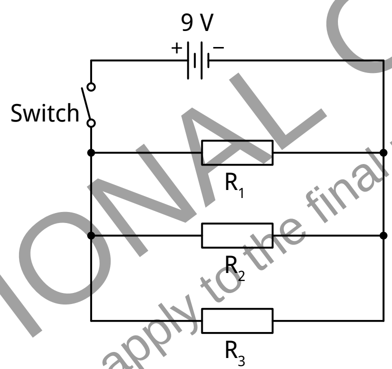
8.1 A battery in series with three resistors



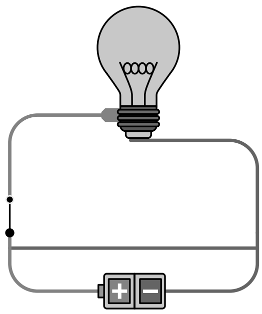
8.2 A battery, an open switch, a resistor and an LED connected in series



8.3 Three resistors connected in parallel to a battery and an open switch



9. With reference to the circuit below, will the lamp be on or off? Give a reason for your answer.

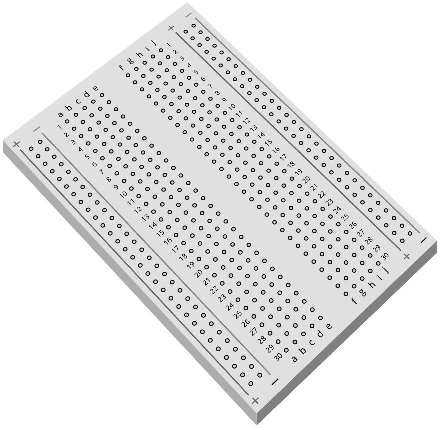


The lamp will be off, because there is a short circuit between the two terminals of the battery. No current will flow through the lamp.

Activity 4.6

SB page 222

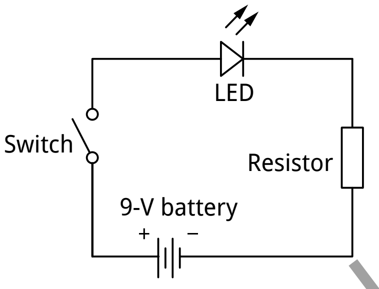
1. Identify the component illustrated below and state what it is used for.



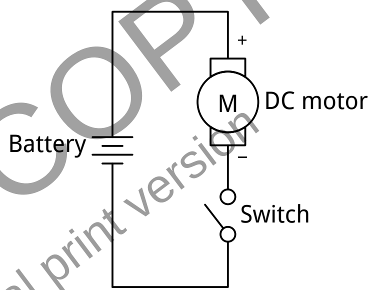
A breadboard. It is used to prototype and test electrical circuits before they are built.

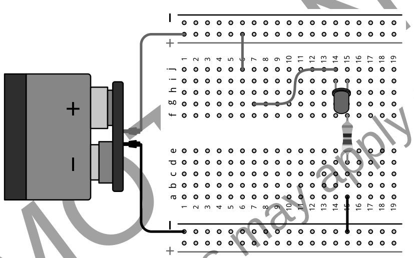
2. Use a neat, labelled sketch to show how you would connect each of the given circuits onto the breadboard.

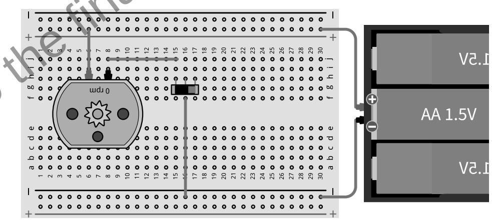
2.1



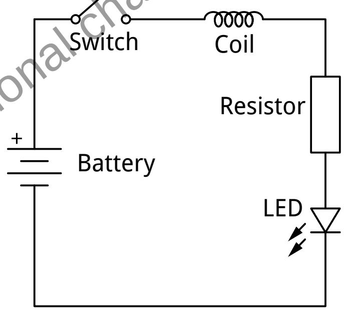
2.2

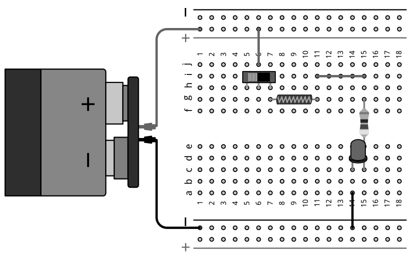




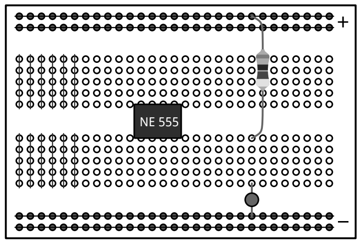


2.3





3. 3.1 **With the aid of a simple drawing, show how an IC must be connected onto a breadboard.**



3.2 **Why is it so important to connect an IC onto a breadboard the right way?**

If it is connected any other way, the legs of the IC will short out one another.

4. **Explain the difference between a *breadboard* and *Veroboard*.**

Breadboard: A breadboard is a rectangular, plastic board with holes to which electrical components and connecting wires can be connected. Underneath the plastic top, there is an arrangement of connectors that connect the holes in a specific way. A breadboard is used to prototype and test electrical circuits before they are built.

Veroboard: A Veroboard is a special type of insulated board with parallel strips of copper track on the underside. The top is simply a clear board (resin-bonded plastic or fiberglass) with many perforated holes. It is used to build simple circuits where the components are connected permanently – they are soldered onto the Veroboard.

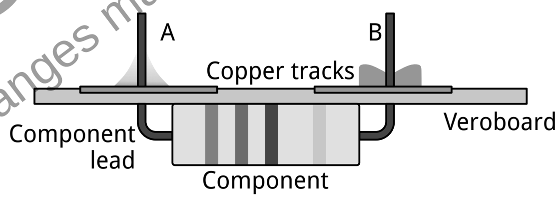
5. **Components are soldered onto a Veroboard using a soldering iron. Why must the tip of the soldering iron be tinned regularly?**

To ensure maximum heat is transferred from the soldering iron's tip to the joint.

6. **Why is it important to work in a well-ventilated room when soldering?**

Because when you solder, harmful/toxic fumes are released.

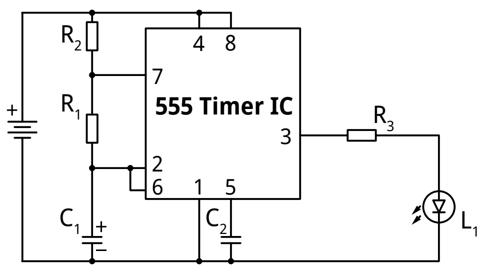
7. **With reference to the illustration below, which joint represents a well-soldered joint? Write down only A or B.**

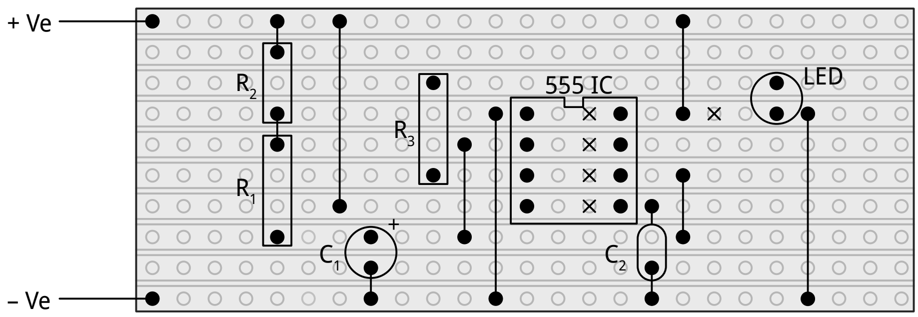


B

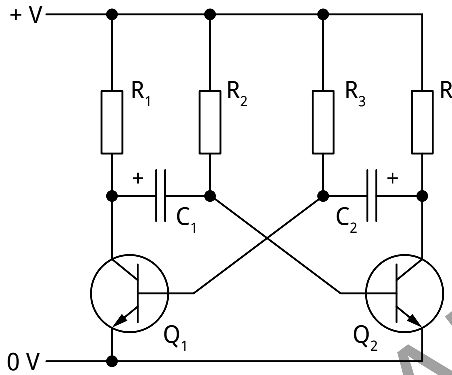
8. **Make a copy of a Veroboard layout in your workbook and design the following circuits on the Veroboard:**

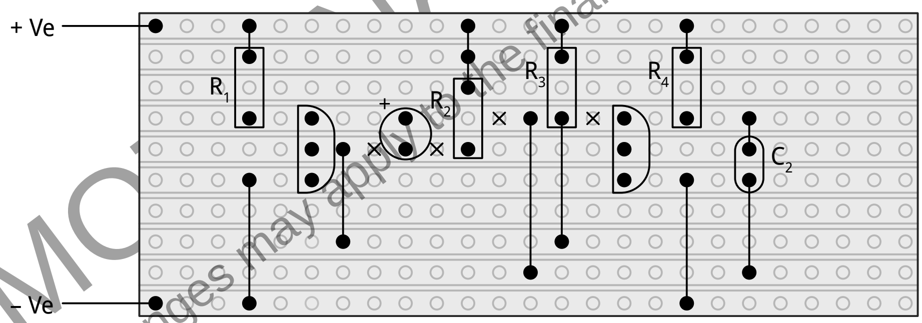
8.1


R2
R1
C1
4 8
7
555 Timer IC
3
2
6 1 5
C2
R3
L1


+ Ve
– Ve
R2
R1
R3
555 IC
LED
C1
C2

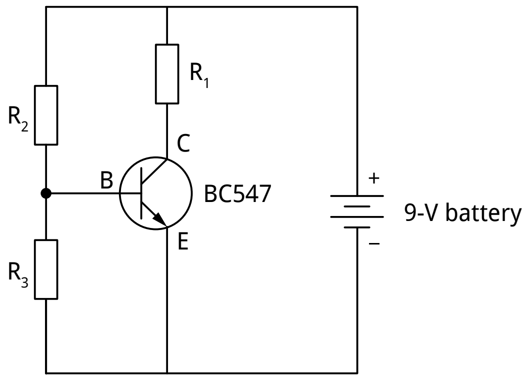
8.2

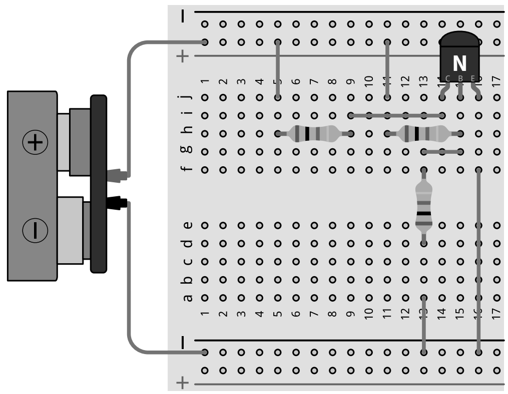

+ V
R1
R2
R3
R4
C1
C2
Q1
Q2
0 V


+ Ve
– Ve
R1
R2
R3
R4
C2

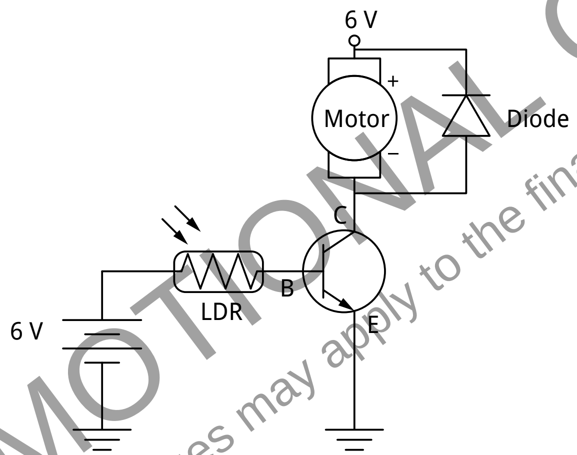
9. Make a copy of a breadboard layout in your workbook and design the following circuits on the breadboard:

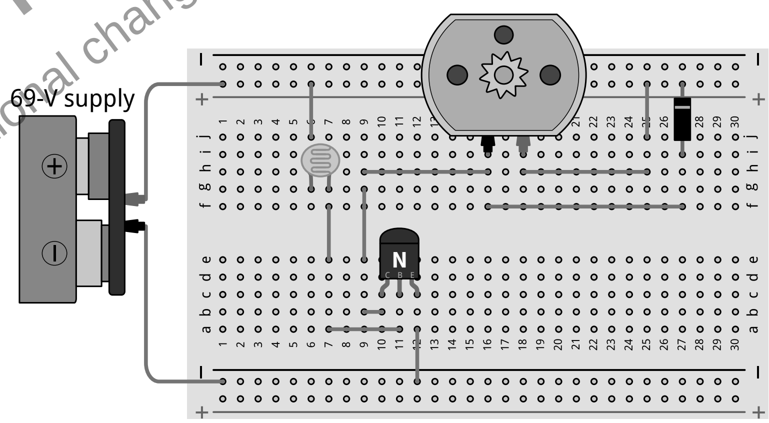
9.1





9.2





Activity 4.7

SB page 253

1. Refer to Figure 4.7.1 and 4.7.2 illustrated below.

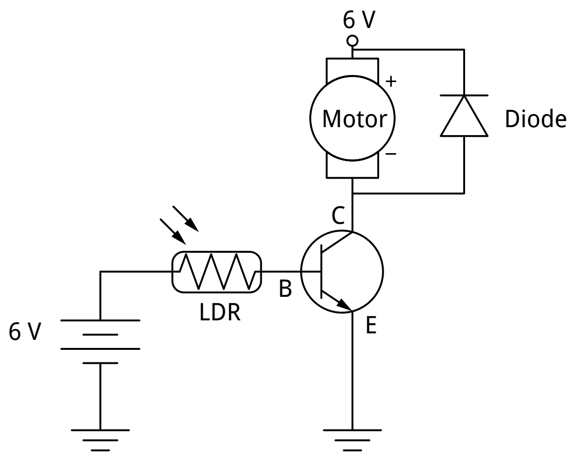


Figure 4.7.1: Circuit A

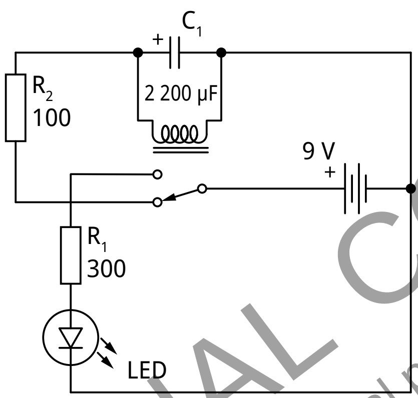


Figure 4.7.2: Circuit B

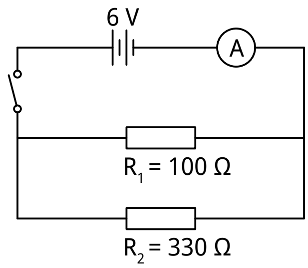
1.1 Briefly explain the operation of circuit A.

Circuit A represents a light-activated motor-control circuit. With no light falling onto the light-dependent resistor (LDR) or photoresistor, its resistance will be very high; therefore the transistor will be off. As soon as light starts to fall on the LDR, its resistance will drop, depending on the intensity of the light, switching on the transistor, which in turn switches on the DC motor.

1.2 Briefly explain the operation of circuit B.

Circuit B represents a circuit using a relay to make an LED switch on and off continuously. When the circuit is connected to the power source, the capacitor will start to charge. When the capacitor is fully charged, it will activate the relay which will open the normally close switch (NC) and close the normally open (NO) switch, switching on the LED. The capacitor will now start to discharge, deactivating the relay, thus switching the LED off again. This process will repeat itself, turning the LED on and off all the time.

2. With reference to the figure below, calculate:



2.1 The total resistance of the circuit

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{100} + \frac{1}{330}$$
$$= 0{,}013$$

2.2 The total current flowing through the circuit.

$$I_T = \frac{V_T}{R_T}$$
$$= \frac{6}{76{,}74}$$
$$= 0{,}078 \text{ A}$$

3. With reference to the figure below, calculate:

3.1 The total resistance in the circuit

$$\frac{1}{R_{23}} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$= \frac{1}{30} + \frac{1}{50}$$
$$= 0{,}053$$
$$R_{23} = 18{,}75\ \Omega$$

$$\therefore R_T = R_2 + R_{23} + R_4$$
$$= 20 + 18{,}75 + 20$$
$$= 58{,}75\ \Omega$$

3.2 The total current flowing through the circuit

$$I_T = \frac{V_T}{R_T}$$
$$= \frac{10}{58{,}75}$$
$$= 0{,}170 \text{ A}$$

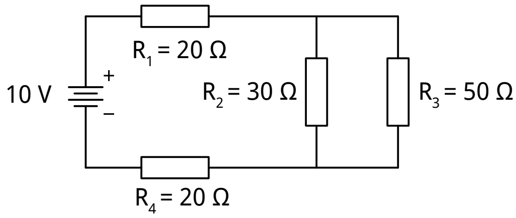
3.3 The voltage drop across R_1

$$V_{R1} = I_T \times R_1$$
$$= 0{,}170 \times 20$$
$$3{,}4 \text{ V}$$

3.4 The voltage drop across R_4

$$V_{R4} = I_T \times R_1$$
$$= 0{,}170 \times 20$$
$$3{,}4 \text{ V}$$

3.5 The current flowing through R_2.



$I_{R2} = \frac{V_{R2}}{R_2}$

But $V_{R2} = V_T - V_{R1} - V_{R4}$
$= 10 - 3{,}4 - 3{,}4$
$= 3{,}2$ V

$\therefore I_{R2} = \frac{3{,}2}{30}$
$= 0{,}106$ A

4. 4.1 Define ***Kirchhoff's voltage law*****.**

Kirchhoff's voltage law states that the sum of the voltage drops across the resistances of a closed circuit equals the total voltage applied to the circuit.

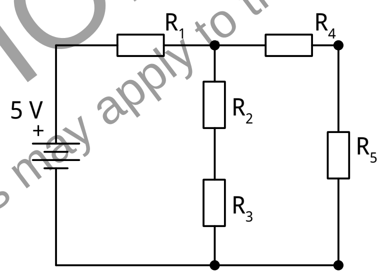
Or

The algebraic sum of all voltages within the loop must be equal to zero, i.e. ΣV total = 0 or, if three resistors are connected, $V_{R1} + V_{R2} + V_{R3} - V_T = 0$ V

4.2 Define ***Kirchhoff's current law*****.**

Kirchhoff's current law states the sum of all the currents flowing towards a junction always equals the sum of all the currents flowing away from that junction.

5. With reference to the figure below, determine the voltage drop across R_1 if the voltage drop across R_2 and R_3 equals 3,4 V.

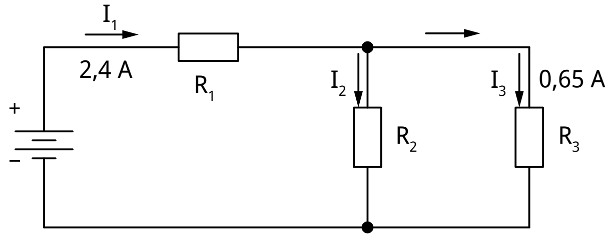


$V_T = V_{R1} + V_{R2} + V_{R3}$

But $V_{R2} + V_{R3} = 3{,}4$ V

$\therefore {}_{R1} = V_T - 3{,}4$ V
$= 5 - 3{,}4$
$= 1{,}6$ V

6. Apply Kirchhoff's current law to determines the value of I_2 in the figure below.



$I_1 = I_2 + I_3$

$\therefore I_2 = I_1 - I_3$

$= 2{,}4 - 0{,}65$

$= 1{,}75 \text{ A}$

NOTE TO FACILITATOR: PROJECTS

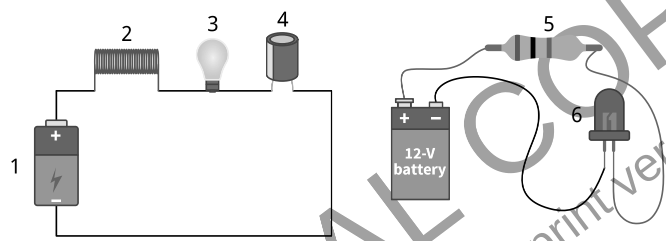
The following projects, included in Addendum A, may be considered:

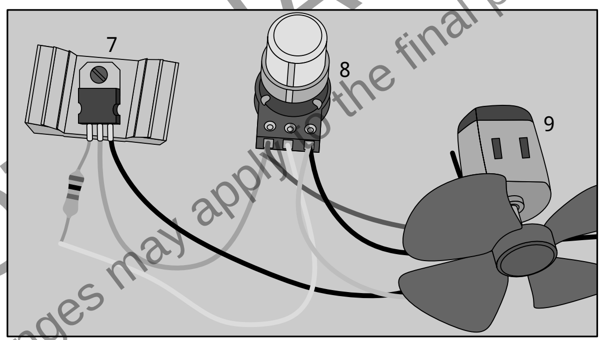
- *1.2 Morse-code sounder;*
- *1.3 Water-level indicator;*
- *1.4 Metal detector;*
- *2.2 Transistor astable multivibrator (Flip-flop);*
- *2.4 Electronic piano; and*
- *3.1 Arduino tone generator.*

Summative assessment

SB page 255

1. Identify the electronic components labelled 1–9 in the illustrations below.



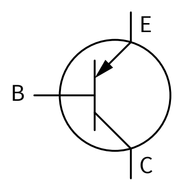


1	Battery	2	Coil	3	Lamp
4	Polarised capacitor	5	Resistor	6	LED
7	Regulator IC	8	Potentiometer	9	DC motor

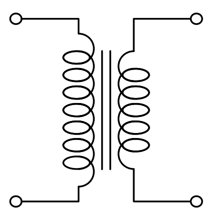
(9)

2. Draw the IEC symbols used for each of the following components:

2.1 PNP transistor



2.2 Transformer

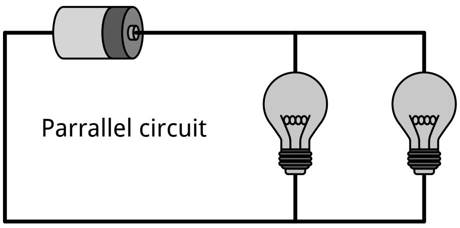


(2 × 1) (2)

3. **Name the THREE main components of a basic electric circuit.**
   - Energy source
   - Electrical components
   - Continuous current (3)

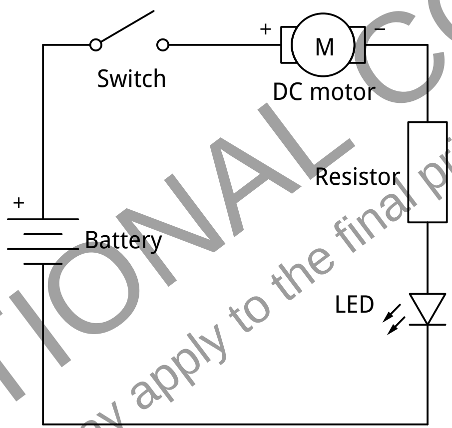
4. **Refer to the figure below.**

   4.1 **Will current flow through the circuit if one of the lamps is blown? Give a reason for your answer.**



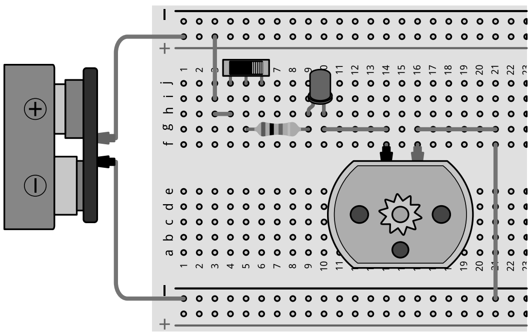
Yes, current will still be flowing through the other lamp.
The two lamps are connected in parallel. (2)

5. **Sketch a neat, labelled circuit diagram that contains each of the following components connected in a series circuit:**
   - **Battery**
   - **Resistor**
   - **LED**
   - **DC motor**
   - **Switch.**



(5)

6. **With reference to the circuit diagram in question 5 above, show how you would connect the circuit on a breadboard.**



(5)

7. Explain the advantage of building a circuit on a breadboard as opposed to a Veroboard.

The circuit connected onto the breadboard is not permanent. If you make a mistake, you can correct the circuit. The circuits built on Veroboards are permanent as components are soldered onto the board. No corrections can be made should a fault be detected. (3)

8. How you care for and use a soldering iron can influence its effectiveness. Name TWO important points that you must consider.

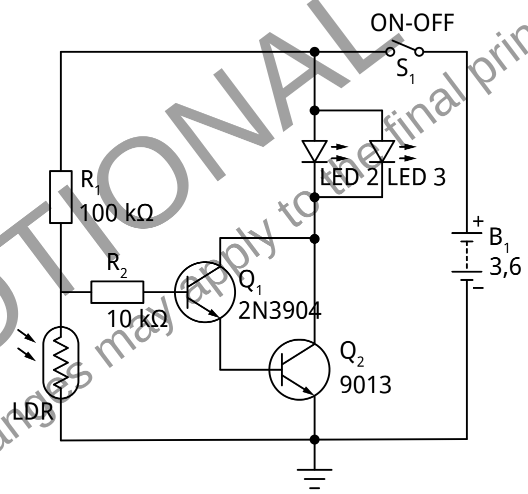
Any TWO of the following:

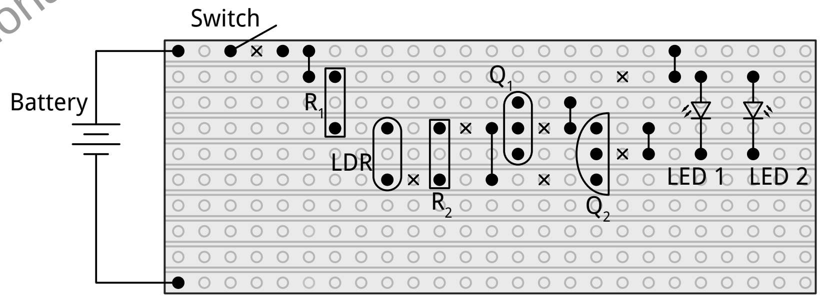
- The tip of the soldering iron must always be kept clean (shiny). Use a damp sponge or cloth.
- Soldering irons must be switched off when not in use. This preserves the element and soldering tip.
- The tip of the soldering iron must be tinned (covered in a thin layer of tin) regularly to help conduct heat while soldering. (2)

9. Name any ONE of the important safety precautions that must be taken when you use soldering irons.

- The soldering iron gets very hot (± 400 °C) and must be handled with care.
- Always place the soldering iron back into its stand when it is not in use.
- Work in a well-ventilated room as harmful fumes are generated during the soldering process. (1)

10. Make a copy of a Veroboard layout in your book and design the layout for the following circuit on the Veroboard.

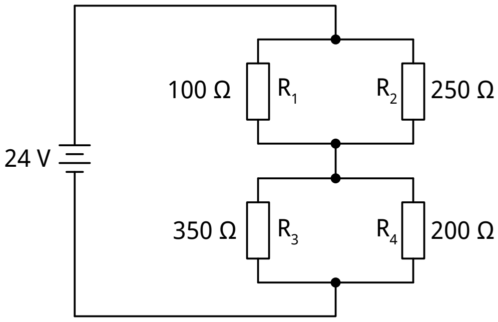




x = breaks in copper tracks

(10)

11. Study the figure below and answer the questions that follow.



11.1 Calculate the total parallel resistance of R_1 and R_2.

$\frac{1}{R_{12}} = \frac{1}{R_1} + \frac{1}{R_2}$

$= \frac{1}{100} + \frac{1}{250}$

$= 0{,}014$

$= 71{,}43\ \Omega$ (3)

11.2 Calculate the total parallel resistance of R_3 and R_4.

$\frac{1}{R_{34}} = \frac{1}{R_1} + \frac{1}{R_2}$

$= \frac{1}{350} + \frac{1}{200}$

$= 0{,}0785$

$= 127{,}39\ \Omega$ (3)

11.3 Calculate the total resistance of the circuit.

$R_T = R_{12} + R_{34}$

$= 71{,}43 + 127{,}39$

$= 198{,}82\ \Omega$ (3)

11.4 Calculate the total current (I_T) of the circuit.

$I_T = \frac{V_T}{R_T}$

$= \frac{24}{198{,}82}$

$= 0{,}121$ A or 121 mA (3)

11.5 Calculate the potential difference across R_4.

$V_{R4} = I_T \times R_{34}$

$= 0{,}121 \times 127{,}39$

$= 15{,}414$ V (3)

11.6 Calculate the current passing through R_3.

$V_{R4} = V_{R3} = 15{,}414$ V

$\therefore I_{R3} = \frac{V_{R3}}{R_3}$

$= \frac{15{,}414}{350}$

$= 0{,}044$ A or 44 mA (3)

TOTAL: 60

Module 5

Electronic tools and equipment

After students have completed this module, they should be able to:

- use the following electronic measuring instruments:
  - multimeter (digital and analogue)
  - oscilloscope
  - signal generator
  - function generator;
- explain how to take care of the above-mentioned instruments;
- explain how to use the given measuring instruments and interpret various readings;
- use the measuring instruments for a particular purpose;
- explain how to use and care for the following handheld measuring instruments:
  - ammeter
  - voltmeter
  - voltage testers
  - clamp-on meters
  - insulation-resistance meter;
- distinguish between analogue and digital meters;
- state the advantages of using digital meters;
- explain the concept of *parallax error*;
- set up and demonstrate the use of measuring instruments within the given range in practical simulations; and
- explain the correct care and storage of the instruments within the range of this module.

Introduction

Measuring instruments are used to test, calculate and measure the values of electrical quantities such as current, voltage, resistance and power. Students are already familiar with some of the measuring instruments used in the electrical and electronic field. Because these instruments play such an important role in electronic and digital concepts for robotics, many of them will be revised in this module. These delicate devices must be handled with care if they are to have a long service life. Some important aspects regarding their correct use, care and storage will therefore be discussed. We will compare digital meters to analogue meters to learn why digital meters are generally preferred.

Practical activity 5.1 SB page 279 **PAIR ACTIVITY**

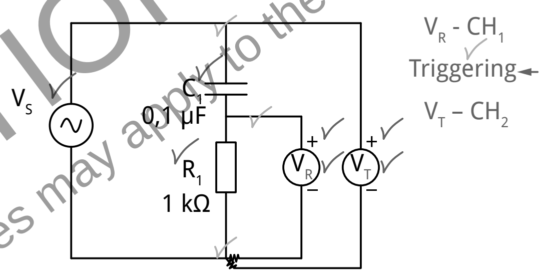
Simulation of oscilloscope

You will need:

- 1,0-kΩ resistor (R_1)
- 0,1-μF capacitor (C_1)
- Matrix board with hook-up wires (intermediate board)
- Audio signal generator (50 Hz–10 kHz)
- Dual-trace oscilloscope

Method

1. **Draw a series circuit by making use of the resistor and capacitor that is connected to a signal generator. Indicate how the oscilloscope is connected to the circuit. One input (CH2) of the oscilloscope is connected across the signal generator and the other input (CH1) across the resistor. The triggering must be set across CH1 (the resistor). Ensure that all the earth connections are connected on one side of the resistor. (This means all the black crocodile clips are connected.)** **(10)**

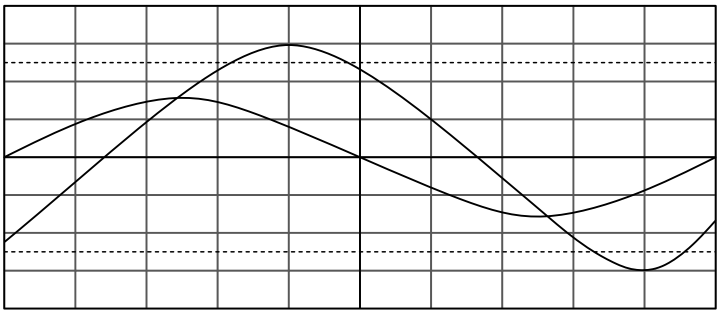


NOTE

- *Assume that this circuit was built correctly.*
- *The necessary adjustments have been made on the oscilloscope so that one complete cycle of the reference signal (V_R on CH 1) is displayed over 10 cm on the screen. The V/div setting has been adjusted so that the waves are as high (big) as possible.*

Practical activity 5.1 (continued)

2. **The following oscillograms (waves) are observed:**



T/div = 0,2 ms V/div = 0,2 V

Interpret the information and do the necessary calculations for the following:

V = (V/div)(No blocks)(0,707)

V_S = _____
V_R = _____
f = _____
Phase angle = _____
Supply current = V_R/R = _____ **(10)**

V = (V/div)(no blocks)(0,707)

V_S = (0,2)(3)(0,707) = 424 mV

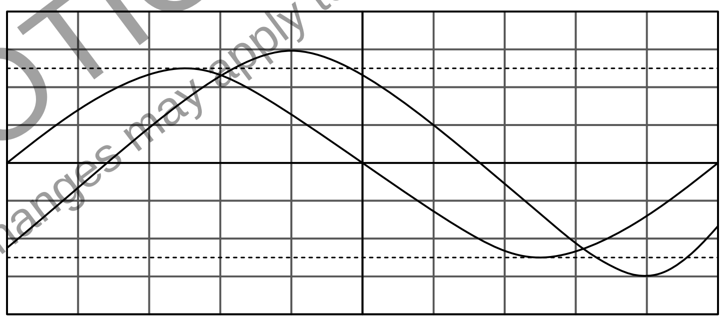
V_R = (0,2)(1,5)(0,707) = 212 mV

$f = \frac{1}{T} = \frac{1}{(V/div)(no\ blocks)} = \frac{1}{(0{,}2\ ms)(10)} = 500\ Hz$

Phase angle = $\frac{360}{10}$ = 36 × 1,5 = 54° V_R leads V_S

Supply current = $\frac{V_R}{R} = \frac{212\ mV}{1\ 000}$ = 212 μA (10)

3. **The frequency is now changed and the oscillograms observed on the oscilloscope at the new frequency are shown below.**



T/div = 10 μs V/div = 0,2 V

Interpret the information and do the necessary calculations for the following:

V = (V/div)(No blocks)(0,707)

V_S = _____
V_R = _____
f = _____
Phase angle = _____
Supply current = V_R/R = _____

Practical activity 5.1 (continued)

V = (V/div)(no blocks)(0,707)

V_S = (0,2)(3)(0,707) = 424 mV

V_R = (0,2)(2,5)(0,707) = 353,5 mV

$f = \frac{1}{T} = \frac{1}{(V/div)(no\ blocks)} = \frac{1}{(10\ \mu s)(10)} = 10$ Hz

Phase angle = $\frac{360}{10}$ = 36 × 1 = 36° V_R leads V_S

Supply current = $\frac{V_R}{R} = \frac{353,5\ mV}{1\ 000}$ = 353,5 μA (10)

Observation:
Answer the questions below by comparing the diagrams above. Establish how a change in frequency will influence the relationship between V_R and V_S:

1. **What is the phase relationship between V_R and V_S at frequency 1? (Refer to the angle as well as leading or lagging.)**

   At 500 Hz V_R leads V_S by 54° (2)

2. **What is the phase relationship between V_R and V_S at frequency 2? (Refer to the angle as well as leading or lagging.)**

   At 10 kHz V_R leads V_S by 36° (2)

3. **Did a change in frequency influence the phase relationship (angle) between the V_R and V_S?**

   Yes, it did. The phase angle is reduced from 54° to 36° (1)

4. **What effect does the change in frequency have on the magnitude of V_S and V_R?**

   4.1 V_S

   V_S stayed exactly the same at 424 mV.

   4.2 V_R

   V_R increased from 212 mV to 353,5 mV. (3)

5. **What influence does the change in frequency have on the current flowing in the circuit? Based on your finding, what do you think happened to the *overall resistance* (called the *impedance*) of the circuit as the frequency increased? (Note that no calculations are needed to answer this question.)**

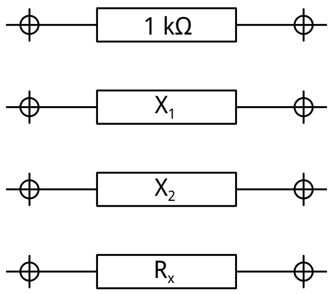
   The current increased from 212 μA to 353,5 μA, which means the impedance will decrease. (2)

TOTAL: 40

Practical activity 5.2 SB page 280 **GROUP ACTIVITY**

Using an oscilloscope and a signal generator to determine the effect of AC on R, L and C component combination circuits

You will need:

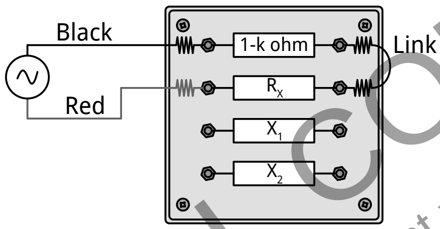


- Capacitor, coil, unknown resistor and a 1 000-Ω resistor (as shown – X_1 and X_2; can be either the coil or the capacitor)
- Audio signal generator (50 Hz–10 kHz)
- Dual-trace oscilloscope
- Connecting leads

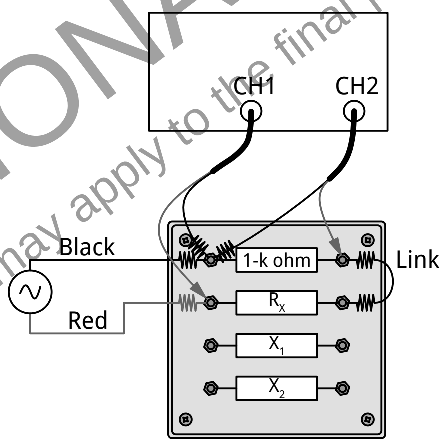
Method

Step 1:

- Connect the two resistors in series to the function generator. Ensure that the black crocodile clip is connected to the end of R_X and the red crocodile clip is connected to the end of the 1-kΩ resistor.
- Connect CH2 of the oscilloscope across the 1-kΩ resistor (This will be the reference voltage.)
- Connect the other channel (CH1) of the oscilloscope across the signal generator (i.e. the supply voltage).



Connections for function generator



Oscilloscope connected across R_X

Step 2:

- Set the function generator to a low frequency (about 500 Hz).
- Next, change the setting to a higher frequency (about 2 kHz).
- Draw the waves observed at both the low and high frequencies. Determine and record the phase relationship between the waves at both these frequencies. (10)

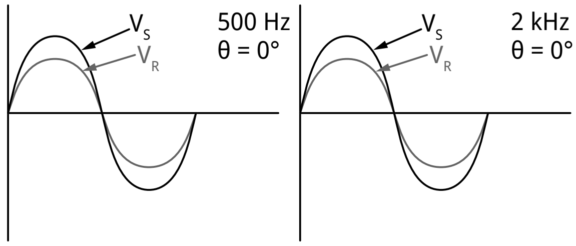
IMPORTANT

The black crocodile clips must be joined at the same point.

NOTE

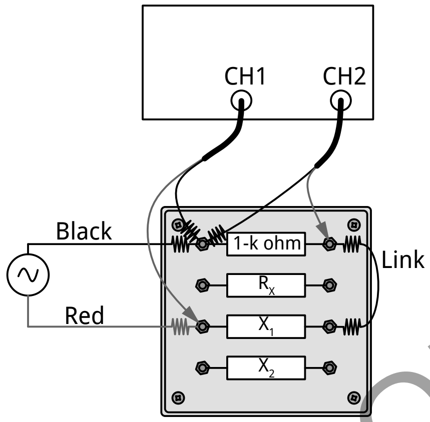
It is important to know which wave is leading. The wave representing CH2 (1 kΩ) or the wave across the unknown component.

Practical activity 5.2 (continued)

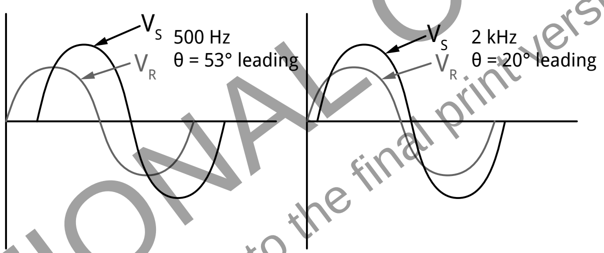


Waveforms observed for 1 kΩ and R_X

Step 3:
Move the connections across R_X to X_1 and repeat step 2 above. (10)

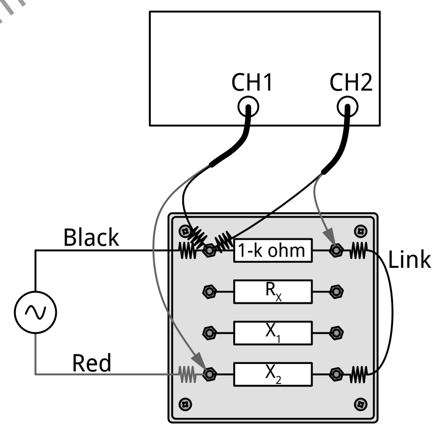


Oscilloscope connected across X_1



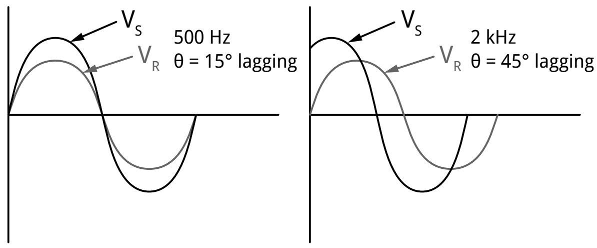
Waveforms observed for 1 kΩ and x_1

Step 4:
Move the connections across X_1 to X_2 and repeat step 2 again. (10)



Oscilloscope connected across X_2

Practical activity 5.2 (continued)



Waveforms observed for 1 kΩ and X_2

TOTAL: 30

Activity 5.1

SB page 281

1. **What does *caring* for measuring instruments involve?**

   Looking after instruments, storing them in a safe, dry, clean space and handling them with care.

   (Any suitable answer)

2. **Name THREE *general advantages* of caring for instruments.**

   - Increased accuracy
   - Extended service-life
   - Avoids costly breakdowns/economical in the long term

3. **Name THREE requirements for the areas in which measuring instruments are stored.**

   Any THREE logical answers
   - Dry
   - No excessive heat
   - Away from direct sunlight
   - Using silica gel packages to combat moisture/humidity

4. **Explain the term *calibration*.**

   Calibration refers to the process of comparing a measurement made by an instrument with the value of the same measurement as defined by an accepted standard to check the accuracy of the instrument.

5. **A digital multimeter is shown on the next page. State the settings that should be used and explain how the leads should be connected to the multimeter to measure or check each of the following:**

   5.1 240-V AC

   - Set the dial to 750 V AC.
   - Insert the black lead into the COM socket.
   - Insert the red lead into the V/Ω/mA socket.

- Connect the ends of the leads across the circuit (in parallel) where you want to measure the voltage.
- Read the numbers off the display.

5.2 15 mA (AC or DC)

- Set the dial to 20 mA.
- Insert the black lead into the COM socket.
- Insert the red lead into the V/Ω/mA socket.
- Switch off the supply of the item you are measuring.
- Create a "break" in the wire.
- Connect the ends of the leads in series with the break.
- Switch on the item you are measuring.
- Read the numbers off the display.
- Remember your answer will be in mA.

5.3 25 kΩ

- Set the dial to the 200-k resistance setting.
- Insert the black lead into the COM socket.
- Insert the red lead into the V/Ω/mA socket
- Switch off the power supply of the item you are measuring.
- Connect the leads across the component you want to measure.
- Read the numbers off the display.
- Remember the reading will be in kΩ.

5.4 8 A

- Set the dial to 10 A.
- Insert the black lead into the COM socket.
- Insert the red lead into the 10-A socket.
- Switch off the power supply of the item you are measuring.
- Create a "break" in the wire.
- Connect the ends of the leads in series with the break in the circuit.
- Switch on the item you are measuring.
- Read the numbers off the display.

6. **What is the purpose of an *oscilloscope*?**

To give a visual display of an electrical signal, showing both amplitude and frequency

7. **What type of waveforms can a *function generator* produce?**

- Sine wave
- Square wave
- Saw-tooth wave

8. **State whether each of the following statements is TRUE or FALSE.**

   8.1 **A *signal generator* can measure voltage and frequency.**

   False

   8.2 **An *analogue multimeter* uses a needle to indicate readings on a calibrated scale.**

   True

   8.3 **An *oscilloscope* can measure current values.**

   False

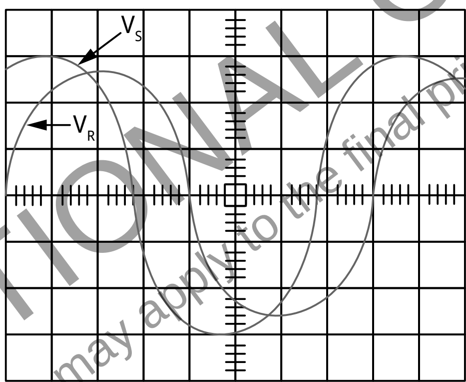
   8.4 **An *oscilloscope* can show the phase displacement between two waveforms.**

   True

   8.5 **A *digital multimeter* can be used to measure a greater variety of readings than an analogue meter.**

   True

9. **The waveforms observed on an oscilloscope are shown below. The setting are as follows:**
   - **Channel 1: (V_S) V/div = 0,5 V**
   - **Channel 2: (V_R) V/div = 0,2 V**
   - **T/div = 20 µs**



Interpret the waves to calculate the following:

9.1 **V_R**

V_R = V/div × number of blocks × 0,707
= 0,2 V/div × 2,5 blocks × 0,707
= 0,35 V

9.2 **V_S**

V_S = V/div × number of blocks × 0,707
= 0,5 V/div × 3 blocks × 0,707
= 1,06 V

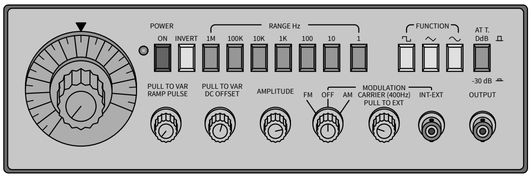
9.3 Frequency

$$F = \frac{1}{T} = \frac{1}{20\ \mu s \times 8} = 6{,}26\ kHz$$

9.4 Phase angle

$$\theta = \frac{360}{40} \times 6 = 54°$$

10. Refer to the sketch below and explain how you would set the frequency to 15 kHz.



- Select and press 10 K in the Range series.
- Adjust the frequency dial (big dial on the left) to 1,5.

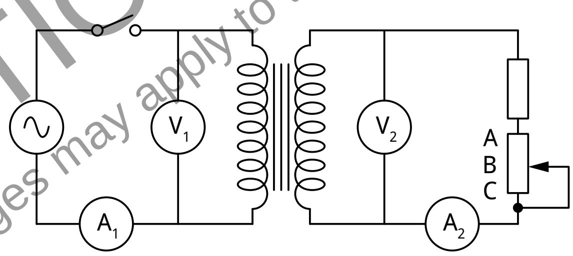
Practical activity 5.3 SB page 289 **SIMULATION ACTIVITY**

Measure the primary and secondary voltage and the current of a transformer connected to a load.

You will need:
- Transformer with Prim 240 V/50 Hz and Sec 12-0-23
- Connecting wires
- 2 × voltmeters
- 2 × ammeters
- Fixed resistor
- Variable resistor

Instructions:

1. Wire the circuit according to the diagram given below.



2. Record all readings using the following as reference:
   $V_1 = V_{prim}$ = voltage of the supply
   $V_2 = V_{sec}$ = voltage of load (secondary)
   $A_1 = I_{prim}$ = current on primary side (drawn from the supply)
   $A_2 = I_{sec}$ = current on the secondary side (drawn by the load)
3. Set the variable resistor to minimum (position C at the bottom). Record all the readings.
4. Set the variable resistor to medium (positon B in the centre). Record all the readings.
5. Set the variable resitor to maximum (position A at the top). Record all the readings.

Practical activity 5.3 (continued)

Note that the readings for the table below were taken using:

- a 5-kΩ fixed resistor;
- a 5-kΩ linear variable resistor; and
- a 240-V/12-V transformer with 880 primary turns and 44 secondary turns.

RECORDING OF METER READINGS			
	V_R SET AT POSITION C	V_R SET AT POSITION B	V_R SET AT POSITION A
V_1	240 V	240 V	240 V
V_2	12 V	12 V	12 V
A_1	60 µA	80 µA	120 µA
A_2	1,2 mA	1,6 mA	2,4 mA

Conclusion:

What do you observe and conclude from the readings as the load resistance changes?

Voltage: Voltage on the secondary winding is lower than the voltage on the primary

Current:

- Position A – The variable resistor is set to the top value, meaning zero resistance. Therefore, the only resistance in the secondary winding is the top resistor of 5 kΩ, resulting in a high secondary current (2,4 mA).
- Position B – The variable resistor is set to the centre value, meaning its resistance is approximately 2,5 kΩ. This added to that of the top resistor equals 7,5 kΩ, resulting in a lower secondary current (1,6 mA).
- Position C – The variable resistor is set to the bottom value, meaning its resistance is at the maximum of 5 kΩ. This added to the top resistor equals 7,5 kΩ, resulting in an even lower secondary current (1,2 mA).

Furthermore, the primary current is always higher than the secondary current; so, this transformer reduces voltage by a ratio of 20, while it increases current by a ratio of 20.

Activity 5.2

SB page 297

1. **Distinguish between** ***analogue*** **and** ***digital meters*****.**

   The analogue meter uses electromagnetic fields, while the digital meter uses electronic circuitry. An analogue meter has a permanent magnetic moving coil that uses the deflection of a pointer to indicate the measurement being taken. Digital meters have digital/numeric displays in easily readable format.

2. **Why are *digital meters* more accurate than *analogue meters*?**

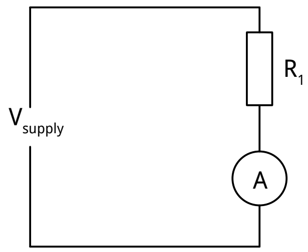
   Any logical answers can be accepted.
   - Easy to read (no error parallax)
   - Not influenced by magnetic fields
   - No need to zero the needle
   - No moving parts that can wear

3. **When using an analogue meter, why must you take the reading from directly above the meter?**

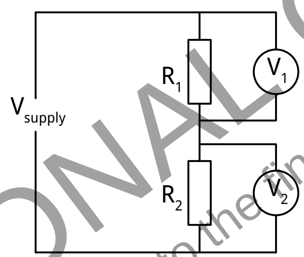
   To avoid parallax error which will lead to inaccurate readings

4. **By means of a simple sketch, show how the following meters should be connected into a circuit:**

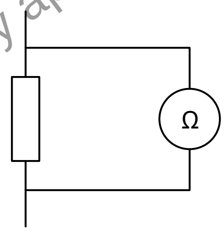
   4.1 An ammeter used to measure current through a single resistor



   4.2 Two voltmeters used to measure the voltage drop across two resistors connected in series



   4.3 An ohmmeter used to measure the resistance of a resistor.



5. **You can use a multimeter and a clamp-on meter as an ammeter. Why would the clamp-on meter be a better choice?**

   - No need to switch off the supply
   - No need to create a break in the circuit
   - Saves time
   - No chance of forgetting to change the leads of the socket on the multimeter.

6. **Why do we have to use an insulation tester rather than a multimeter when testing the insulation resistance of a new installation?**
   - A multimeter uses a 9-V battery (low voltage and current).
   - An insulation tester tests at double the supply voltage.

7. **Name the THREE main tests for which an insulation-resistance tester is used.**
   - Continuity
   - Insulation between conductors
   - Insulation between conductors and earth

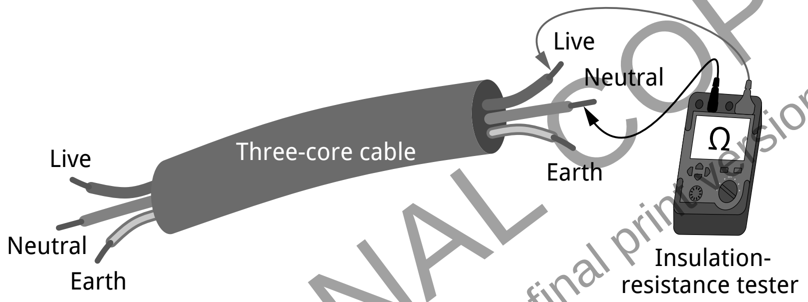
8. **If you want to test whether all the points of a household installation is earthed, which test would you perform?**

   Continuity test

9. **What is the minimum acceptable insulation reading between conductors, as set by the regulating authorities?**

   Insulation resistance between conductors must not be less than 1 megaohm. (Many regulating authorities now accept 0,5 MΩ as sufficient.)

10. **Identify the test that is performed in the illustration below.**



   Insulation between conductors live and neutral

NOTE TO FACILITATOR: PROJECTS

The following projects, included in Addendum A, may be considered:
- *2.5 Binary-input converted to seven-segment display;*
- *3.3 Arduino waveform display*

Summative assessment

SB page 298

1. **Give TWO reasons why caring for measuring instruments is of the utmost importance.**
   - Ensures longer service life: With proper care, measuring instruments can serve you well for a long time. Tools that are not maintained will break sooner, and you will have to replace them earlier.
   - More economical in the long term: It can help you avoid costly breakdowns, repairs and downtime. (Any two relevant points) (2)

2. **Name TWO requirements for the area in which measuring equipment is stored.**

Store equipment in an area that is dry, not exposed to extreme heat or humidity and away from direct sunlight. In areas with high humidity silica gel packets, air-conditioning or a dehumidifier can be used. (Any two) (2)

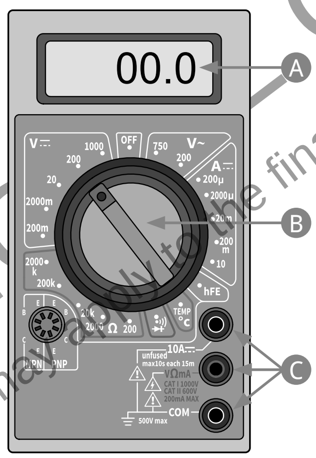
3. **Explain what is meant by *calibration* of equipment?**

Calibration is the process of comparing a measurement made by an instrument with the value of the same measurement as defined by an accepted standard to check the accuracy of the instrument. (3)

4. **What is the difference between a *manual-ranging* and an *auto-ranging multimeter*? Refer to examples of actual settings and readings in your answer.**

- Manual-ranging: You have to manually select the correct range within a selected function before taking a measurement. The reading must also be interpreted according the scale selected. For example, if you set the meter to the MΩ scale and the display reads 2,5 you must know that it is actually 2,5 MΩ.
- Auto-ranging: You simply select the function and the multimeter will automatically select the appropriate range. Once you have selected the function (volts, amps, ohms, etc.), the meter will select the range or scale automatically. E.g., select the voltage scale and it automatically selects the correct scale and gives you the correct readout, e.g. 2 kV. (4)

5. **Identify the parts labelled as A to C in the sketch below.**

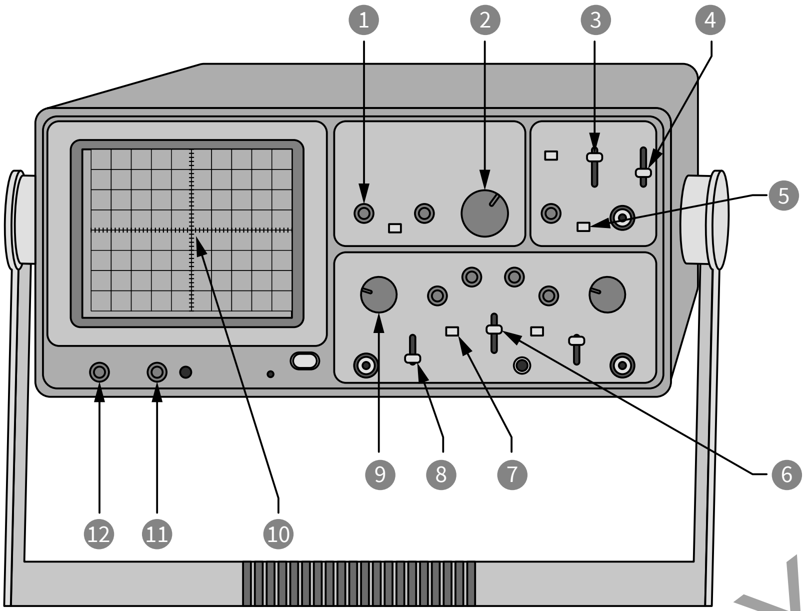


- Digital display
- Selector switch
- Connector sockets (3)

6. **With reference to the illustration below, state the purpose of the following buttons. They have been labelled for easy reference.**

6.1 Horizontal position (1) **6.2 T/div (2)** **6.3 Mode (6)**

6.4 V/div (9) **6.5 Focus (11)**



6.1 Horizontal position: Moves the waveform horizontally across the screen
6.2 T/div: Allows one to select the rate at which the waveform is drawn across the screen
6.3 Mode: On dual trace oscilloscopes, this allows one to display one waveform at a time, two waveforms simultaneously and/or to add the two waveforms
6.4 V/div: Varies the size of the waveform on the screen
6.5 Focus: Allows one to adjust the sharpness of the waveform (5)

7. **Choose the function in COLUMN B that matches each of the buttons of a** *function generator* **listed in COLUMN A.** (6)

COLUMN A	COLUMN B
7.1 BNC output socket (50 Ω)	**A provides a numeric display of the frequency being generated by the function generator**
7.2 Frequency range selector	**B allows one to select the waveform – sine wave, square wave or saw-tooth wave**
7.3 Digital output display	**C enables one to select the frequency range to be generated, e.g. 100 Hz, 1 kHz or 10 kHz**
7.4 Function selector	**D to set/adjust the amplitude of the waveform that is being generated (can range from a few mV to about 10 V, depending on the amplitude value required)**
7.5 Frequency adjustment knob	**E connection cable for connecting the function generator to other equipment**
7.6 Amplitude selector	**F allows one to set/adjust the frequency to a specific value**

7.1 E **7.2** C **7.3** A **7.4** B **7.5** F **7.6** D (6)

8. **The following changes need to be made *or* readings (measurements) need to be taken. State whether an *oscilloscope* or a *function generator* should be used.**

   8.1 To set the voltage or amplitude of a signal

   Function generator

   8.2 To measure the frequency of the wave

   Oscilloscope

   8.3 To change the signal from a sine wave to a square wave

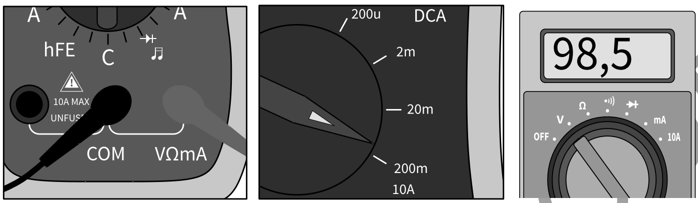
   Function generator

   8.4 To set the frequency to a specific value

   Function generator (4)

9. **For each of the following illustrations, identify the setting of the meter (i.e. state what is being measured) and then interpret the reading on the display.**

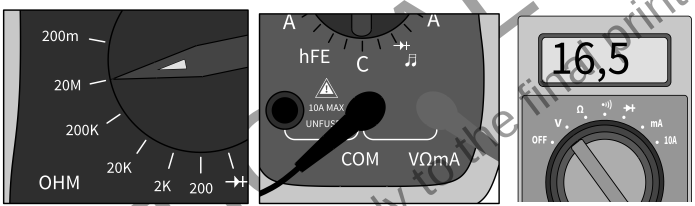
   9.1



(1)

   Current: 98,5 mA

   9.2



(1)

   Resistance: 16,5 MΩ

10. **Use the waveforms and settings shown below to calculate the following:**

   10.1 The peak RMS voltage of V_R (3)

   V_R = V/div × number of blocks × 0,707
   = 50 mV × 1 block × 0,707 = 35,35 mV (3)

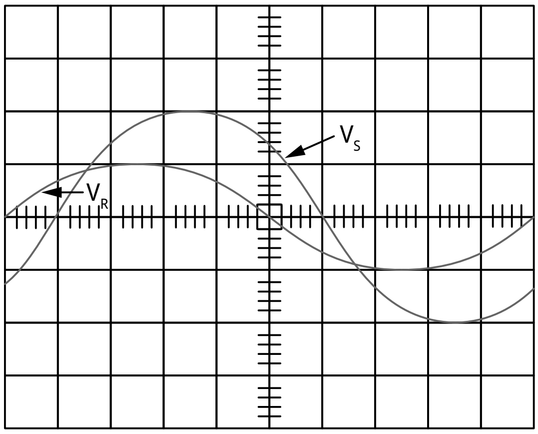
   10.2 The peak RMS voltage of V_S (3)

   V_S = V/div × number of blocks × 0,707
   = 50 mV × 2 blocks × 0,707 = 70,7 mV (3)

   10.3 The frequency of the waves

   $F = 1/T = \frac{1}{02 \text{ ms} \times 10} = 500 \text{ kHz}$ (3)

10.4 The phase angle



T/div = 0,2 ms V/div = 50 Mv

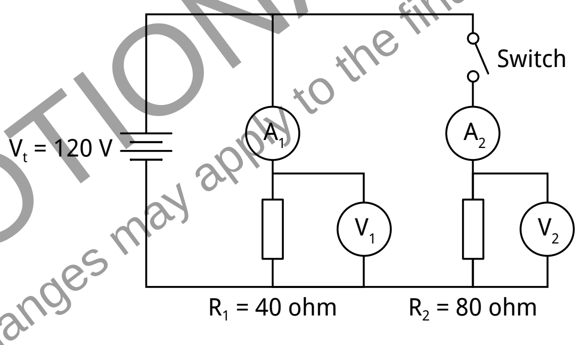
$\theta = \frac{360}{50} \times 5 = 36°$ (3)

11. Complete the table below for the settings and/or readings of the *signal/function generator*.

RANGE SETTING	DIAL SETTING	FREQUENCY
10 K	**1,5**	**15 kHz**
1 K	0,8	**800 Hz**
100	**1,9**	190 Hz
1 K	1,2	**1 200 Hz**
1 M	**1,4**	1,4 MHz

(5)

12. Use the values from the circuit shown below to complete the table for the readings on the meters labelled A_1, A_2, V_1 and V_2, respectively.



SWITCH OPEN		SWITCH CLOSED	
A_1	3 A	A_1	3 A
A_2	0 A	A_2	1,5 A
V_1	120 V	V_1	120 V
V_2	0 V	V_2	120 V

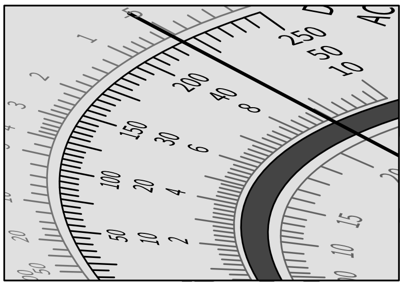
(8)

13. **Discuss the advantages of digital multimeters compared to analogue multimeters?**

ANY three correct answers.

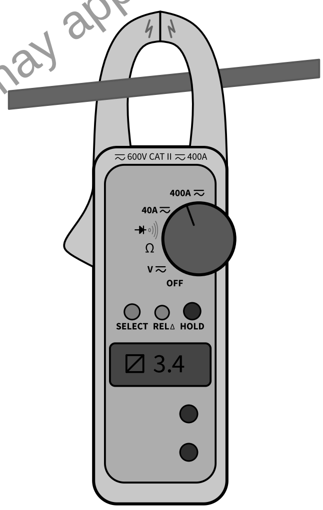
- As mentioned earlier, digital readouts are more accurate since the LCD display is easy to read.
- The numerical display of DMMs prevent parallax errors (explained in section 5.3.3).
- Unlike analogue multimeters, no adjustment is required.
- The reading speed is increased, as the display is easier to read.
- DMM displays have no moving parts. This makes them free from wear and shock failures.
- Digital meters are available in smaller sizes.
- Digital measuring instruments are very tough.
- They have a high input impedance, so there is less loading effect.
- DMMs can be used to test continuity, capacitors, diodes and transistors. More advanced DMMs can also measure frequency. (7)

14. **Explain whether an accurate reading can be taken from the display on the meter shown below if it is set to the 50-V scale.**



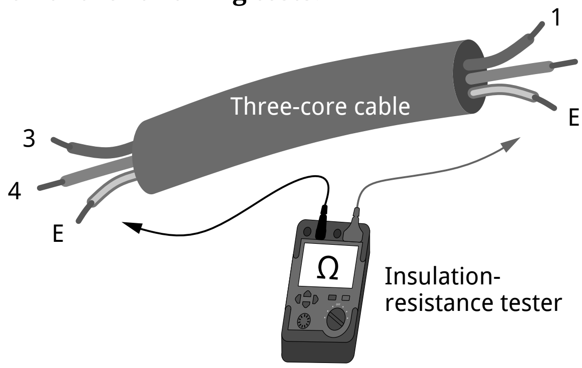
The display is not viewed perpendicular from above. It will lead to an error in parallax. (1)

15. **By means of a reasonably neat sketch, show how a clamp-on meter needs to be connected to a cable to measure the current flow.**



(3)

16. **An insulation-resistance tester is shown in the sketch below. Explain the *connection* you would make, as well as the *acceptable readings* you would expect, for each of the following tests:**



16.1 Continuity test

Continuity test

- Connect test leads across points 1 and 3. Take the reading. It should read less that 1 Ω, depending on the length and thickness of the conductor.
- Now connect across points 2 and 4 and repeat.
- Then across both ends of the E wire and repeat. (2)

16.2 Insulation between conductors

Insulation between conductors

- Connect leads across point 1 and 2. Take the reading. It should be higher than 1 MΩ. (2)

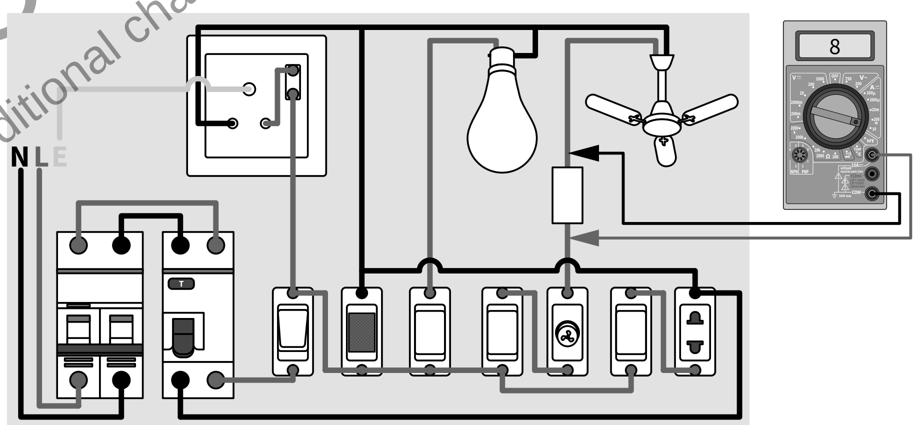
16.3 Insulation between conductors and earth

Insulation between conductors and earth

- Connect one lead to E and the other lead to 1. Take the reading. It should be higher than 1 MΩ.
- Connect one lead to E and the other lead to 2. Take the reading. It should be higher than 1 MΩ. (2)

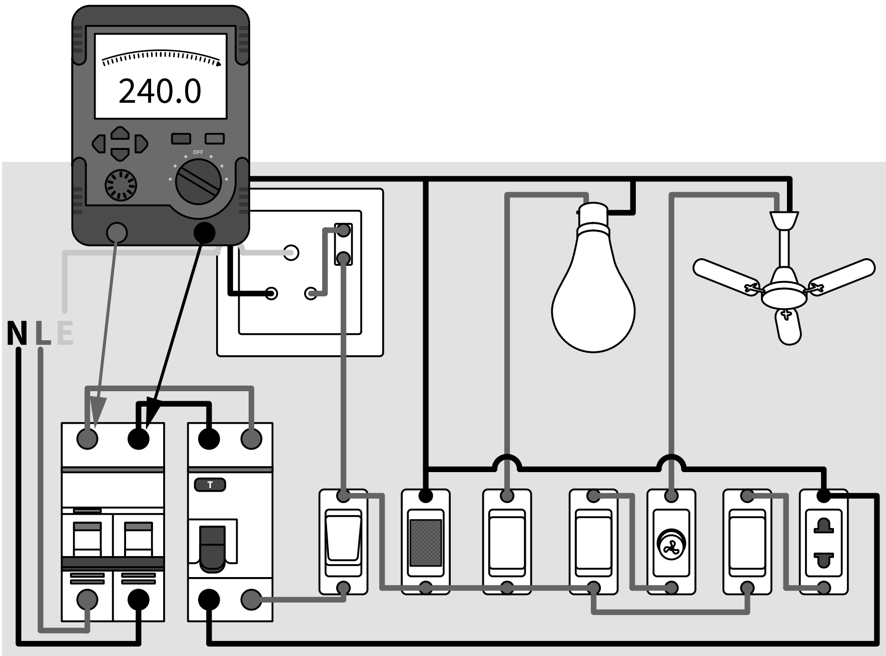
17. **A distribution board is shown in each of the sketches below. Study the sketches and state the mistake that was made in the connection of the measuring instrument.**

17.1 A meter set to measure current



The red wire/circuit was not “broken” as the ammeter must be connected in series with the load. (1)

17.2 A meter used to measure insulation between conductors



A multimeter cannot be used as its supply is a 9-V battery. A megger/insulation tester must be used as the installation must be tested at double the supply voltage. (1)

TOTAL: 87

Module 6

Digital systems, PLCs and principles

After students have completed this module, they should be able to:

- describe the operation of the following logic gates and their respective truth tables:
  - AND
  - OR
  - NOT
  - NAND
  - NOR
  - XOR
  - XNOR;
- correctly use IEC symbols to represent logic gates;
- use each logic gate in a simple application;
- interpret basic data-sheet information;
- compare *PLCs* and *relay systems*;
- sketch the block diagram of a PLC;
- explain the function of the processor in a PLC;
- name and sketch the schematic symbols used in ladder diagrams;
- explain how a given simple ladder diagram will function;
- predict the end result of a given simple ladder diagram;
- explain *Boolean logic* and *logic design*;
- discuss the term *logical diagram* and its purpose;
- draw a simple logic diagram incorporating different logical gates based on a scenario or expression;
- interpret a simple logic diagram;
- discuss the term *truth table* and its purpose;
- draw a truth table;
- describe the operation of logic gates and their respective truth tables;
- draw a truth table for given logic circuits; and
- validate a logical design (diagram) using a truth table.

Introduction

Basic digital and logic concepts are the building blocks of all digital equipment including computers, banking, communication systems and modern vehicles. Because it is extremely important that students understand these concepts (covered in Level 2 of this course), they are revised in this module. What is more, knowing these concepts in this everchanging digital age may even allow students to create new designs and present solutions that can improve people's lives. Students will be introduced to *programmable logic controllers* or *PLCs*. These digital devices can be programmed to perform various functions and are used in various applications in industries such as the steel industry, automobile industry, chemical industry and the energy sector. The content is aimed at laying the foundation for further studies in this field.

Activity 6.1

SB page 326

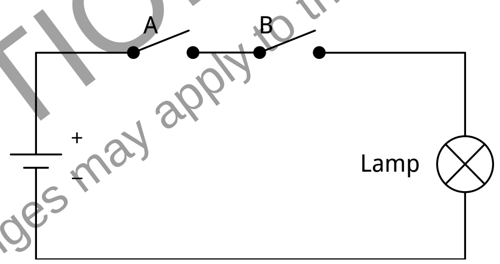
1. **If a logic gate has THREE inputs, how many possible input combinations will there be for the truth table?**

   2^3 = 8 possible input combinations

2. **Complete the *input combinations* for the two-input truth table given below.**

A	B	OUTPUT
0	0	
0	1	
1	0	
1	1	

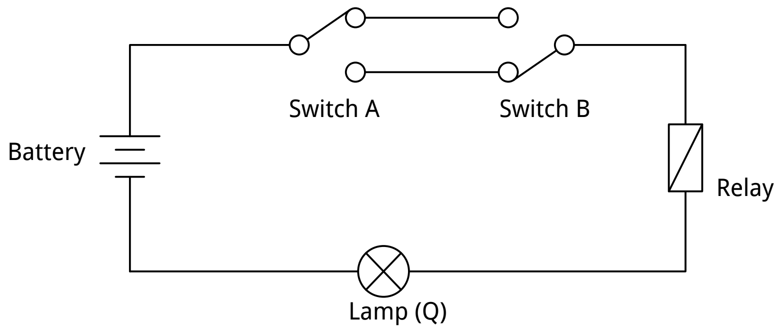
3. **By referring to the switching circuit below, identify the logic gate that it represents and complete the truth table for this circuit.**



AND Gate

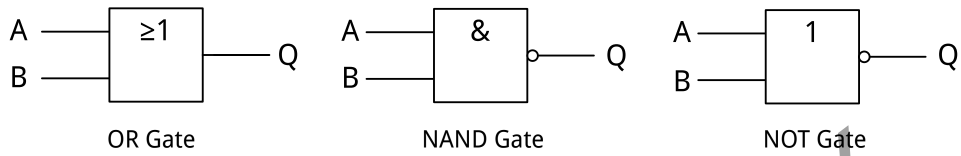
SWITCH A (INPUT)	SWITCH B (INPUT)	LAMP (OUTPUT)
0	0	0
0	1	0
1	0	0
1	1	1

4. **Name the logic gate that is represented by the following switching circuit:**

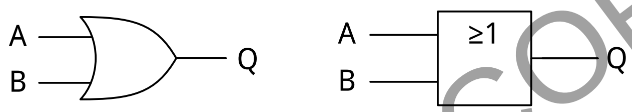


XOR Gate

5. **Draw the IEC symbols for each of the following logic gates:**
   - **OR gate**
   - **NAND gate**
   - **NOT gate.**

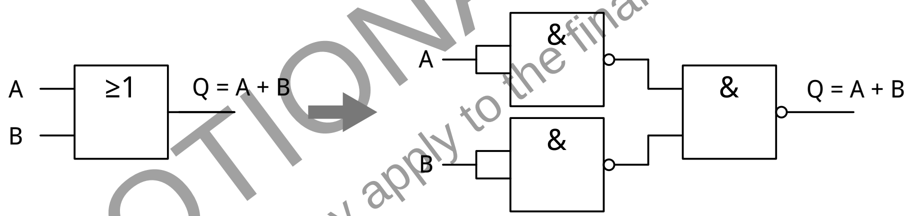


6. **Write down the output/Boolean expression for the following gate:**



Q = A + B

7. **Draw the NAND gate equivalent (combination) for an OR gate.**



8. **An extract of a data sheet for a 74LS86 logic IC is shown below. Read the data sheet and answer the questions that follow.**

Guaranteed Operating Ranges						
Symbol	**Parameter**		**Min**	**Typ**	**Max**	**Unit**
V_{CC}	Supply voltage	54	4,5	5,0	5,5	V
		74	4,75	5,0	5,25	
T_A	Operating ambient temperature range	54	–55	25	125	°C
		74	0	25	70	
I_{OH}	Output current – high	54, 74			–0,4	mA
I_{OL}	Output current – low	54			4,0	mA
		74			8,0	

8.1 What is the minimum operating voltage for this logic IC?

4,5 V /4,75 V

8.2 What is the highest ambient temperature in which this logic IC will be able to operate optimally?

125 °C or 70 °C

Activity 6.2

SB page 337

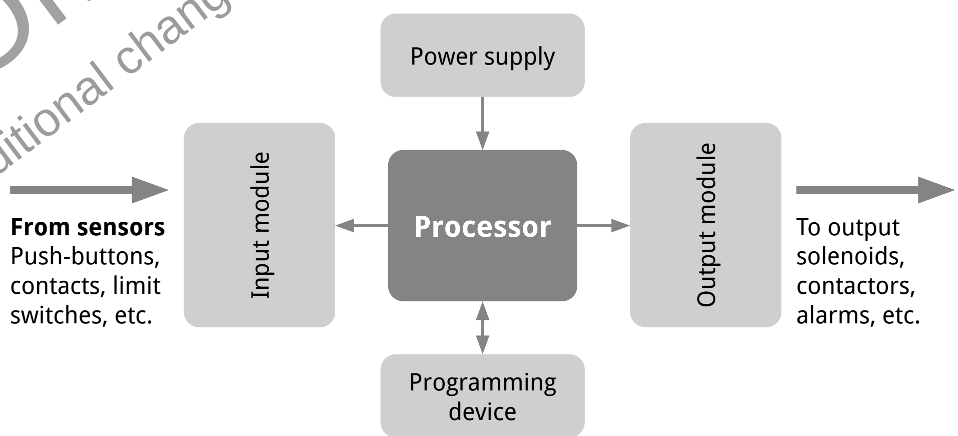
1. What does the abbreviation *PLC* stand for?

Programmable logic controller

2. Compare *relay logic* and *PLCs* with regards to the characteristics listed in the table below.

CHARACTERISTIC	RELAY LOGIC	PLC
2.1 Size	Large, complicated system that takes up lots of space	Compact, solid-state device that is relatively small
2.2 Energy consumption	Uses a lot of energy	Uses about a tenth of the amount of energy of relay systems
2.3 Service life	Limited mechanical life because of moving parts	A solid-state device (no moving parts) thus long service life
2.4 Maintenance	Needs more maintenance	Error-diagnostic units means it require less maintenance
2.5 Cost	More expensive than PLC system – the more the relays, the greater the cost	Costs much less compared to relay-logic systems (one-time investment)
2.6 Reliability	Mechanical breakdowns can occur at any time – many moving parts	More reliable because it has no moving parts
2.7 Modification/ Flexibility	Difficult to update or modify an existing program	Very flexible and easy to change or modify (write a new program)
2.8 Response	Slower response time than PLC	Fast response time – can process thousands of items per second

3. Draw a neat, labelled block diagram of a simple PLC.



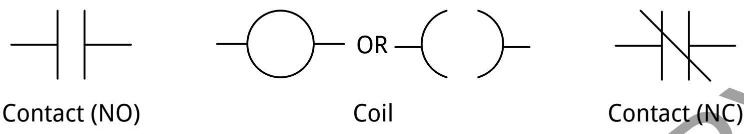
4. Name and briefly explain the THREE main steps in the execution of each instruction for a PLC.

1. Checking the inputs – (INPUT): The PLC reads the inputs via the input interface.
2. Execution of instructions – (PROCESS): The PLC will now look at the first instruction in the program and execute it.
3. Updating the outputs – (OUTPUT).

5. Briefly explain the function of the *processor* of a PLC.

- The processing of all arithmetic operations
- Logic operators
- The storage of information
- Computer interface
- Local-area network, etc.

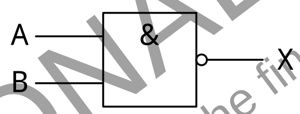
6. Draw the THREE main symbols used in ladder diagrams and name each symbol.



7. In ladder diagrams, circuits are connected as horizontal lines between two vertical lines. What do we call these *horizontal lines*?

Rungs

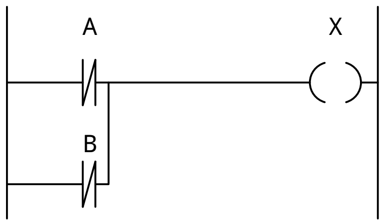
8. 8.1 Identify the logic gate shown in the figure below.



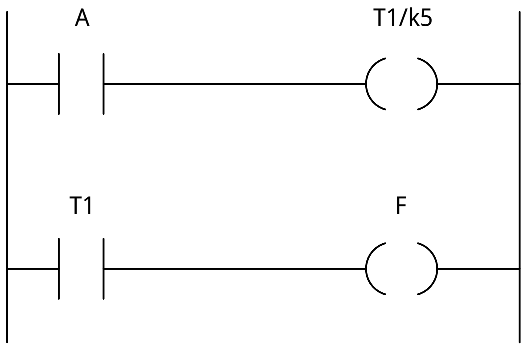
NAND Gate

8.2 Draw the truth table as well as ladder diagram for this logic gate.

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0



9. **Explain the operation of the on-delay timer ladder diagram in the figure below.**

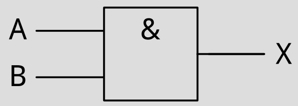
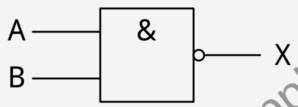
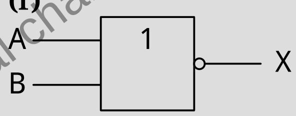
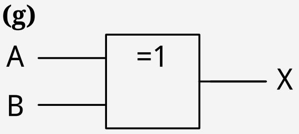


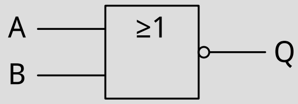
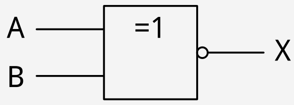
With reference to the figure above, when contact A is closed, the timer (T1) starts running and after 10 seconds (indicated by k10), the timer contact (T1) closes and at the same time activates the coil (F). The output F will now be a '1'.

Activity 6.3

SB page 344

Redraw the table below and complete it by providing the missing details.

<table>
<tr><th>LOGIC IC</th><th>IEC SYMBOL</th><th>TRUTH TABLE</th></tr>
<tr><td>AND gate</td><td>(a)
</td><td>(b)
<table>
<tr><th>SWITCH A (INPUT)</th><th>SWITCH B (INPUT)</th><th>LAMP (OUTPUT)</th></tr>
<tr><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>1</td></tr>
</table>
NOTE:
0 = open switch | 1 = closed switch | (0 = off and 1 = on)</td></tr>
<tr><td>(c)
NAND gate</td><td></td><td>(d)
<table>
<tr><th>A (INPUT)</th><th>B (INPUT)</th><th>Q (OUTPUT)</th></tr>
<tr><td>0</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>1</td></tr>
<tr><td>1</td><td>0</td><td>1</td></tr>
<tr><td>1</td><td>1</td><td>0</td></tr>
</table></td></tr>
<tr><td>(e)
NOT gate</td><td>(f)
</td><td>
<table>
<tr><th>A</th><th>X</th></tr>
<tr><td>0</td><td>1</td></tr>
<tr><td>1</td><td>0</td></tr>
</table></td></tr>
<tr><td>XOR gate</td><td>(g)
</td><td>(h)
<table>
<tr><th>A (INPUT)</th><th>B (INPUT)</th><th>Q (OUTPUT)</th></tr>
<tr><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td>1</td></tr>
<tr><td>1</td><td>0</td><td>1</td></tr>
<tr><td>1</td><td>1</td><td>0</td></tr>
</table></td></tr>
</table>

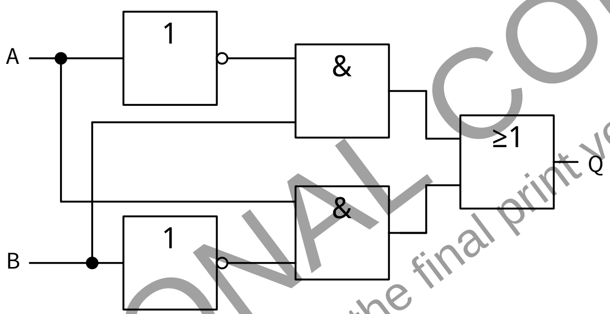
<table>
<tr><th>LOGIC IC</th><th>IEC SYMBOL</th><th>TRUTH TABLE</th></tr>
<tr><td>(i)
NOR gate</td><td>
</td><td>(j)
<table>
<tr><th>A (INPUT)</th><th>B (INPUT)</th><th>Q (OUTPUT)</th></tr>
<tr><td>0</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td></tr>
</table></td></tr>
<tr><td>XNOR gate</td><td>(k)

</td><td>(l)
<table>
<tr><th>A (INPUT)</th><th>B (INPUT)</th><th>Q (OUTPUT)</th></tr>
<tr><td>0</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>1</td></tr>
</table></td></tr>
</table>

Activity 6.4

SB page 348

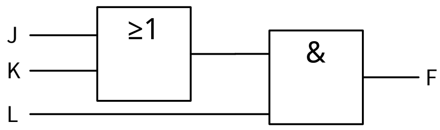
1. **Draw the combination circuit as well as the truth tables for each of the following Boolean expressions:**

1.1 $Q = \overline{A}.B + A.\overline{B}$



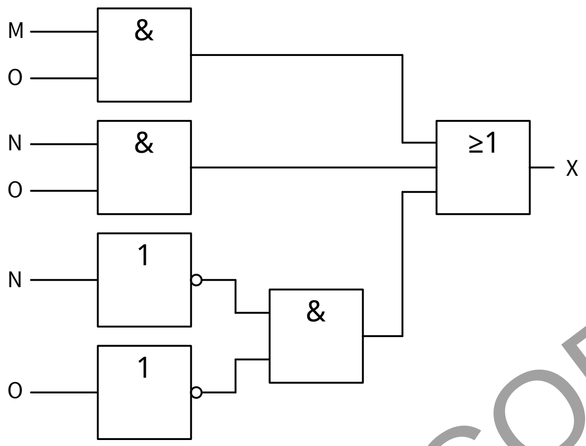
A	B	$\overline{A}$	$\overline{B}$	$\overline{A}$ + B	A + $\overline{B}$	Q
0	0	1	1	0	0	0
0	1	1	0	1	0	1
1	0	0	1	0	1	1
1	1	0	0	0	0	0

1.2 **F = (J + K) . (L)**



J	K	L	J + K	F
0	0	0	0	0
0	0	1	0	0
0	1	0	1	0
0	1	1	1	1
1	0	0	1	0
1	0	1	1	1
0	1	0	1	0
1	1	1	1	1

1.3 **$X = M.O + N.O + \overline{N}.\overline{O}$**



M	N	O	$\overline{N}$	$\overline{O}$	M.O	N.O	$\overline{N}.\overline{O}$	X
0	0	0	1	1	0	0	1	1
0	0	1	1	0	0	0	0	0
0	1	0	0	1	0	0	0	0
0	1	1	0	0	0	1	0	1
1	0	0	1	1	0	0	1	1
1	0	1	1	0	1	0	0	1
1	1	0	0	1	0	0	0	0
1	1	1	0	0	1	1	0	1

2. **Explain the term *truth table*.**

A truth table can be defined as a mathematical table that shows all possible outcomes that would occur given all possible scenarios that are considered at the input.
OR
The truth table also shows the result (output) of particular input states.

3. **How many input combinations can a truth table with four input bits have?**

$2^4 = 16$ input combinations.

Summative assessment

SB page 349

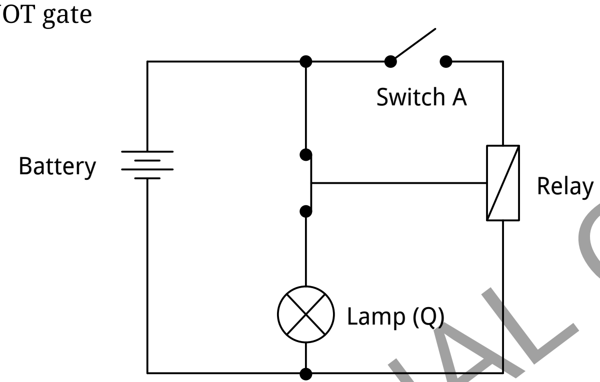
1. **Draw a truth table for a three-input device. Show all the possible input combinations.**

A	B	C	OUTPUT
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

(8)

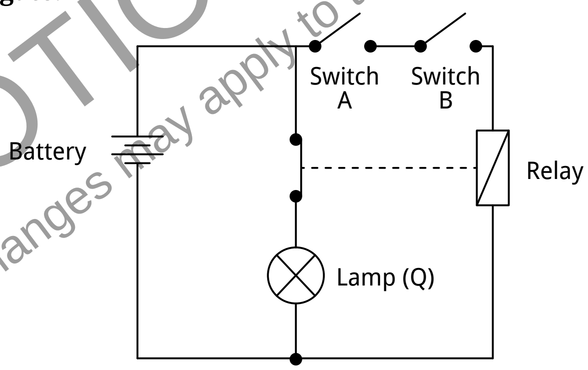
2. **Which logic gate does the following switching circuit represent?**

NOT gate



(1)

3. **Draw the switching circuit diagram for a NAND gate and compile the truth table for this gate.**

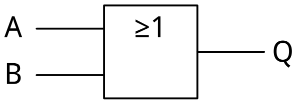


SWITCH A (INPUT)	SWITCH B (INPUT)	LAMP (OUTPUT)
0	0	1
0	1	1
1	0	1
1	1	0

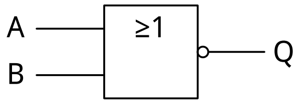
(9)

4. Draw the IEC symbol for each of the following gates:

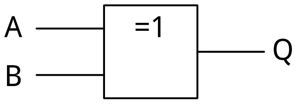
4.1 OR gate



4.2 NOR gate



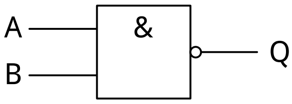
4.3 XOR gate



(6)

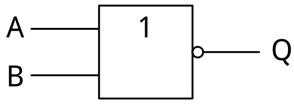
5. Name the gates represented by each of the following IEC symbols:

5.1



NAND gate

5.2



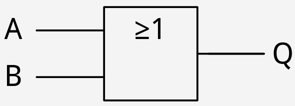
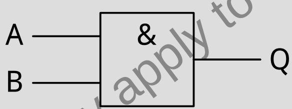
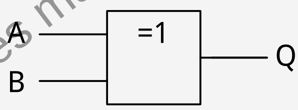
NOT gate

(2)

6. Which logic gate does the following Boolean expression represent?
$Q = \overline{A}.B + A.\overline{B}$ or $Q = A \oplus B$

XOR gate (1)

7. Complete the following table with reference to logic gates.

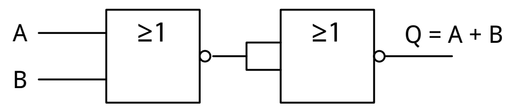
LOGIC FUNCTION	IEC SYMBOL	BOOLEAN EXPRESSION
OR gate	**7.1** 	**7.2** Q = A + B
7.3 AND gate	**7.4** 	Q = A.B
7.5 XOR gate		**7.6** $Q = \overline{A}.B + A.\overline{B}$ or $Q = A \oplus B$

(6)

8. Name THREE examples of applications where logic gates are used.

- Logic devices such as counters, flip flops, and shift registers
- Calculators and computers
- Musical instruments
- Electronic games
- Digital measuring instruments
- Smart phones
- Digital watches and calculators
- Microprocessors and microcontrollers (Any 3) (3)

9. **Draw the NAND gate equivalent for an OR gate.**



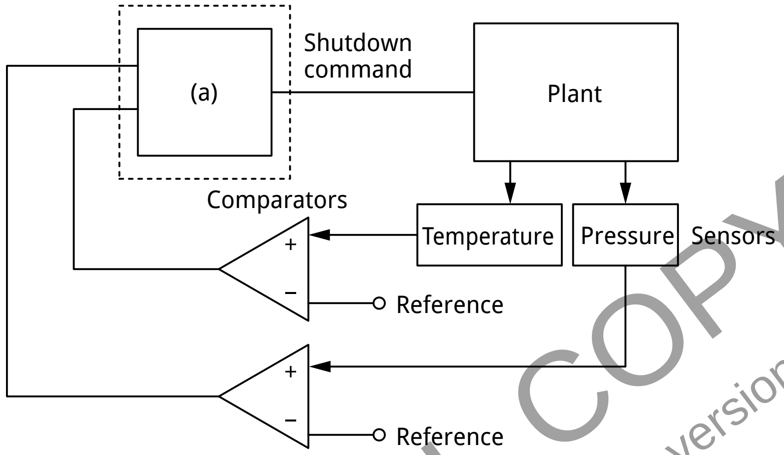
(4)

10. **The following logic circuit is used to monitor the temperature and pressure of a specific plant. If either the temperature *or* the pressure *or* both the temperature and pressure are high 1, then the logic gate represented by (a) must switch the plant off.**

10.1 **What type of gate is represented by (a)?**

OR gate (1)

10.2 **Draw the truth table for the gate you identified in 10.1.**



A (PRESSURE SENSOR)	B (TEMPERATURE SENSOR)	Q (OUTPUT)
0	0	0
0	1	1
1	0	1
1	1	1

(4)

11. **The following truth table was taken from a data sheet of a logic gate.**

IN		OUT
A	B	Z
L	L	L
L	H	H
H	L	H
H	H	L

11.1 **What gate does this truth table represent?**

XOR gate (1)

11.2 **Interpret the inputs and outputs of this gate.**

The output for this gate will be 1 when either input A or B is 1. For all the other input combinations, the output will be 0. (4)

12. The processor (or CPU) is the brain of a PLC. Name TWO of the other main components of a PLC.

Any TWO of the following:

- Input module
- Output module
- Power supply
- Programming device

(2)

13. Name THREE advantage of PLCs.

Any THREE of the following:

- Compact, solid-state device that is relatively small
- Uses about a tenth of the amount of energy that relay systems use
- A solid-state device (no moving parts) therefore has a long service life
- Error-diagnostic units mean it requires less maintenance
- Costs much less compared to relay-logic systems (one-time investment)
- More reliable because it has no moving parts
- Very flexible and easy to change or modify (write a new program)
- Fast response time – can process thousands of items per second

(3)

14. State the purpose of a *timer function* in a PLC.

The purpose of the timer function is to activate or deactivate a device after or before a preset interval of time.

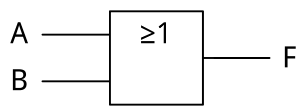
OR

The purpose of the timer function is to run an operation for a predetermined period and then deactivate it. (2)

15. Refer to the figure below and answer the questions that follow.

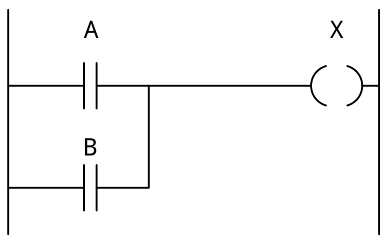
INPUT A	INPUT B	OUTPUT (F)
0	0	0
0	1	1
1	0	1
1	1	1

15.1 Draw the symbol of the logic gate this truth table represents.



(2)

15.2 Draw the ladder diagram that this truth table represents.

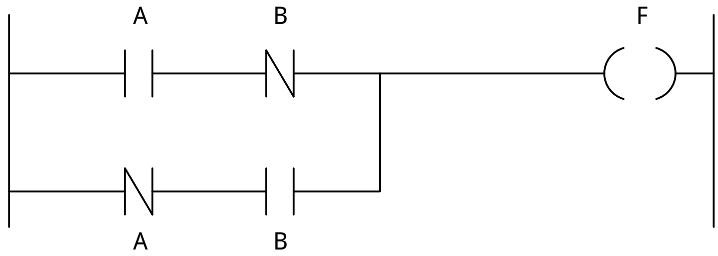


(3)

15.3 Write the Boolean expression for this truth table.

F = A + B (2)

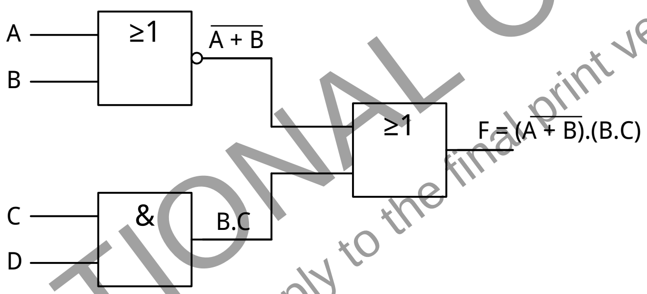
16. Complete a truth table for the following ladder diagram.



A	B	C	A.B	F = (A.B) + C
0	0	0	0	0
0	0	1	0	1
0	1	0	0	0
0	1	1	0	1
1	0	0	0	0
1	0	1	0	1
1	1	0	1	1
1	1	1	1	1

(8)

17. Draw the truth table for the following logic circuit.



A	B	C	$\overline{A + B}$	B.C	F = ($\overline{A + B}$) + (B.C)
0	0	0	1	0	1
0	0	1	1	0	1
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	0	0
1	1	0	0	0	0
1	1	1	0	1	1

(8)

TOTAL: 80

Addendum A

Projects

This addendum includes fourteen projects that may serve as additional assessment aids or enrichment. Note that four projects are linked to Robotics – the designed circuits are built on breadboards and connected to an Arduino. Basic coding skills are required. These joint projects should be discussed with the Robotics lecturers.

The Student Book contains only 13 projects. The additional project (a joint project) can be used as enrichment or as a substitute for any project.

The projects should be assigned according to the abilities and learning experience of the students. The available time and resources should also be considered.

1. Prescribed projects

1.1 Fading LED lights

Introduction

Strips of LEDs that glow and fade are used for decorative purposes. Fading LED circuits can be created using various methods. This is a very simple fader circuit using very few components.

eLINK

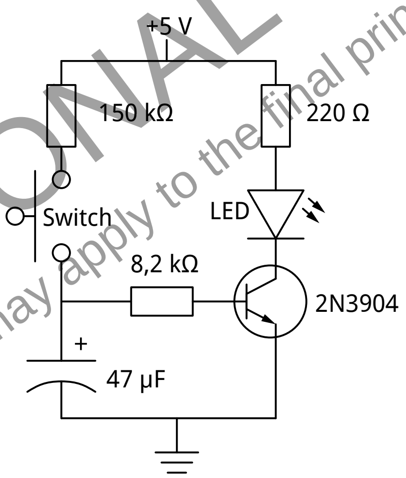
This project is derived from the following source:

futman.pub/FadingLEDProject

Component list

COMPONENT	QUANTITY
150-kΩ resistor	1
8,2-kΩ resistor	1
220-Ω resistor	1
47-μF electrolytic capacitor	1
2N304 transistor (or equivalent)	1
LED (any colour)	1
Normally open switch	1

Circuit diagram



Basic circuit operation

When the switch is closed, the capacitor slowly starts charging through the 150-kΩ resistor. As the capacitor charges, it slowly switches on the transistor which, in turn, switches on the LED. Consequently, the LED lights up gradually until it glows brightly. When the switch is opened, the capacitor will start discharging through the 8,2-kΩ resistor and the transistor. Less and less current will flow through the transistor, causing the LED to fade until it is completely off.

1.2 Morse-code sounder

Introduction

Morse code was generally used as a means of communication between two stations during World War II. In Morse code, each number and letter of the alphabet are represented by a series of dots and dashes. This is a simple circuit that generates a sound at a certain frequency when a button is pushed. Use this fun circuit to send a message to someone. They must decode it and then reply in code.

eLINK

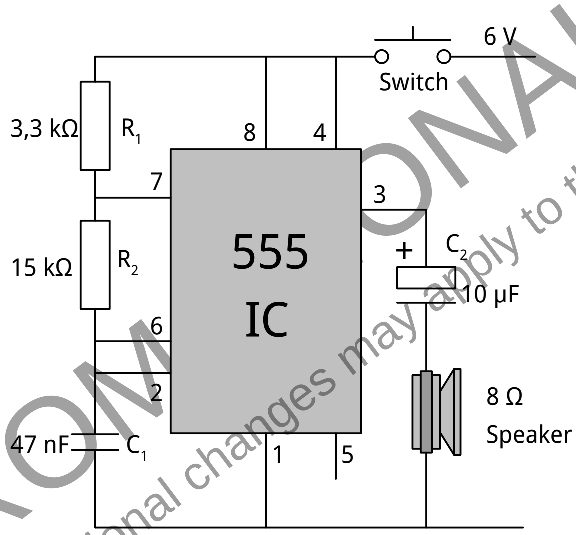
This project is derived from the following source:

futman.pub/MorseCodeProject

Component list

COMPONENT	QUANTITY
Switch (push-button normally open)	1
15-kΩ resistor (R_2)	1
3,3-kΩ resistor (R_1)	1
47-nF non-electrolytic capacitor (C_1)	1
10-μF electrolytic capacitor (C_2)	1
555 IC	1
8-Ω speaker (small)	1

Circuit diagram



Basic circuit operation

The circuit works like a simple astable multivibrator. The frequency of the circuit is determined by R_1, R_2 and C_1. The switch can be pressed for a short period, which will generate what is known in morse code as a *dot* (.); or it can be pressed for longer to generate what is called a dash (_). When the dots and the dashes are combined in a certain sequence, they represent a letter.

NOTE

The astable multivibrator is another type of cross-coupled transistor switching circuit that has NO stable output states as it changes from one state to the other.

1.3 Water-level indicator

Introduction

This circuit is designed to automatically switch an AC pump on or off, depending on the level of the water in the tank. This prevents the tank from overflowing, and it protects the pump when the water levels are too low.

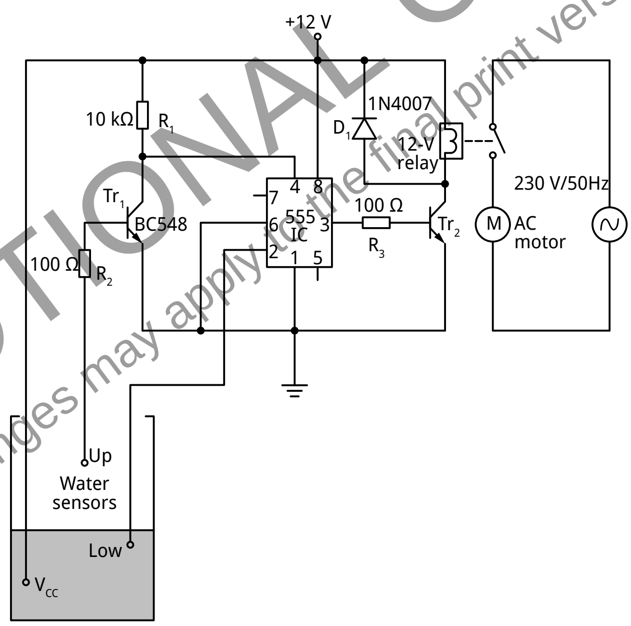
eLINK

This project is derived from the following source:
futman.pub/WaterlevelProject

Component list

COMPONENT	QUANTITY
555 IC	1
10-kΩ resistor	1
100-Ω resistor	2
Transistor – BC548	2
1N4007 diode	1
12-V/30-A DC relay	1
AC motor	1
Water sensors (clean metal rods)	3

Circuit diagram



Basic circuit operation

When the voltage at pin 2 (trigger) of an 555 IC is less than a third V_{CC}, the output of the IC will be high. The IC may be reset by applying a low voltage to the fourth pin (reset pin). Three wires are immersed in the water tank. The two levels that are specified are the low water level (Low) and the high water level (Up).

One of the pins of the probe is connected off V_{CC}. The lower-level sensor is connected to pin 2, the trigger of the IC. Therefore, the voltage at the second pin is at V_{CC} while it is inside water. When the water level drops, the second probe is no longer immersed, and the voltage at the trigger pin drops to below V_{CC}. Consequently, the output of IC is high. The output of the IC is fed to a BC548 transistor, which triggers the relay coil; this in turn switches on the water pump. When the water level rises, the upper-level probe is submerged, and the transistor turns off. Its collector voltage is V_{CE} (sat) = 0,2. The low voltage on the fourth pin resets the IC. Therefore, the output of the IC changes to 0 V, and the motor is switched off.

1.4 Metal detector

Introduction

This simple metal-detector circuit is designed to locate hidden metallic objects such as coins, pipes, etc. Only four components are needed. After you have built the circuit, test it by moving it over any metal object.

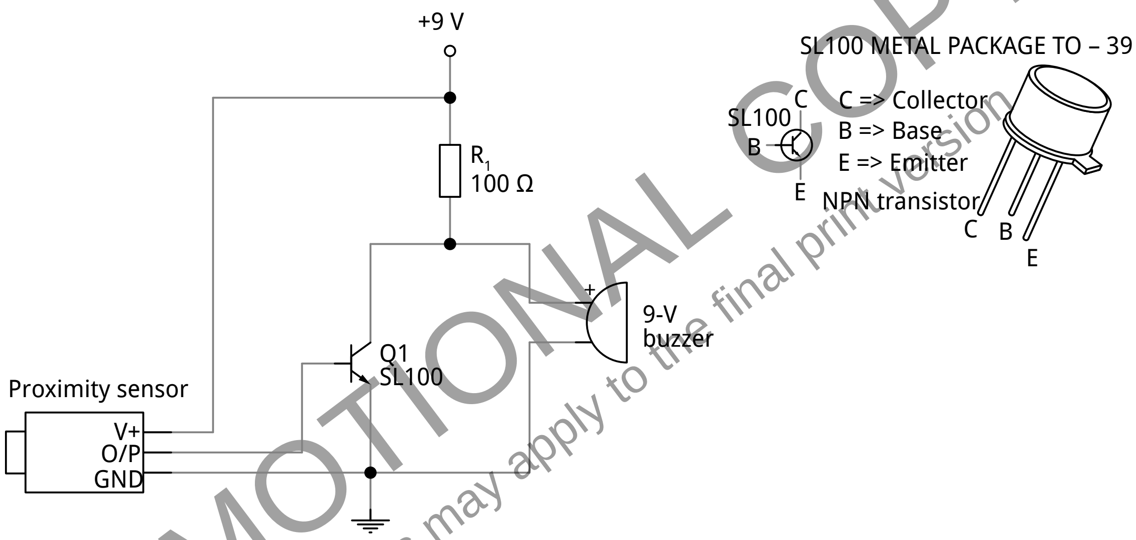
eLINK

This project is derived from the following source:
futman.pub/MetaldetectorProject

Component list

COMPONENT	QUANTITY
Proximity sensor (inductive)	1
Transistor SL100 (or equivalent)	1
100-Ω resistor	1
9-V buzzer	1

Circuit diagram



Basic circuit operation

This simple metal detector circuit makes use of an inductive proximity sensor. The range of this sensor is a few millimetres to a few centimetres. The output signal of the sensor is connected to the base of the transistor (SL100). As soon as a metal object is detected, the proximity sensor will produce an output, switching on the transistor and sounding the buzzer. When no metal object is detected, the buzzer will remain off (silent).

1.5 Simple cell-phone detector using an op-amp

Introduction

This sensitive cell-phone detector circuit uses a CA3140 op-amp IC, a 555-timer IC and a few other discrete components. The device can detect a cell phone within an 8 to 10 metre range. (The range varies depending on the various cell-phone brands.) When a cell phone is detected, an LED will light up and a piezo buzzer will sound for a few seconds.

eLINK

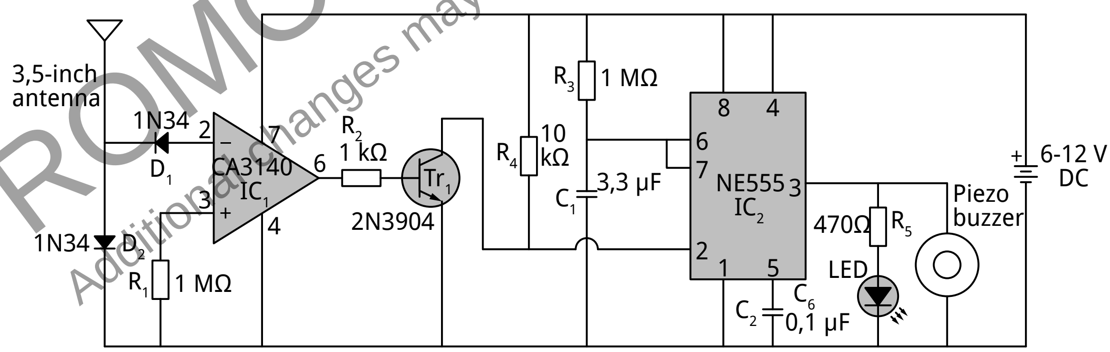
This project is derived from the following source:

futman.pub/MobileDetectorProject

Component list

COMPONENT	QUANTITY
3,5-inch antenna	1
1-MΩ resistor (R_1 and R_3)	2
1-kΩ resistor (R_2)	1
10-kΩ resistor (R_4)	1
470-Ω resistor (R_5)	1
LED	1
1N34 diodes (point-contact germanium diode)	2
9-V piezo buzzer	1
3,3 µF electrolytic capacitor (C_1)	1
0,1 µF capacitor (C_2)	1
CD 3140 IC	1
555 IC	1
Transistor 2N3904	1

Circuit diagram



Basic circuit operation

In this circuit, there are two stages: the RF detector and amplification stage and the 555-monostable timer circuit. IC_1 functions as a signal amplifier and IC_2 as a time delay. The two 1N34 diodes are point-contact germanium diodes used for signal detection. The diodes in conjunction with the 3,5-inch antenna will pick up the high frequency RF cell-phone signal (0,9–3 GHz) as soon as the phone is active, convert the electromagnetic-radiated signal to a low-power electric signal and then send it to the operational amplifier (IC_1). The output from IC_1 will activate the 555-timer IC and trigger an LED and a piezo buzzer for a few seconds.

1.6 Air-freshener dispenser with a DC motor

Introduction

The main function of this circuit is to dispense a quantity of air freshener at selected time intervals. The fan serves to spread the fragrance throughout the room.

eLINK

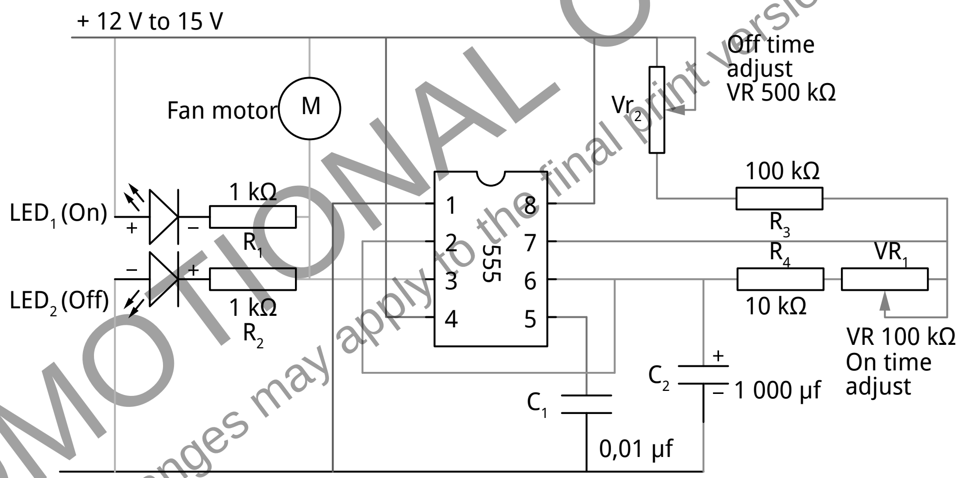
This project is derived from the following source:

futman.pub/AirfreshnerProject

Component list

COMPONENT	QUANTITY
555 IC	1
LED (LED_1 red and LED_2 green)	2
1-kΩ resistor (R_1 and R_2)	2
12-V DC motor (fan)	1
500-kΩ variable resistor (VR_2)	1
100-kΩ variable resistor (VR_1)	1
0,01 μF capacitor (C_1)	1
1 000-μF electrolytic capacitor (C_2)	1

Circuit diagram



Basic circuit operation

This circuit uses a 555 timer to set the off time and the on time for the air freshener. Once the switch is turned on, the fan will remain off for the first 10 minutes. Thereafter, the circuit will turn the fan on for 40 seconds. The timer will continue in this sequence: 10 minutes off, 40 seconds on. The off and on time can easily be increased or decreased as required. The LEDs indicate whether the circuit is on or off. A second switch can be installed to switch the circuit on and off manually.

2. Author-generated projects

2.1 Continuity tester

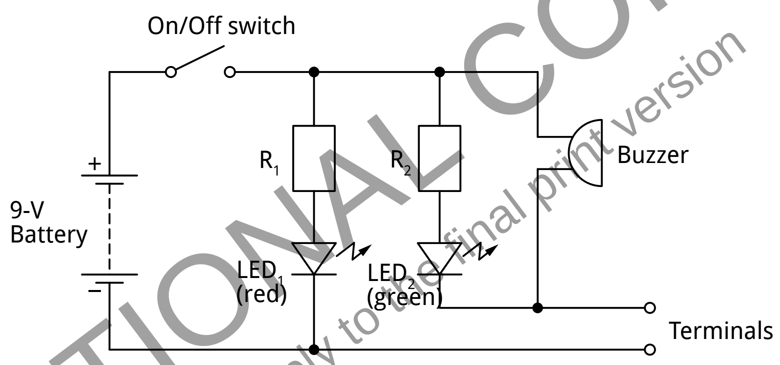
Introduction

A continuity test is important for any electrical circuit. This simple tester is used to test whether there is current continuity between two points; for example, to check whether a wire has a break in it or if a switch works and to test relay-switch combinations. Only a closed, complete circuit has continuity, allowing the current to flow from one end to the other.

Component list

COMPONENT	QUANTITY
9-V battery	1
470-Ω resistor	2
LED_1 (ultra-bright red)	1
LED_2 (ultra-bright green)	1
9-V buzzer	1

Circuit diagram



Basic circuit operation

- When the switch is off, no current flows through circuit.
- When the switch is on, current flows from the positive terminal through R_1 and the red LED (LED_1) and back to negative terminal. The LED is forward biased and therefore emits light to indicate that the circuit is ready to be used.
- The green LED does not light up and the buzzer does not sound because there is no continuous path between the crocodile clips.
- If the switch is on *and* the crocodile clips touch each other, i.e. there is continuity between the crocodile clips, the red LED will light up, but current can flow through R_2 and the green LED (LED_2), causing the LED to light up *and* the buzzer to sound.
- When there is no continuity between the crocodile clips, the buzzer will cease to sound.

2.2 Transistor astable multivibrator (Flip-flop)

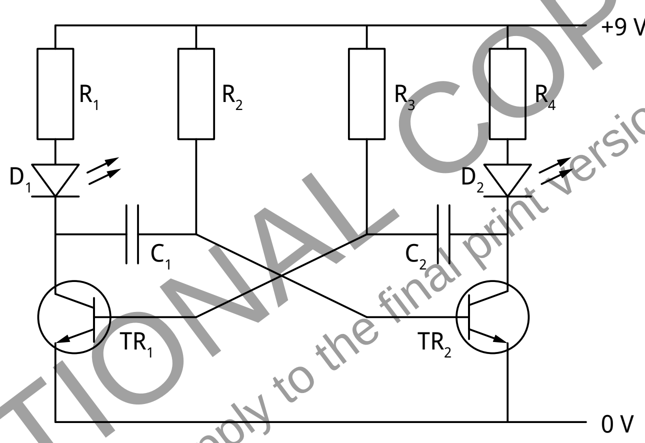
Introduction

This project is based on a simple astable multivibrator (free-running oscillator). This is a commonly used type of relaxation oscillator that is simple, reliable and easy to construct. It produces a constant square-wave output.

Component list

COMPONENT	QUANTITY
9-V battery	1
220-Ω resistor (R_1 and R_4)	2
22-kΩ (R_2 and R_3)	2
BC337 transistor (TR_1 and TR_2)	2
LED_1 red (super bright)	1
LED_2 green (super bright)	1
47 μF capacitors (C_1 and C_2)	2

Circuit diagram



Basic circuit operation

Two LEDs flash on and off alternately every few seconds. They mimic the indicator lights of a real alarm. The time that the lights are on and off, respectively, can be varied by changing the values of the capacitors. The circuit is designed to use very little current to prolong battery life so that the device can be left on permanently. An on/off switch can be included, should you prefer.

2.3 A 9-V to 240-V inverter

Introduction

The purpose of the inverter is to take a DC supply (from a 9-V or 12-V battery) and convert it into a 240-V AC supply. Inverters are currently being installed by homeowners and businesses in South Africa because we are experiencing so much load-shedding. An inverter allows home- and small-business owners to continue using devices or appliances such as televisions, sound systems, laptops, Wi-Fi routers, etc. during these power outages.

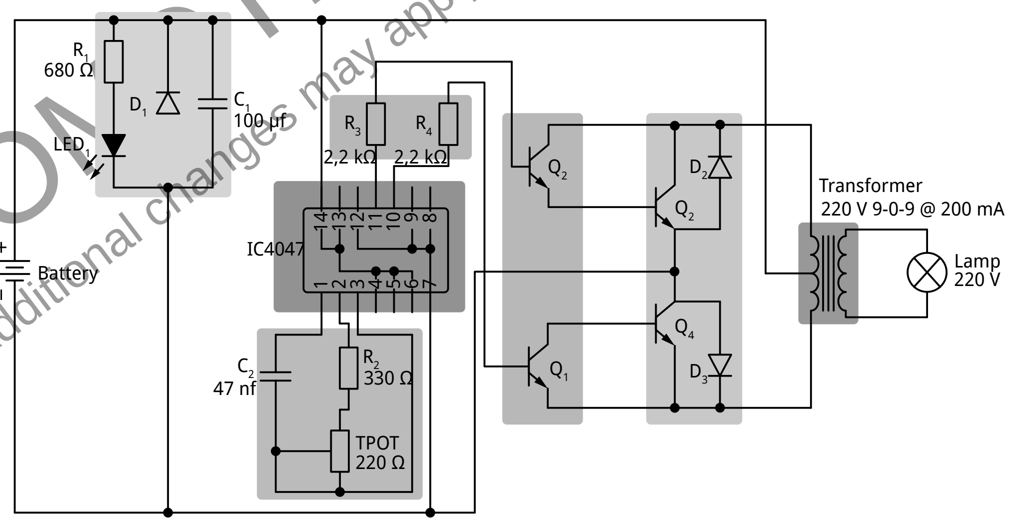
Component list

COMPONENT	QUANTITY
680-Ω resistor (R_1)	1
2,2-kΩ resistor (R_3)	2
330-Ω resistor (R_2)	1
2,2-kΩ variable resistor (R_4)	1
C1815 NPN transistor (Q_2 and Q_3)	2
TIP 122 PNP transistors (Q_1 & Q_4)	2
1N4007 diode (D_1, D_2 and D_3)	3
220-V/9-0-9 V @ 300 mA transformer	1
LED	1
CD4047 IC	1
47-nF capacitor (C_2)	1
12-V battery	1
100-µF (C_1)	1
220-V AC lamp	1

IMPORTANT

The CD4047 IC is a CMOS IC that is sensitive to static charge and can be damaged when it is touched with one's bare hands.

Circuit diagram



Basic circuit operation

Yellow section

This section consists of a power-indicating LED (LED_1) and a current-limiting resistor (R_1). The LED lights up when the power is applied (i.e. turned on by the switch). Diode (D_1) is used for reverse-polarity protection. If the battery is connected the wrong way round, this diode will effectively form a short circuit to prevent damaging the circuit.

Red section

The integrated circuit is comparable to an astable device – a device with no stable states. It will generate a square-wave output, continuously changing between 0 V and 9 V.

Green section

This consists of the resistor-capacitor (RC) timing component. The frequency is set by the values of the resistor and the capacitor. The variable resistor (labelled as *TPOT* in the circuit diagram) is used to adjust the frequency output of the integrated circuit.

Orange section

Q_1 and Q_2 are transistors that are configured in such a way that when one is driven on the other one is driven off. They are controlled by R_3 and R_4 as well as the output of IC 4047. Pin 10 and 11 of IC 4047 alternately switch voltage output. That alternately switches on Q_1 and Q_2. These transistors act as driver transistors to switch on transistors Q_3 and Q_4.

Blue section

The centre tap of the transformer is connected to the positive terminal of the 9-V battery. Diodes D_2 and D_3 are called *free-wheeling diodes* and are used to protect the transistor during switch off. This is necessary because of the inductive “kick” caused by the switching of the transformer.

Pink section

The transformer is used to step the 9 volts up to 220 volts trading-off current.

2.4 Electronic piano

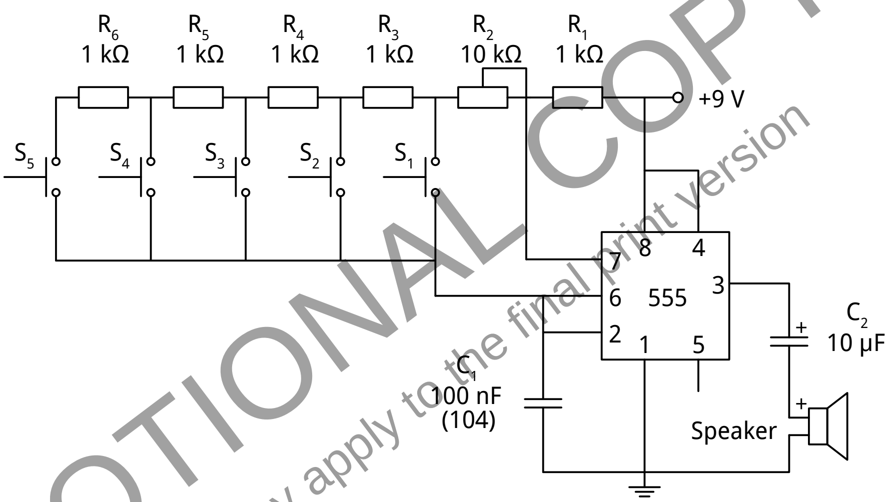
Introduction

This simple circuit consists of a few push-button switches which, when pressed, produce different sounds via a speaker.

Component list

COMPONENT	QUANTITY
555 IC	1
8-Ω Speaker	1
100-nF capacitor (C_1)	1
10-μF electrolytic capacitor (C_2)	1
1-kΩ resistors (R_1, R_2, R_3, R_4, R_5 and R_6)	6
10-kΩ variable resistor	1
Push-to-make (push-button) switches (S_1 – S_5)	5

Circuit diagram



Basic circuit operation

In this circuit, the 555-timer IC functions as an astable multivibrator, producing a square wave of different frequencies at the output. The speaker will produce different sounds, depending on the frequency of the signal. To change the frequency of the output signal, vary the total resistance of the circuit by pressing different switches. In other words, every time you press a button, the amount of resistance connected changes to generate a square wave of a different frequency. The speaker will therefore produce different tones.

Pin 6 and pin 2 will allow retriggering of the 555-timer IC after every timing cycle. These pins must be connected to the ground through a capacitor. The output pin 3 is connected to the speaker through a 10-μF capacitor and the fourth pin is connected to the 9-V battery to avoid any sudden resets.

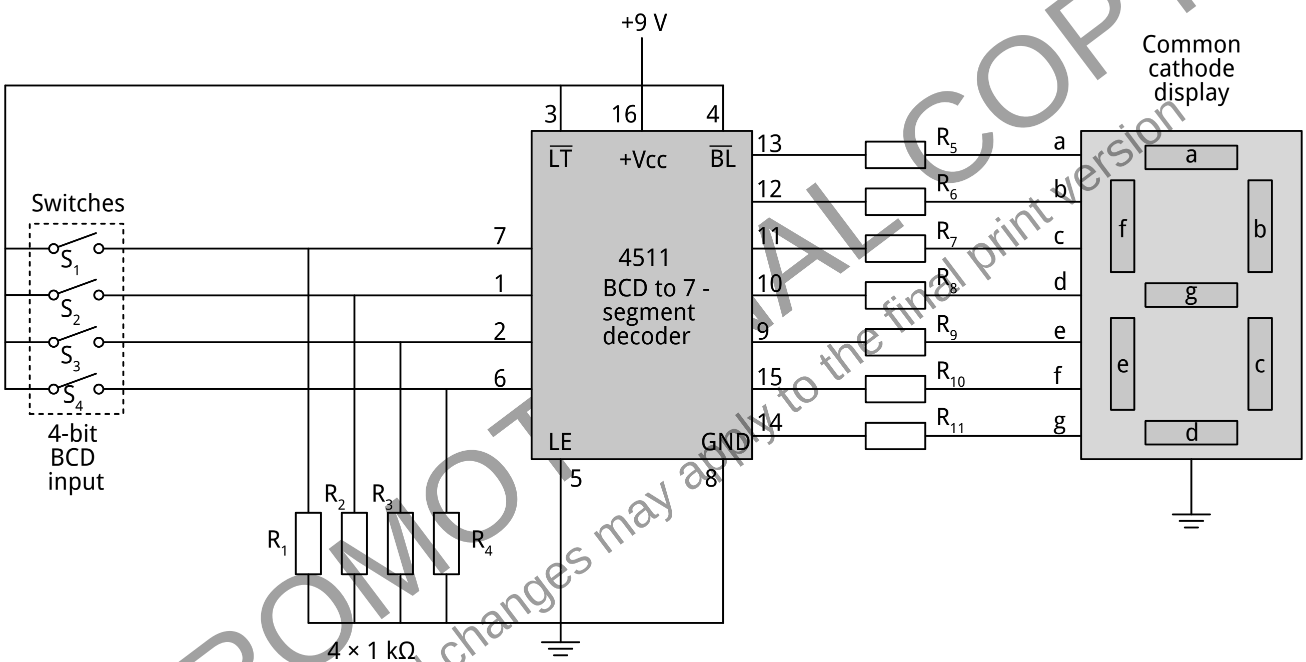
2.5 Binary input converted to seven-segment display

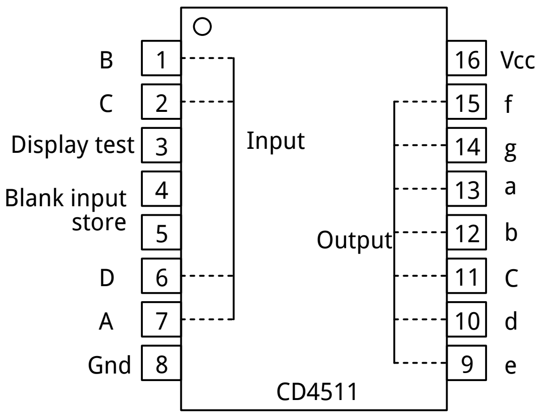
A binary-coded decimal (BCD) to seven-segment display decoder is a combinational logic circuit that converts a four-bit BCD input into seven output signals that can drive a seven-segment display. The purpose of the decoder is to show the numerical value of the BCD input on the display in a readable form.

Component list

COMPONENT	QUANTITY
CD4511 BCD to 7-segment decoder IC	1
7-segment display (common anode)	1
1-kΩ resistors (R_1–R_4)	4
470-Ω resistors (R_5–R_{11})	7
Switches (SPST) (S_1–S_4)	4

Circuit diagram





Pin connection of the CD 4511 IC

NOTE

Like the CD4047 IC, the CD4511 IC is a CMOS IC and is sensitive to static charge. It, too, can be damaged when touched with one's bare hands.

Basic operation

- The decoder has four input lines (S_1–S_4) that represent the BCD value, ranging from 0000 to 1001. Each input line can be either logic 0 or logic 1.
- The decoder has seven output lines (*a, b, c, d, e, f* and *g*) that correspond to the seven segments of the display. Each output line can be either logic 0 or logic 1.
- Depending on the type of display, the output lines can either be common cathode (CC) or common anode (CA) lines. In a CC display, the output lines are connected to the anodes of the LEDs and a logic 1 turns on a segment. In a CA display, the output lines are connected to the cathodes of the LEDs and a logic 0 turns on a segment.
- The decoder uses a truth table or a logic diagram to determine which output lines should be activated for each input value. For example, to display the number 3, the output lines *a, b, c, d* and *g* should be activated.

3. Robotics integrated projects

3.1 Arduino tone generator

Programming an Arduino to produce audible changes in the output of a speaker

An Arduino is programmed to simulate a square output wave. This is fed to the input of an audio amplifier which will intensify the signal. The output is a speaker. Any change in the programming frequency or amplitude of the input signal will result in an audible change in the output signal. The frequency will be set using a potentiometer that is connected to an analog input on the Arduino.

Components list

COMPONENT	QUANTITY
10-Ω resistor (R_1)	1
10-kΩ variable resistor (VR_1)	1
220-μF electrolytic capacitor (C_1)	1
10-μF electrolytic capacitor (C_2)	1
0,1-μF capacitor (C_3)	1
8-Ω speaker	1
LM 386N IC	1
IC socket (8-pin IC holder)	1

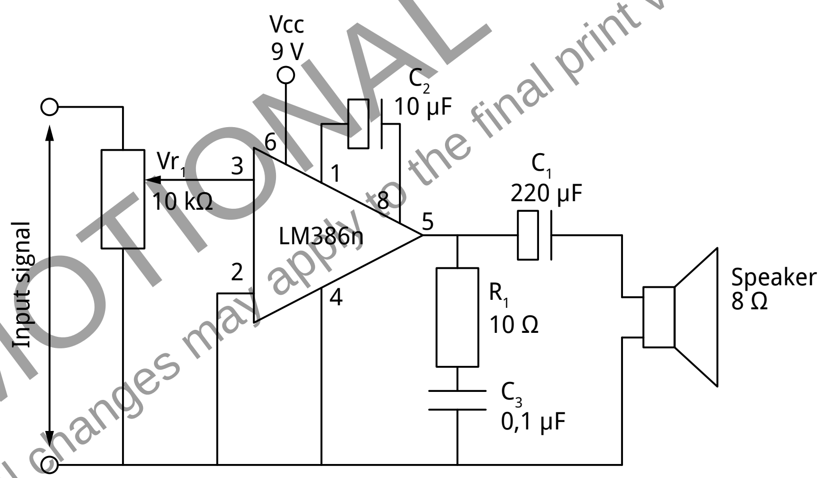


Figure 3.1.1: Circuit diagram – electrical components

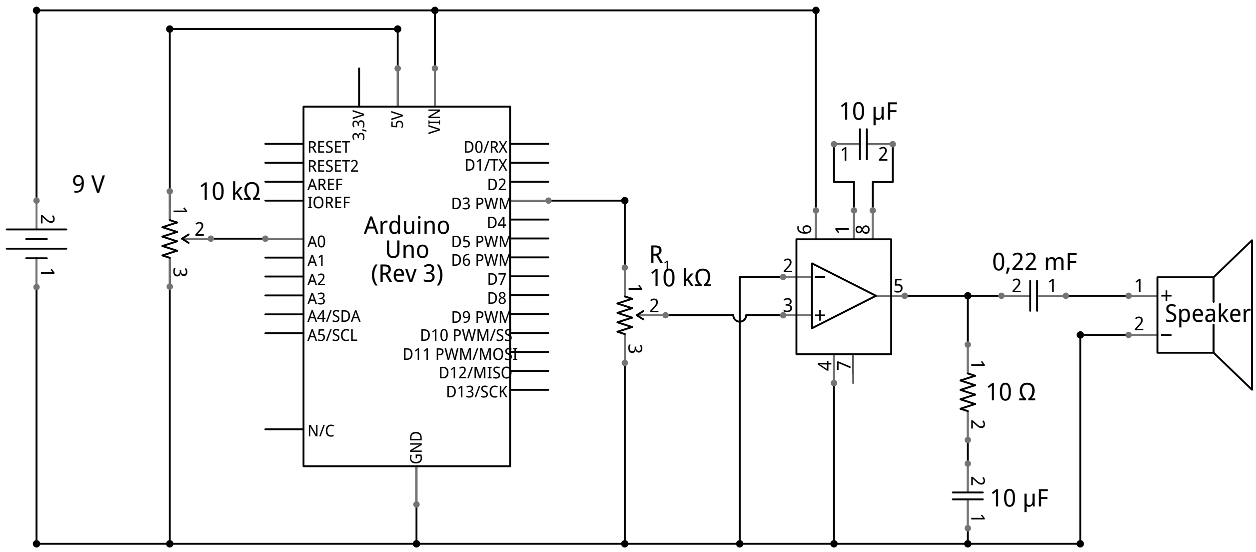


Figure 3.1.2: Circuit diagram of the tone generator

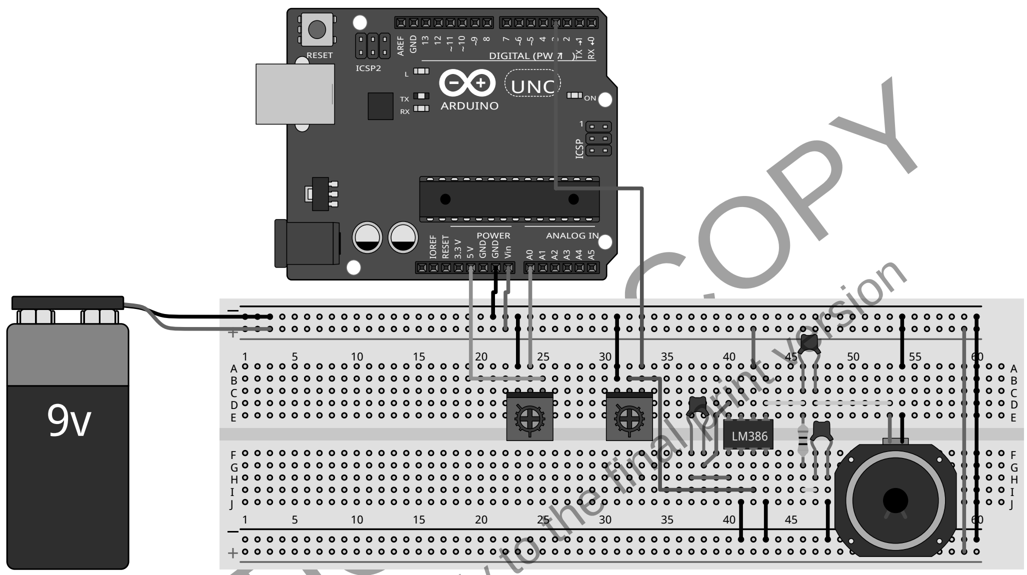


Figure 3.1.3: Breadboard design for the tone generator

Connect the potentiometer to the analog input pin (A0) and the speaker to the output pin (9) on your Arduino board.

Code

You will need to write the code to program an Arduino to produce audible changes in the output of a speaker.

```
// Pin assignments
const int potentiometerPin = A0;   // Potentiometer analog
input pin
const int speakerPin = 9;         // Speaker output pin

void setup() {
  pinMode(speakerPin, OUTPUT);
}

void loop() {
  // Read the analog input from the potentiometer
  int potValue = analogRead(potentiometerPin);

  // Map the potentiometer value to a frequency range
  int frequency = map(potValue, 0, 1023, 100, 5000);

  // Generate the tone on the speaker pin
  tone(speakerPin, frequency);

  // Wait for a short duration
  delay(100);
}
```

Figure 3.1.4: Example of the Arduino code for this project

In this code, we first define the pin assignments for the potentiometer and the speaker. In the *setup()* function, we set the speaker pin as an output. Then, in the *loop()* function, we continuously read the analog input from the potentiometer using *analogRead()*. We map the potentiometer value from the range 0–1023 to a frequency range of 100–5000 Hz using the *map()* function.

Finally, we generate the tone on the speaker pin using the *tone()* function, passing the calculated frequency as a parameter to the *tone()* function. We also introduce a short delay of 100 milliseconds between each sample from the potentiometer.

3.2 Robot-controlled electromagnet

Programming a robot to move and pick up a metallic object using an electromagnet

This program prompts a robot (buggy) to move from position A to a certain location where it will pick up a metallic object using an electromagnet. The arm lifts the object and moves it to point B, where the object is released. The buggy then returns to point A.

The electromagnet can be as simple or as complicated as you like, as long as it has a metal core (to concentrate the magnetic field) with a number of insulated copper windings around it. The simplest magnet would be wire wrapped around a few nails.

The current supplied by the output of the robot will not produce an adequate magnetic field. A second power source is needed.

Factors that determine the strength of the electromagnet:
- Size of the battery – the bigger the battery, the more current it supplies
- Type of core – a soft metal core is preferable
- Number of wire windings around the core – the more windings, the stronger the magnet.

Components list

COMPONENT	QUANTITY
On/Off switch (could be electronically controlled by robot)	1
5-V relay with at least one normally open switch	1
Electromagnet – homemade	1
9-V or 12-V battery	1

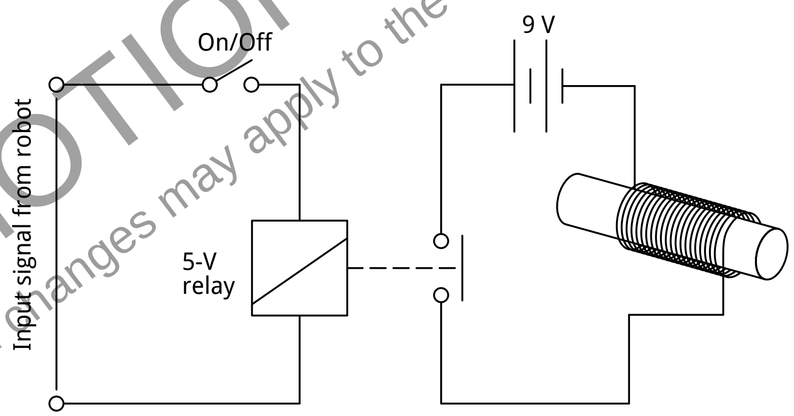


Figure 3.2.1: Circuit diagram – electrical components

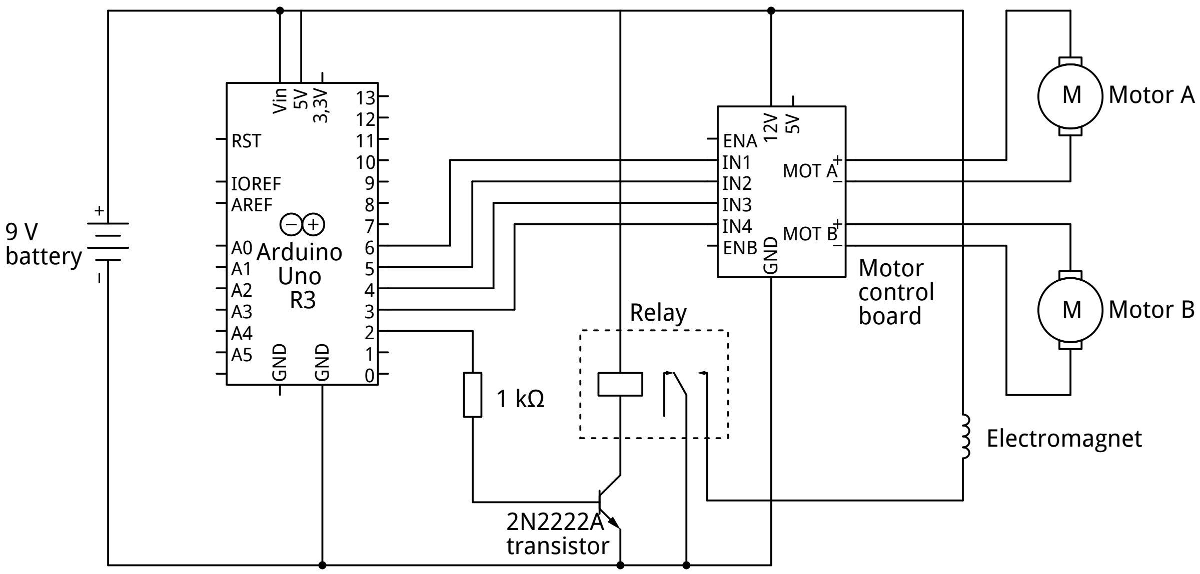


Figure 3.2.2: Circuit diagram of the electromagnet robot system

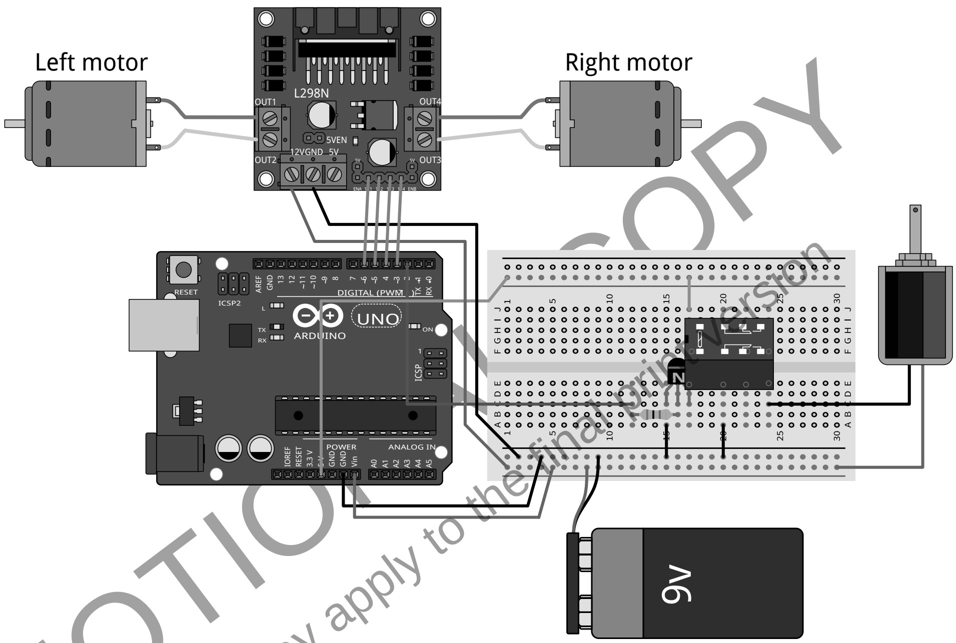


Figure 3.2.3: Breadboard circuit for electromagnet buggy

Code

You will have to write the code to program an Arduino to move to a specific location where it will pick up an object.

```
// Motor pins
const int motorAPin1 = 6;   // Motor A control pin 1
const int motorAPin2 = 5;   // Motor A control pin 2
const int motorBPin1 = 4;   // Motor B control pin 1
const int motorBPin2 = 3;   // Motor B control pin 2

// Electromagnet pin
const int electromagnetPin = 2;   // Electromagnet control pin
```

```
void setup() {
  // Set motor pins as outputs
  pinMode(motorAPin1, OUTPUT);
  pinMode(motorAPin2, OUTPUT);
  pinMode(motorBPin1, OUTPUT);
  pinMode(motorBPin2, OUTPUT);

  // Set electromagnet pin as output
  pinMode(electromagnetPin, OUTPUT);

  // Stop initially
  stop();
}

void loop() {
  // Move to first location
  moveForward(1000);   // Move forward for 1 second
  delay(500);         // Wait for 0.5 seconds

  // Activate electromagnet
  activateElectromagnet(1000);

  // Move to second location
  moveBackward(1000);  // Move backward for 1 second
  delay(500);         // Wait for 0.5 seconds

  // Deactivate electromagnet
  deactivateElectromagnet(1000);

  //Do nothing
  while (true);
}

// Function to move the buggy forward
void moveForward(int duration) {
  digitalWrite(motorAPin1, HIGH);
  digitalWrite(motorAPin2, LOW);
  digitalWrite(motorBPin1, HIGH);
  digitalWrite(motorBPin2, LOW);
  delay(duration);
  stop();
}

// Function to move the buggy backward
void moveBackward(int duration) {
  digitalWrite(motorAPin1, LOW);
  digitalWrite(motorAPin2, HIGH);
  digitalWrite(motorBPin1, LOW);
  digitalWrite(motorBPin2, HIGH);
  delay(duration);
  stop();
}
```

```
// Function to stop the buggy
void stop() {
  digitalWrite(motorAPin1, LOW);
  digitalWrite(motorAPin2, LOW);
  digitalWrite(motorBPin1, LOW);
  digitalWrite(motorBPin2, LOW);
}

// Function to activate the electromagnet
void activateElectromagnet(int duration) {
  digitalWrite(electromagnetPin, HIGH);
  delay(duration);
}

// Function to deactivate the electromagnet
void deactivateElectromagnet(int duration) {
  digitalWrite(electromagnetPin, LOW);
  delay(duration);
}
```

Figure 3.2.4: Example of the Arduino code for this project

In this code, we define the motor pins (motorAPin1, motorAPin2, motorBPin1, motorBPin2) for controlling the two motors that drive the robot (buggy). We also define the electromagnet pin (*electromagnetPin*) for activating and deactivating the electromagnet.

In the *setup()* function, we set the motor pins and the electromagnet pin as outputs. We also call the *stop()* function to ensure that the buggy is initially not moving.

In the *loop()* function, we can create a sequence of steps that the buggy will follow. For our initial sequence, it moves forward, activates the electromagnet, moves backward and then deactivates the electromagnet.

Each action that the buggy can perform will have its own function that we can call to create the sequence: *moveForward()*, *moveBackward()*, *stop()*, *activateElectromagnet()* and *deactivateElectromagnet()*. Except for the stop function, each of these functions will have a duration parameter that will tell it how long to wait before executing the next function.

3.3 Arduino waveform display

This program allows an input-output wave comparison

The following inverting operational-amplifier circuit uses a LM741 op-amp. This op-amp is built on a breadboard. The input is a 1-kHz (2-V peak-peak) sine wave. In this circuit the gain will be 1, but the aim is to show that the input and output is 180° out of phase with each other.

The Arduino is used as an oscilloscope to display the two waveforms.

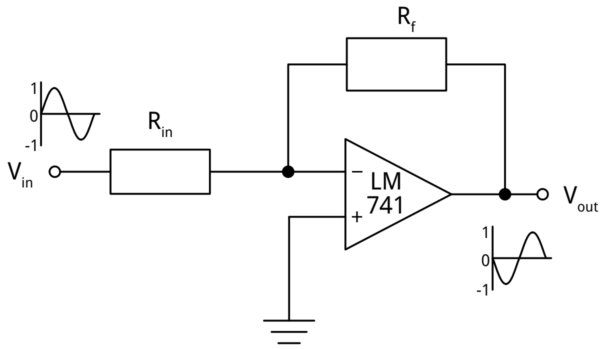


Figure 3.3.1: Circuit diagram – electrical components

Component list

COMPONENT	QUANTITY
LM741 op-amp IC	1
1-kΩ resistor (R_f)	1
1-kΩ resistor (R_{in})	1

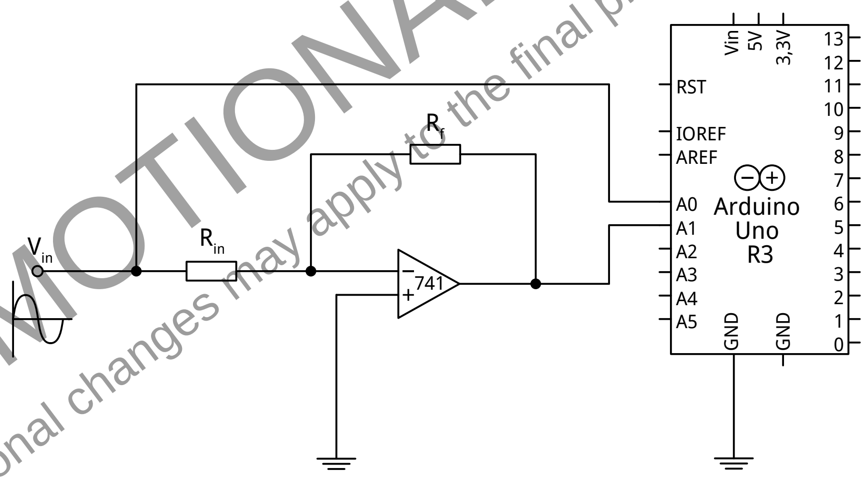


Figure 3.3.2: Circuit diagram of Arduino connected to an inverting op-amp circuit

Code

Connect V_{in} to analog pin 0 (A0) and V_{out} to Analog pin 1 (A1) on your Arduino. Download the following script onto the device:

```
const int analogPin1 = A0;  // Analog input pin 1
const int analogPin2 = A1;  // Analog input pin 2

void setup() {
  Serial.begin(115200);
}

void loop() {
  int sensorValue1 = analogRead(analogPin1);  // Read analog
input 1
  int sensorValue2 = analogRead(analogPin2);  // Read analog
input 2

  // Send the sensor values to Serial Plotter
  Serial.print(sensorValue1);
  Serial.print(“,”);
  Serial.println(sensorValue2);

  Serial.flush();
}
```

Figure 3.3.4: Example of the Arduino code for this project

In this code, we define the analog input pins A0 and A1, where the signal to be measured is connected. In the *setup()* function, we initialise the Serial Communication with a *baud rate of 115200*. The baud rate should match the baud rate that will be selected in the Serial Plotter.

Inside the *loop()* function, we read the analog inputs using *analogRead()*. We store the values in *sensorValue1* and *sensorValue2*. Then, we send both values to the Serial Plotter using *Serial.print()* and *Serial.println()*. The values are separated by a comma *(,)* that the serial plotter will use to distinguish between the two inputs.

Make sure you open the Serial Plotter in the Arduino IDE and select the correct baud rate (115200) to match the one set in the code. You should now be able to view the waveforms of both analog inputs on the Serial Plotter.

> **NOTE**
>
> This is an additional project that can be used for enrichment or as a substitute for any of the projects.

3.4 Ultrasonic distance display

Two seven-segment displays connected to an ultrasonic distance sensor

You will manually select the input code which will then be displayed on the seven-segment digital display.

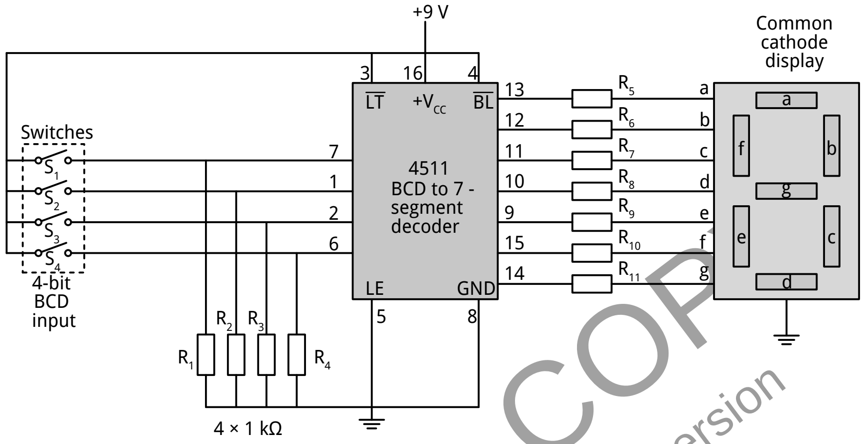


Figure 3.4.1: Circuit diagram – electrical components

Component list

COMPONENT	QUANTITY
CD4511 BCD to 7-segment decoder IC	1
Seven-segment display (common anode)	1
1-kΩ resistors (R_1–R_4)	4
470-Ω resistors (R_5–R_{11})	7
Switches (SPST) (S_1–S_4)	4

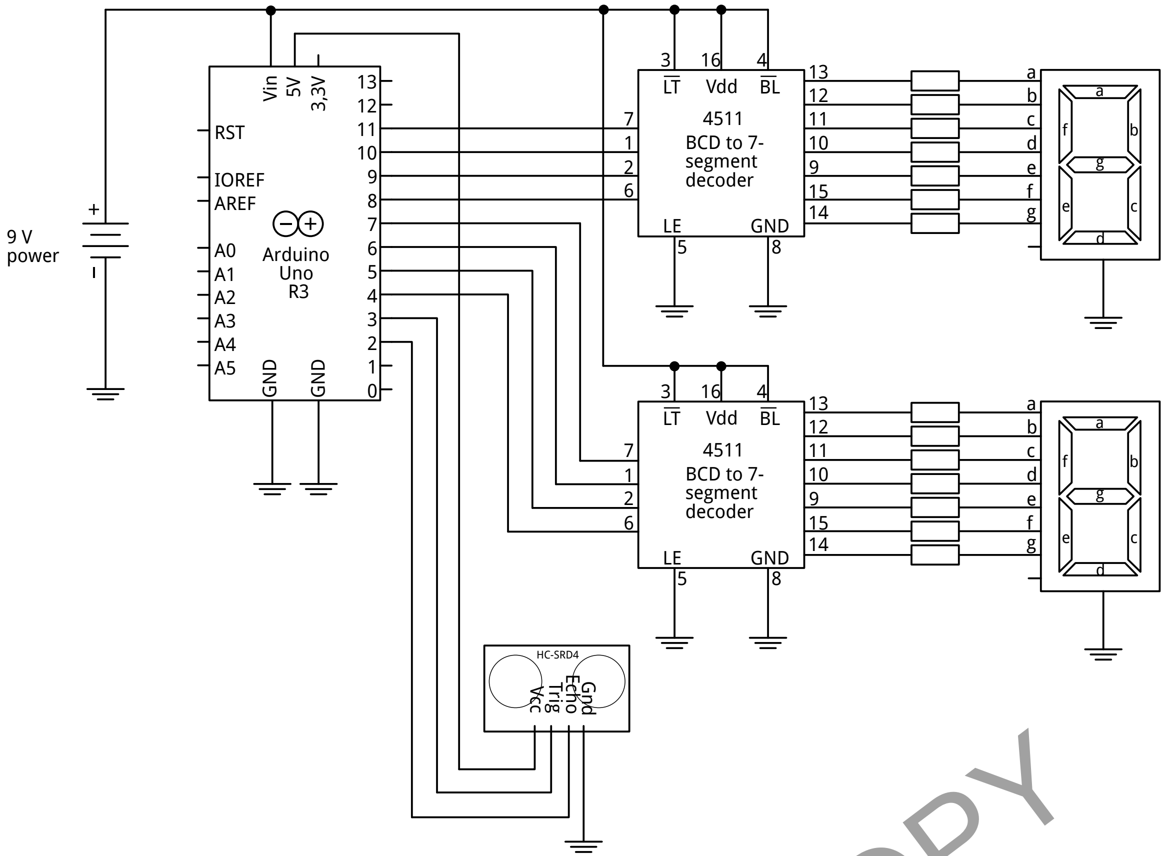


Figure 3.4.2: Circuit diagram for two seven-segment displays connected to an ultrasonic distance sensor

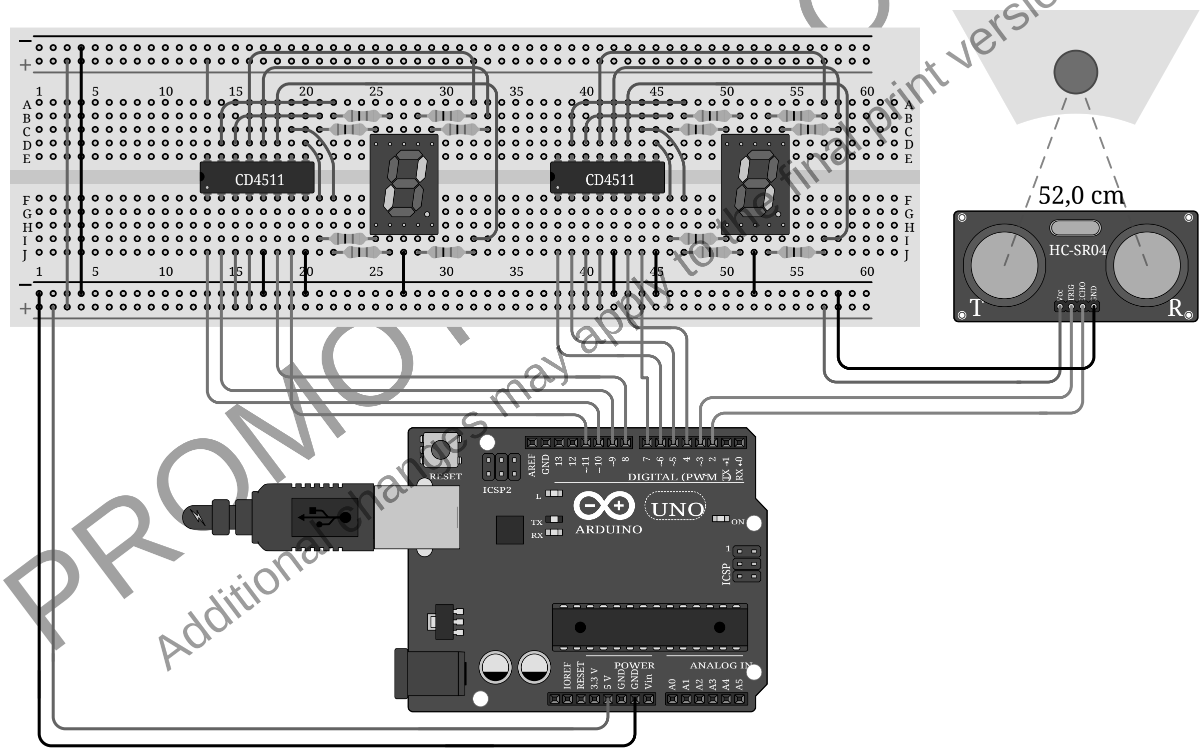


Figure 3.4.3: Breadboard design for the ultrasonic distance display

Code

The Arduino can be used to generate the standard four-bit BCD code (0 to 9) or just randomly generate a four-bit BCD code (0 to 9) which is then displayed on the seven-segment digital display.

```
const int echoPin = 2;    // Echo pin of the ultrasonic
sensor
const int trigPin = 3;    // Trigger pin of the ultrasonic
sensor
const int bcdOutputs1[] = {11, 10, 9, 8}; // Output pins for
first BCD code
const int bcdOutputs2[] = {7, 6, 5, 4};  // Output pins for
second BCD code

void setup() {
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  for (int i = 0; i < 4; i++) {
    pinMode(bcdOutputs1[i], OUTPUT);
    pinMode(bcdOutputs2[i], OUTPUT);
  }
}

void loop() {
  // Trigger the ultrasonic sensor
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Measure the echo pulse duration
  unsigned long duration = pulseIn(echoPin, HIGH);

  // Convert duration to distance in centimeters
  int distance = duration / 58;

  // Display distance as two BCD codes
  int tensDigit = distance / 10;
  int onesDigit = distance % 10;

  displayBCD(tensDigit, onesDigit);

  // Time delay before taking the next sample
  delay(500);
}
```

```
void displayBCD(int tens, int ones) {
  int bcdCodes[] = {
    B0000,  // 0
    B0001,  // 1
    B0010,  // 2
    B0011,  // 3
    B0100,  // 4
    B0101,  // 5
    B0110,  // 6
    B0111,  // 7
    B1000,  // 8
    B1001   // 9
  };

  // Set output pins based on BCD codes
  for (int i = 0; i < 4; i++) {
    digitalWrite(bcdOutputs1[i], bitRead(bcdCodes[tens], i));
    digitalWrite(bcdOutputs2[i], bitRead(bcdCodes[ones], i));
  }
}
```

Figure 3.4.4: Example of the Arduino code for this project

In this code, we define the *trigPin* and *echoPin*, representing the trigger and echo pins of the ultrasonic distance sensor. We also define two arrays which contain the pin numbers for the eight output pins used to display the BCD codes.

In the *setup()* function, we set the *trigPin* as an output and the *echoPin* as an input. We also set the *outputPins* as outputs using a *for* loop.

In the *loop()* function, we trigger the ultrasonic sensor to start a measurement. We calculate the duration of the echo pulse and convert it to a distance in centimetres. We then extract the tens and ones digits from the distance.

Next, we call the *displayBCD()* function to set the output pins based on the BCD codes for the tens and ones digits. The displayBCD() function takes the tens and ones digits as parameters and sets the output pins accordingly.

Finally, we print the distance to the Serial Monitor and introduce a delay of 500 milliseconds (adjust as needed) before starting the next measurement.

Make sure to connect the ultrasonic sensor's trigPin and echoPin to the appropriate Arduino pins, and connect the eight output pins to a BCD-to-7-segment display or any other output mechanism you prefer to visualise the BCD codes

Addendum B

Exemplar papers

Exemplar Paper 1: Theory

Total: 100
Time: 4 hours

QUESTION 1: Magnetism, electromagnetic circuits and related concepts

1.1 Write down the TWO laws of magnetism. (2)

1.2 Define the term *magnetic flux*. (2)

1.3 Calculate the flux density at the poles of an electric motor if the total flux is 0,254 Wb in an area of 0,004 m^2. (3)

1.4 Make a neat, labelled drawing to show the magnetic fields around a current-carrying conductor. Indicate the magnetic field direction as well as the current direction. (2)

1.5 Explain how the strength of a solenoid's magnetic field can be increased. (1)

1.6 Briefly explain how a lifting magnet works. (2)

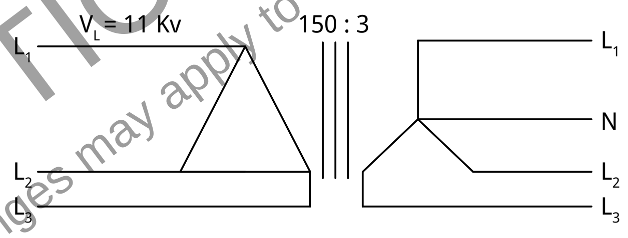
1.7 A conductor that is 120 cm long moves at a velocity of 275 cm/s through a magnetic field to produce an induced emf of 100 V. Calculate the flux density of the magnetic field. (3)

[15]

QUESTION 2: Electrical supply systems, transformers, DC machines, series-parallel networked circuits

2.1 Calculate the efficiency of a transformer if it is rated as 3 kVA. The copper and iron losses amount to 150 VA. (4)

2.2 A three-phase transformer is connected as shown below. Calculate the secondary phase voltage that will supply the load. (3)



2.3 What is meant by a *TNC supply* with respect to construction sites? (1)

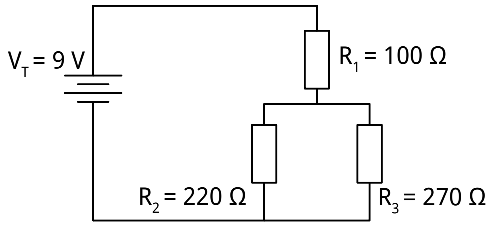
2.4 Which of the three examples shown below is NOT a *cooling method* used in transformers?

Air-blast oil-cooled
Oil-forced air-cooled
Air-blast air-cooled
Oil-forced air blast (1)

2.5 Write down Kirchhoff's laws for series and parallel circuits, respectively. (2)

2.6 Choose the correct answer from those provided.
The total resistance for the circuit shown below is ______. (1)

a) 590 Ω
b) 221,224 Ω
c) 121,22 Ω



2.7 Two columns are shown in the table below. Match the type of cell in COLUMN A with the correct properties for that cell in COLUMN B. Write down only the question number and the letter of your choice, e.g. 2.7.1 F. (3)

COLUMN A	COLUMN B
2.7.1 Lead-acid	A • Must be completely discharged before charging • Has thicker and stronger plates • Can be charged many more times
2.7.2 Deep-cycle	B • Lifespan between two to three years • Excessive charging and heat influence lifespan • Very expensive • Very light-weight • Environmentally friendly • Do not have any self-discharge • Wide variety of shapes and sizes
2.7.3 Lithium-ion	C • Have lifespan of about three to four years. • Robust and reliable • Deliver high currents • Wide range of sizes and capacities • Heavy and bulky

[15]

QUESTION 3: Electronic components and semiconductors

3.1 Complete the table below by naming THREE factors that influence the *specific resistance* of a conductor and providing the units of measure used in calculations.

FACTOR INFLUENCING RESISTANCE		UNIT OF MEASURE
3.1.1		
3.1.2		
3.1.3		

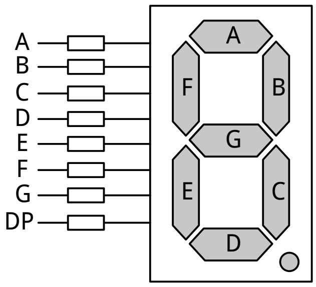
(3)

3.2 What are the main colours of the three subpixels in a liquid-crystal display (LCD)? (1)

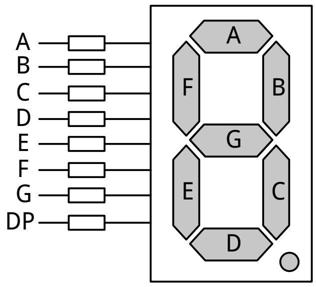
3.3 Name TWO applications of an LCD. (2)

3.4 Which segments must light up in each of the illustrations below to represent the number 36,2? Write down the question number and the applicable letters. (2)

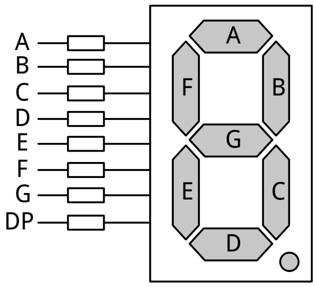
3.4.1



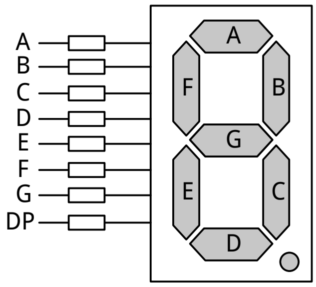
3.4.2



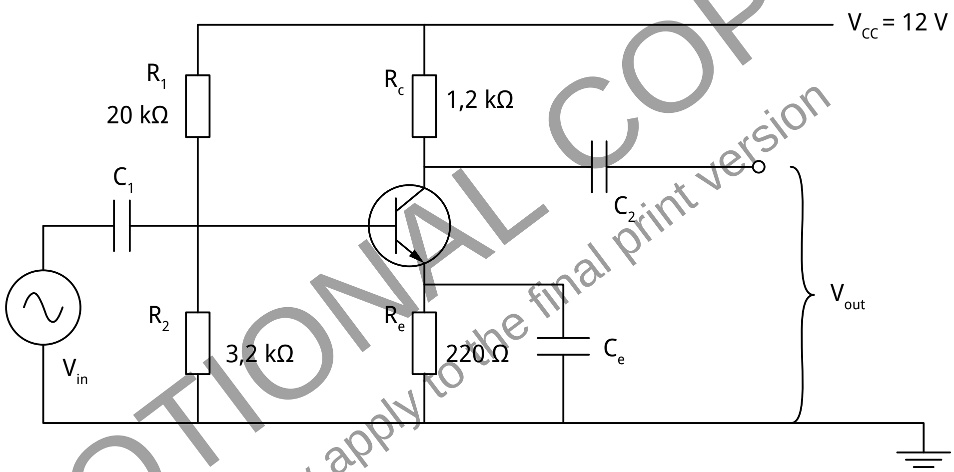
3.4.3



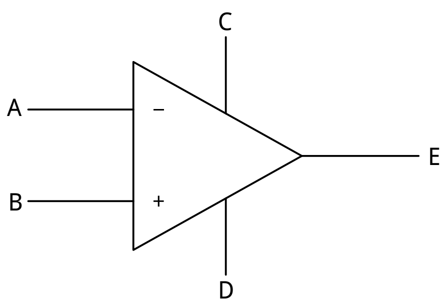
3.4.4



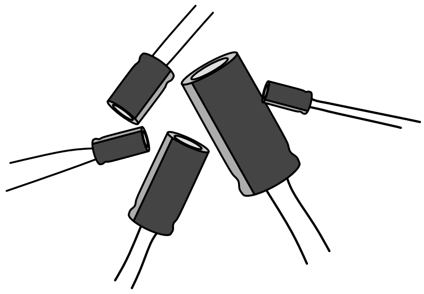
3.5 Draw neat waveforms of the input compared to the output for the single-stage transistor amplifier shown below. (2)



3.6 The IEC symbol for an operational amplifier is shown below. Identify the terminals labelled A, B, C and E. (2)



3.7 The questions that follow are based on the capacitor shown below.



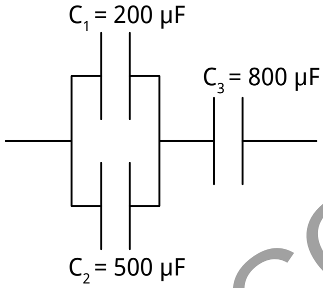
3.7.1 Identify the capacitor. (1)

3.7.2 What must you bear in mind when you connect this component into a circuit? (1)

3.8 A circuit showing capacitors connected in series and parallel is shown below. Determine the following:

3.8.1 The equivalent capacitance (C_{e1}) for the parallel section (no calculation required) (1)

3.8.2 The total capacitance for the circuit. (3)

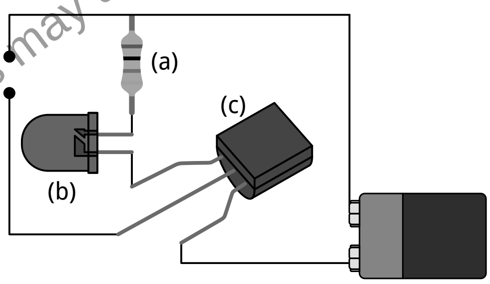


3.9 Name TWO applications of *controllers* in everyday life. (2)

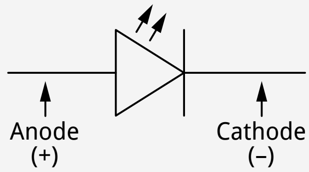
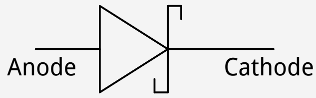
[20]

QUESTION 4: Electrical components, symbols, circuit drawings, prototyping and design

4.1 Identify the components labelled (a), (b) and (c) in the circuit diagram below. (3)



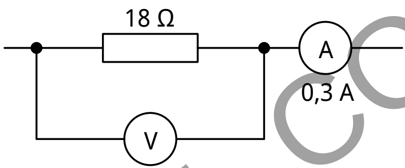
4.2 Complete the following table with reference to electronic components. (3)

COMPONENT	IEC SYMBOL
4.2.1	
NPN Transistor	**4.2.2**
4.2.3	

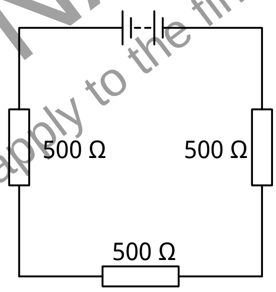
4.3 Discuss the advantages of building a circuit on a breadboard as opposed to a Veroboard. (2)

4.4 Why should a soldering iron always be switched off after use? (1)

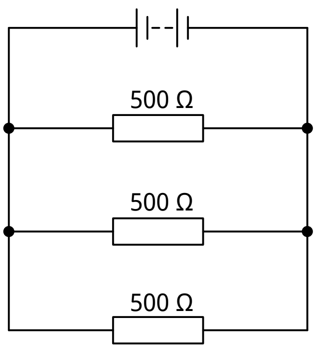
4.5 The diagram below shows part of a circuit. What will the voltmeter reading be given this resistance and current readings? (1)



4.6 With reference to the circuit below, state whether the resistors are connected in *parallel* or in *series*? Motivate your answer. (2)



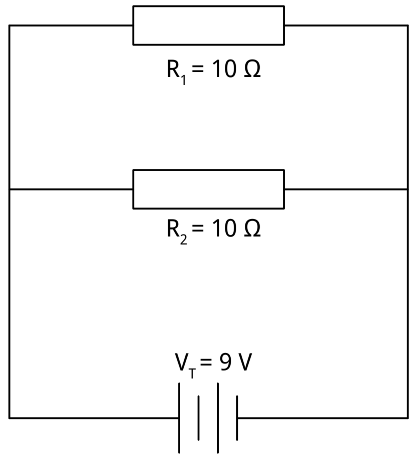
4.7 Study the circuit below and answer the questions that follow.



4.7.1 If a fourth resistor is inserted into the circuit in parallel, how will it influence the total resistance of the circuit? (1)

4.7.2 How will the addition of this fourth resistance impact on the total current through the circuit? (1)

4.8 The questions that follow refer to the circuit shown below:
$R_1 = R_2 = 10\ \Omega$ each and $V_T = 9$ V.



4.8.1 Calculate the total resistance of this circuit. (3)

4.8.2 Calculate the total current flowing through the circuit. (3)

[20]

QUESTION 5: Electronic tools and equipment

5.1 State what can be measured by using each of the following measuring instruments:

5.1.1 Multimeter

5.1.2 Oscilloscope

5.1.3 Function generator (3)

5.2 Explain what the *calibration* of a measuring equipment means. (1)

5.3 State whether the following statements are TRUE or FALSE.

5.3.1 An analogue multimeter uses a needle to indicate readings on a calibrated scale.

5.3.2 An oscilloscope can show the phase displacement between two waveforms.

5.3.3 A digital multimeter cannot measure a greater variety of values than an analogue meter. (3)

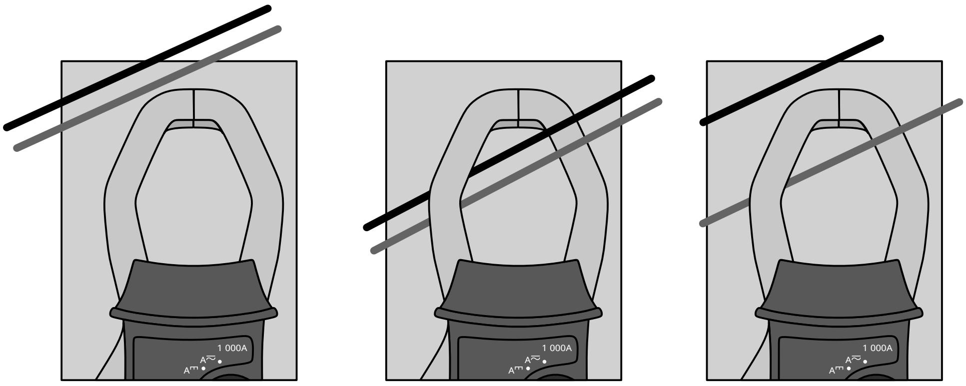
5.4 **5.4.1** What is a *parallax error* with reference to measuring instruments? (1)

5.4.2 State how this error can be prevented. (1)

5.5 A clamp-on meter is used to measure the current flowing in a single-phase system with a live and a neutral conductor.

5.5.1 Identify the correct method from the figures shown below. Motivate your answer. (1)

5.5.2 Briefly discuss the problems with the other two methods. (2)



A B C

5.6 Complete the table below by: naming THREE tests that are performed on any new household installation before it is commissioned (switched on for the customer), providing the meter setting and stating the acceptable reading for the tests conducted.

TEST	METER SETTING	ACCEPTABLE READING

(3)

[15]

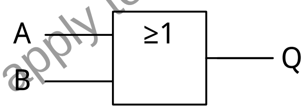
QUESTION 6: Digital systems, PLCs and principles

6.1 In your own words, define the term *truth table*. (2)

6.2 How many switching combinations are possible with *two inputs* into any logic gate? (1)

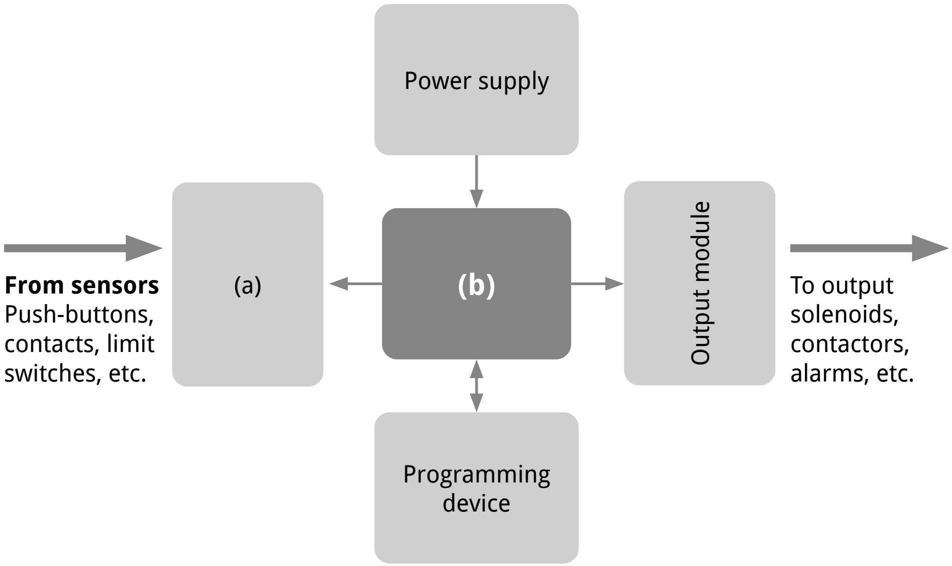
6.3 Draw a labelled switching diagram for a two-input OR gate. (2)

6.4 Identify the logic gate shown below and complete a truth table for this gate. (3)



6.5 Give TWO reasons why PLCs are better suited for industrial automation applications than relay logic. (2)

6.6 Name the blocks labelled (a) and (b) with reference to the block diagram of the PLC given on the next page. (2)



6.7 Draw the ladder diagram that is represented by the truth table shown below. (3)

INPUT A	INPUT B	OUTPUT (F)
0	0	0
0	1	1
1	0	1
1	1	1

[15]

Exemplar Paper 2: Design related

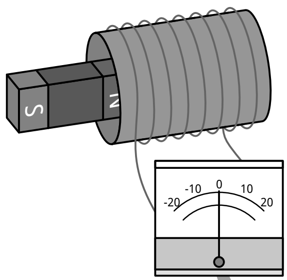
Total: 60
Time: 3 hours

QUESTION 1: Magnetism, electromagnetic circuits and related concepts

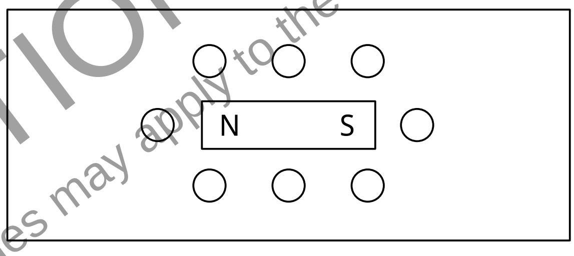
1.1 Electromagnetic induction is the production of an electromotive force (emf) or voltage across an electrical conductor due to the movement between a conductor and a magnetic field (as shown in the figure below).

1.1.1 What needs to take place between the coil and the magnet to produce an emf? (1)

1.1.2 What can be done to increase the magnitude of the induced emf? (1)



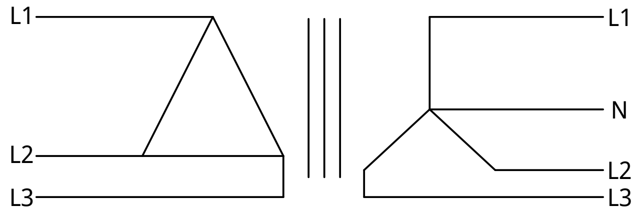
1.2 The sketch below indicates the experiment that was done to determine the direction of the magnetic fields around a bar magnet. Complete the drawing by indicating the direction of the compasses around the magnet. (2)



[4]

QUESTION 2: Electrical supply systems, transformers, DC machines, series-parallel networked circuits

2.1 The following three-phase transformer was connected in delta-star and then connected to a supply. By means of two neat sketches, show how a multimeter, set to voltage scale, should be connected to measure any phase voltages (on the primary and on the secondary sides) of the three-phase transformer shown below. You must redraw the transformer. (4)



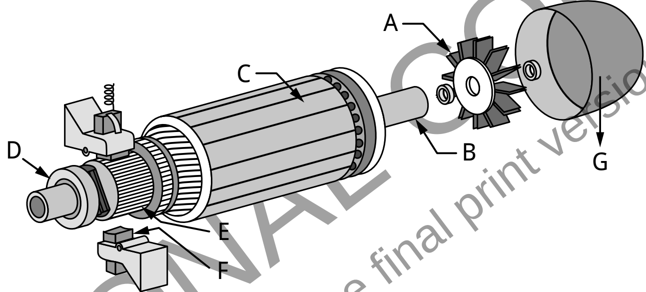
2.2 Before one uses a battery to power an inverter system, it is important to know which operating voltages should be used with no load as well as at full load. Show, by means of a neat sketch, how to measure the *emf* and the *pd* of a battery. (2)

2.3 A car's battery is faulty. Keep in mind that the relative density of the electrolyte is the ratio of the mass of a unit volume of the electrolyte to the mass of the same volume of water (or specific gravity of the electrolyte). The relative density of a fully charged cell is specified by the manufacturer and is generally in the region of 1 230 to 1 280.

Explain how you would test whether the relative density level of the battery is acceptable. Refer to the density of the electrolyte as well as the instrument you would use. (3)

2.4 An electric motor was disassembled to inspect the parts. Once the rotor section had been removed, the technician observed the parts as shown in the picture below.

Identify the parts labelled as A to F in the sketch of the rotor. (3)



[12]

QUESTION 3: Electronic components and semiconductors

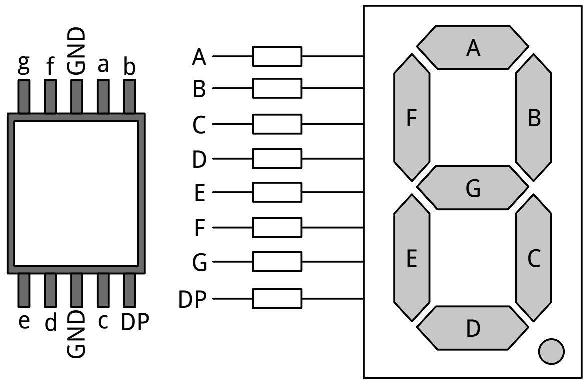
3.1 Before using a 1N4007 diode to build a rectifier circuit (or any other circuit), we need to perform certain tests to ensure the diode is fully functional.

Explain how you would use a multimeter to test whether the diode is fully functional and state the acceptable as well as the unacceptable readings. (3)

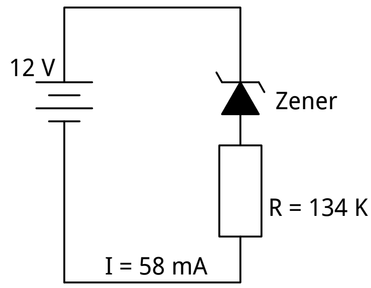
3.2 Explain, with the aid of a neat, labelled sketch, the TWO methods used to identify the terminals of an LED correctly. (4)

3.3 You have been asked to design an electronic circuit to display a digital number (to represent voltage or current) by means of a seven-segment display.

Using the integrated circuit given on the next page, draw the circuit diagram needed to display the number seven (7) on the seven-segment display. Include a battery in the circuit. (2)



3.4 A Zener diode is required to regulate a set voltage cross it. In the circuit shown below, a 12-V battery is connected in series to the Zener diode and a 134-kΩ resistor.

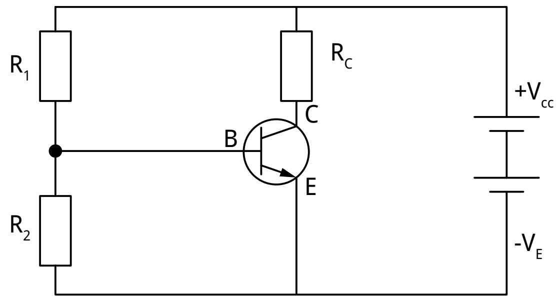


3.4.1 Calculate the voltage drop across the diode. (5)

3.4.2 Select an appropriate Zener diode from the data sheet provided. (1)

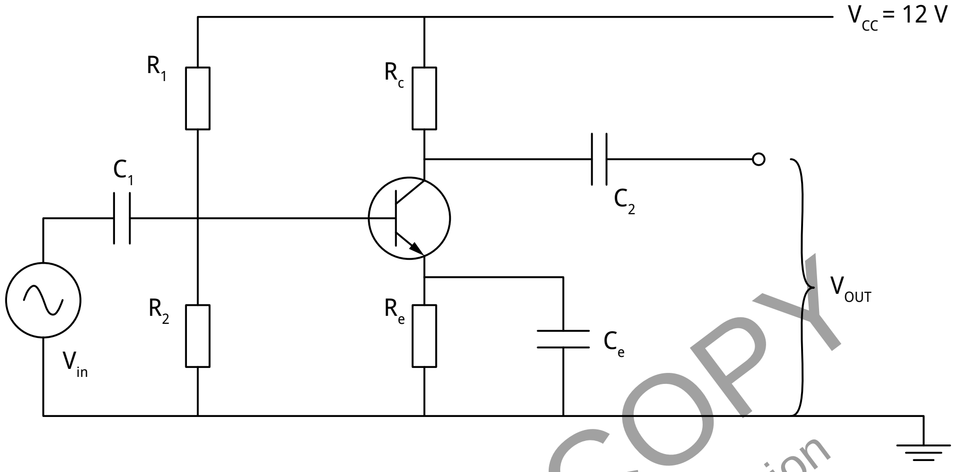
ELECTRICAL CHARACTERISTICS (AT 25 °C, UNLESS OTHERWISE SPECIFIED)									
PART NUMBER	ZENER VOLTAGE	TEST CURRENT		REVERSE LEAKAGE CURRENT		DYNAMIC RESISTANCE f = 1 KHZ		SURGE CURRENT	REGULATOR CURRENT
	V_Z @ I_{ZT1}	I_{ZT1}	I_{ZT2}	I_R @ V_R		Z_{ZT} @ I_{ZT1}	Z_{ZK} @ I_{ZT2}	I_R	I_{ZM}
	V	mA	mA	µA	V	Ω		mA	mA
	NOM.			MAX.		TYP.	MAX.		MAX.
1N4728A	3,3	76	1	100	1	10	400	1380	276
1N4729A	3,3	69	1	50	1	10	400	1260	252
1N4730A	3,9	64	1	10	1	9	400	1190	234
1N4731A	4,3	58	1	10	1	9	400	1070	217
1N4732A	4,7	53	1	10	1	8	500	970	193

3.5 The following transistor circuit was built on a breadboard, but the value of the currents flowing in the circuit is not given.
Copy the circuit given on the next page and show how you would connect a digital multimeter set to the milliampere scale to measure the current flowing out at the emitter terminal. (1)



3.6 A single-stage transistor amplifier with a collector resistor of 34 Ω is shown in the circuit diagram below.

3.6.1 Determine the maximum current that can flow through the transistor. (3)



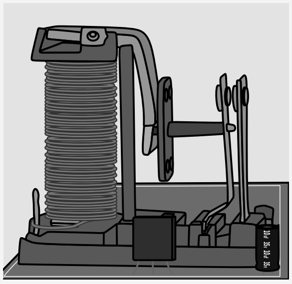
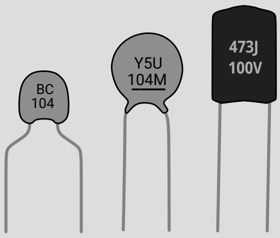
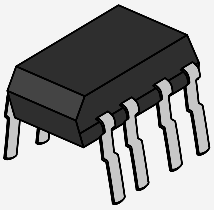
3.6.2 From the data sheet shown below, select a suitable transistor for this circuit. Keep in mind the safety of the component when selecting the transistor. (1)

NPN TRANSISTORS								
CODE	STRUCTURE	CASE STYLE	I_C MAX.	V_{CE} MAX.	H_{FE} MAX.	P_{TOT} MAX.	CATEGORY (TYPICAL USE)	POSSIBLE SUBSTITUTES
BC107	NPN	TO18	100 mA	45 V	110	300 mW	Audio, low power	BC182 BC547
BC109	NPN	TO18	200 mA	20 V	200	300 mW	Audio (low noise), low power	BC184 BC549
BC182	NPN	TO92C	100 mA	50 V	100	350 mW	General purpose, low power	BC1077 BC182L
BC547B	NPN	TO92C	100 mA	45 V	200	500 mW	Audio, low power	BC107B
2N3053	NPN	TO39	700 mA	40 V	50	500 mW	General purpose, low power	BFY51
TIP31A	NPN	TO220	3 A	60 V	10	40 mW	General purpose, high power	TIP31C TIP41A
TIP41A	NPN	TO220	6 A	60 V	15	65 mW	General purpose, high power	
2N3055	NPN	TO3	15 A	60 V	20	117 mW	General purpose, high power	

[20]

QUESTION 4: Electrical components, symbols, circuit drawings, prototyping and design

4.1 In order to design simple electronic circuits, it is important to identify electronic components and know which symbols are used to represent each component.
Identify the components given in the table below and provide the symbol for each of them. (6)

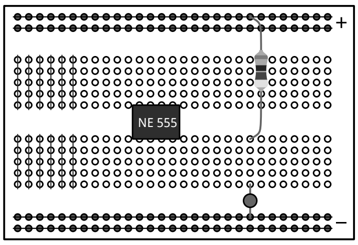
COMPONENT	NAME	IEC SYMBOL
	**4.1.1**	**4.1.2**
	**4.1.3**	**4.1.4**
	**4.1.5**	**4.1.6**

4.2 You have been asked to design a simple series circuit consisting of a 9-V battery, a resistor and a LED.

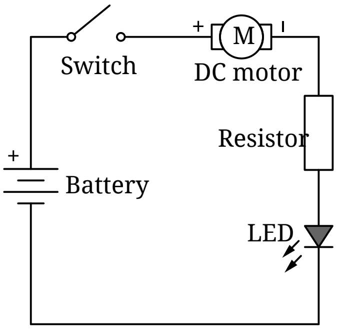
4.2.1 Draw the series circuit you have designed. (3)

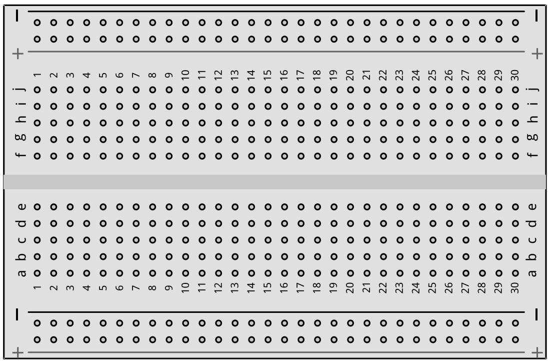
4.2.2 Calculate the value of the resistor that you must use in the circuit to protect the LED from blowing if it has a rating of 20 mA? (3)

4.3 The figure below shows an IC connected onto a breadboard. Give a reason why the IC must be connected as illustrated. (1)

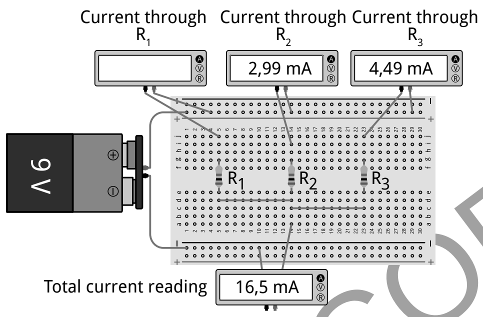


4.4 The given circuit must be built on a breadboard. Draw the breadboard layout for this circuit on the breadboard provided below. (5)





4.5 The following circuit was built on a breadboard to prove Kirchhoff's current law. If the three resistors have the same values and the current readings are as given in the figure below, what will the current reading on the first meter be? (2)



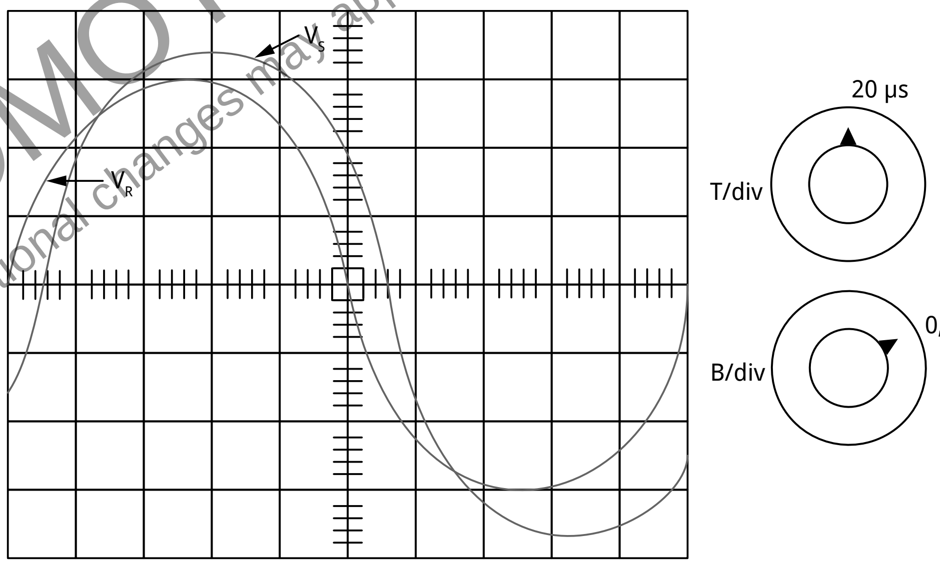
QUESTION 5: Electronic tools and equipment

5.1 A circuit was connected to an oscilloscope and the waveforms shown on the next page were observed. The oscilloscope display with its time and voltage settings is given. Determine the following:

5.1.1 the voltage of both waveforms (2)

5.1.2 the frequency of the waveforms (1)

5.1.3 the phase angle between the two waveforms. (1)



[4]

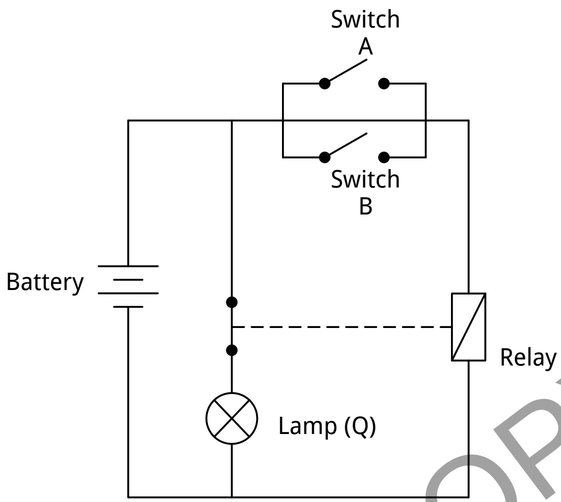
QUESTION 6: Digital systems, PLCs and principles

6.1 Logic gates are the building blocks of digital circuits. Logic gates will make decisions based on a combination of digital signals from their inputs. Draw the IEC symbols for the following logic gates and give the Boolean expression for each gate.

6.1.1 NOR gate (2)

6.1.2 XNOR gate (2)

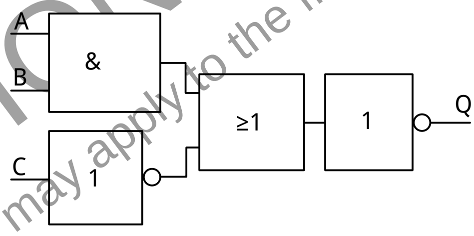
6.2 The following switching circuit was built on a breadboard. Identify the gate represented by this circuit diagram and draw the truth table for this logic gate. (3)



6.3 Design a simple logic circuit that will match the following Boolean expression:

$F = \overline{X.Y + X.Z}$ (4)

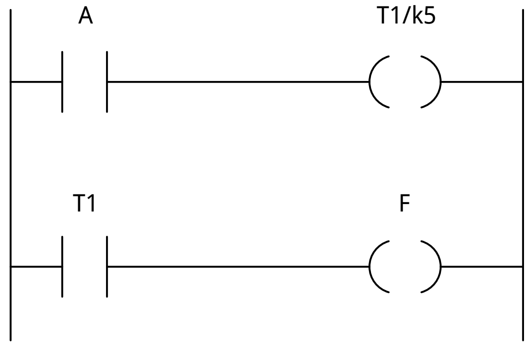
6.4 The figure below represents a simple logic circuit. Answer the questions that follow.



6.4.1 How many input combination will a truth table for this circuit have? (1)

6.4.2 Draw the truth table for this logic circuit. (4)

6.5 You have designed a ladder diagram. Explain the operation of this diagram to a friend. (4)



Exemplar Paper 1: Theory

Memorandum

Total: 100
Time: 3 hours

QUESTION 1: Magnetism, electromagnetic circuits and related concepts

1.1 Write down the TWO laws of magnetism. (2)

Like poles repel each other and unlike poles attract each other.

1.2 Define the term *magnetic flux*. (2)

Magnetic flux *refers to the number of magnetic field lines produced by a magnet perpendicular to a given surface.*

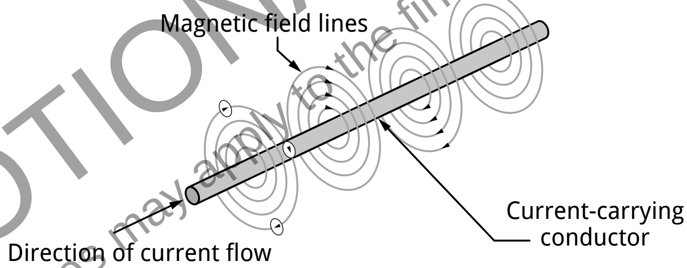
1.3 Calculate the flux density at the poles of an electric motor if the total flux is 0,254 Wb in an area of 0,004 m^2. (3)

$B = \frac{\theta}{A}$

$B = \frac{0.254}{0.004}$

$B = 6.35$ *Tesla (T) or* (Wb/m^2)

1.4 Make a neat, labelled drawing to show the magnetic fields around a current-carrying conductor.
Indicate the magnetic field direction as well as the current direction (2)



1.5 Explain how the strength of a solenoid's magnetic field can be increased. (1)

The strength of a solenoid can be increased by increasing the number of turns in the coil or by increasing the current through the coil.

1.6 Briefly explain how a lifting magnet works. (2)

When current starts to flow through the coils of the lifting magnet, magnetic fields are formed around it, changing it into a magnet and allowing it to pick up metallic objects.

When current stops flowing through the circuit, the lifting magnet will be switched off, thus losing its magnetic characteristics and dropping the metallic objects.

1.7 A conductor that is 120 cm long moves at a velocity of 275 cm/s through a magnetic field to produce an induced emf of 100 V. Calculate the flux density of the magnetic field. (3)

$\beta = \frac{E}{l \times v}$

$\beta = \frac{100}{1,2 \times 2,75}$

$\beta = 30,30\ T$

(Note: The original formula is E = βlv. Here β is the subject of the formula.)

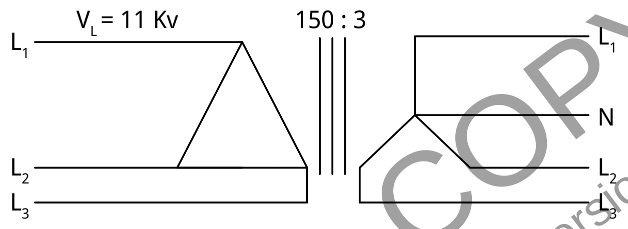
QUESTION 2: Electrical supply systems, transformers, DC machines, series-parallel networked circuits

2.1 Calculate the efficiency of a transformer if it is rated as 3 kVA. The copper and iron losses amount to 150 VA. (4)

$P_{in} = P_{out} + losses = 3\ 000 + 150 = 3\ 150\ VA$

$\eta = \frac{P_{output}}{P_{input}} \times 100 = \frac{3\ 000}{3\ 150} \times 100 = 95,24\%$

2.2 A three-phase transformer is connected as shown below. Calculate the secondary phase voltage that will supply the load. (3)



The primary is connected in delta so $V_L = V_{PH} = 11\ kV$

$\frac{Vsec(ph)}{Vprim(ph)} = \frac{Ns}{Np}$ $\quad V_{SEC} = \frac{(11\ 000)(3)}{150} = 220\ V$

2.3 What is meant by a *TNC supply* with respect to construction sites? (1)

The neutral conductor and the protective earth are combined throughout the network in a single conductor, the PEN conductor (called a four-conductor system*).*

2.4 Which of the three examples shown below is NOT a *cooling method* used in transformers?

Air-blast oil-cooled	Oil-forced air-cooled
Air-blast air-cooled	Oil-forced air blast

(1)

Air-blast air-cooled

2.5 Write down Kirchhoff's laws for series and parallel circuits, respectively. (2)

Series circuit:

- *The current flowing through all the components is the same.*
- *The voltage drops around the circuit add up to the supply voltage.*

Parallel circuit:

- *The voltage drops across all branches are the same.*
- *The current entering a point is the same as the current leaving a point.*

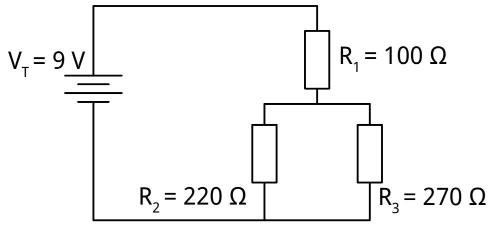
2.6 Choose the correct answer from those provided.

The total resistance for the circuit shown below is ______. (1)

a) 590 Ω

b) 221,224 Ω

c) 121,22 Ω



b) 221,224 Ω

2.7 Two columns are shown in the table below. Match the type of cell in COLUMN A with the correct properties for that cell in COLUMN B. Write down only the question number and the letter of your choice, e.g. 2.7.1 F. (3)

COLUMN A	COLUMN B	
2.7.1 Lead-acid	A	• Must be completely discharged before charging • Has thicker and stronger plates • Can be charged many more times
2.7.2 Deep-cycle	B	• Lifespan between two to three years • Excessive charging and heat influence lifespan • Very expensive • Very light-weight • Environmentally friendly • Do not have any self-discharge • Wide variety of shapes and sizes
2.7.3 Lithium-ion	C	• Have lifespan of about three to four years. • Robust and reliable • Deliver high currents • Wide range of sizes and capacities • Heavy and bulky

[15]

2.7.1 *C*

2.7.2 *A*

2.7.3 *B* **[15]**

QUESTION 3: Electronic components and semiconductors

3.1 Complete the table below by naming THREE factors that influence the *specific resistance* of a conductor and providing the units of measure used in calculations.

FACTOR INFLUENCING RESISTANCE		UNIT OF MEASURE
3.1.1	*Length (ℓ) of conductor*	*Metres (m)*
3.1.2	*Cross-sectional area (A)*	*Square metres (m^2)*
3.1.3	*Resistivity of material (ρ)*	*Ω.m*

(3)

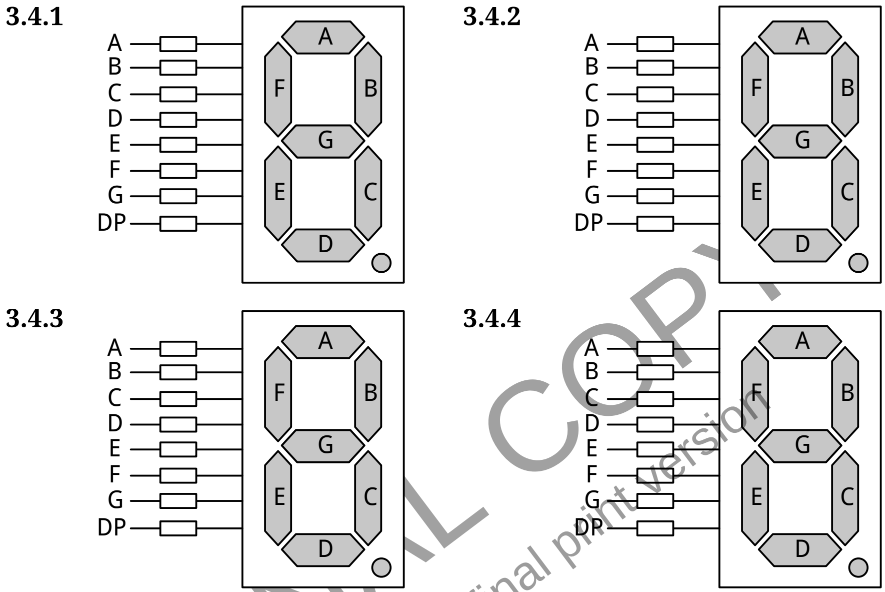
3.2 What are the main colours of the three subpixels in a liquid-crystal display? (1)

Red, green and blue (commonly called RGB)

3.3 Name TWO applications of an LCD (liquid-crystal display). (2)

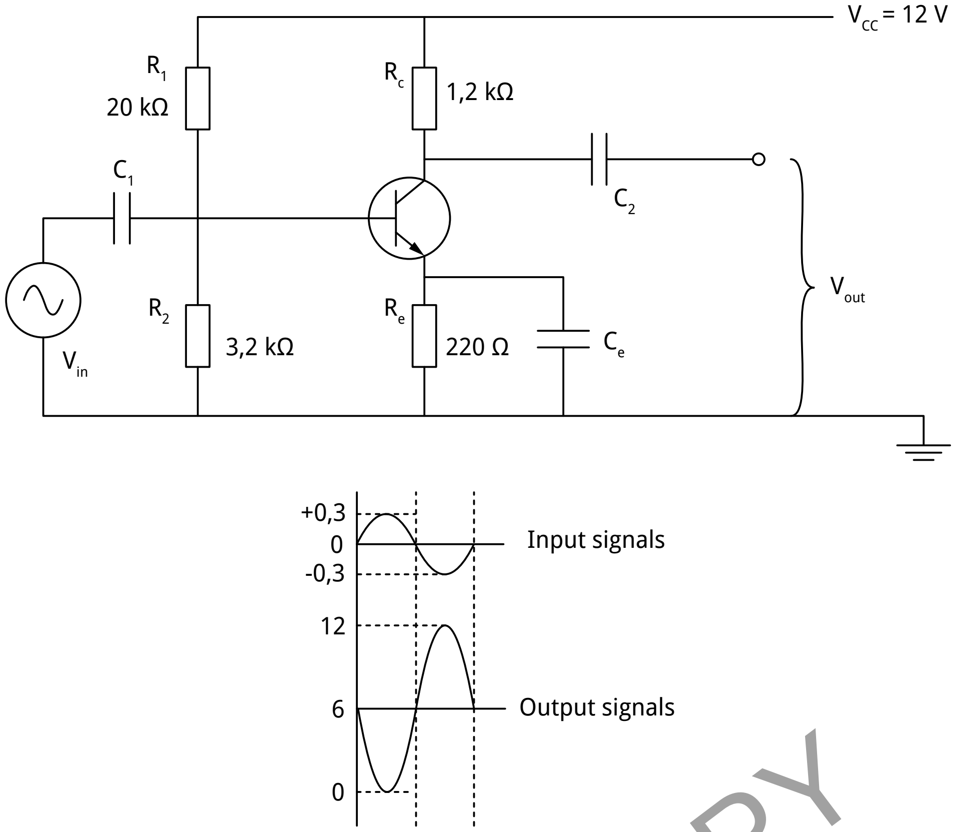
Any two correct answers:
- *Laptops*
- *Digital clocks and watches*
- *Microwave ovens*
- *CD players*

3.4 Which segments must light up in each of the illustrations below to represent the number 36,2? Write down the question number and the applicable letters. (2)

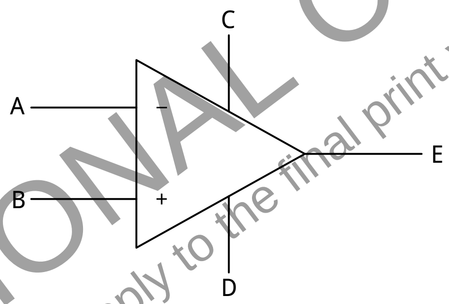


3.4.1 *A, B, G, C, D*
3.4.2 *A, F, E, D, C, G*
3.4.3 *DP*
3.4.4 *A, B, G, E, D* *(½ mark each)*

3.5 Draw neat waveforms of the input compared to the output for the single-stage transistor amplifier shown on the next page. (2)

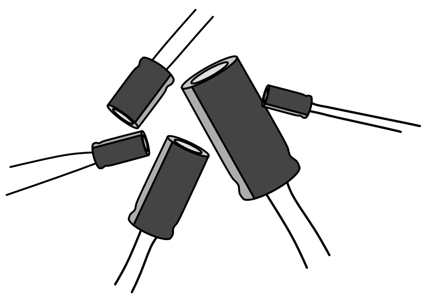


3.6 The IEC symbol for an operational amplifier is shown below. Identify the terminals labelled A, B, C and E on the IEC symbol. (2)



A Inverting input
B Non-inverting input
C - $+V_{cc}$ (positive)
E Output *(1/2 mark each)*

3.7 The questions that follow are based on the capacitor shown below.



3.7.1 Identify the capacitor. (1)

3.7.2 What must you bear in mind when you connect this component into a circuit? (1)

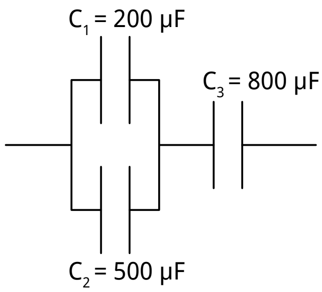
3.7.1 *Electrolytic capacitor*

3.7.1 *It is polarity conscious (has a definite positive and negative terminal) and must be connected into the circuit the correct way around.*

3.8 A circuit showing capacitors connected in series and parallel is shown below. Determine the following:

3.8.1 The equivalent capacitance (C_{e1}) for the parallel section (no calculation required) (1)

3.8.2 The total capacitance for the circuit. (3)



3.8.1 $C_{e1} = 700\ \mu F$

3.8.2 $C_T = \frac{Ce1 \times C3}{Ce1 + C3} = \frac{700\ \mu f \times 800\ \mu f}{700\ \mu f + 800\ \mu f} = 373{,}33\ \mu F$

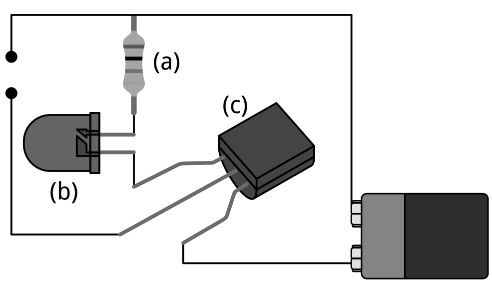
3.9 Name TWO applications of *controllers* in everyday life. (2)

Any TWO correct applications including ones not mentioned here: PLC (programmable logic controller), cruise control in vehicles, variable speed drives, refrigeration systems, washing machines, automatic traffic-light systems, etc.

[20]

QUESTION 4: Electrical components, symbols, circuit drawings, prototyping and design (20)

4.1 Identify the components labelled (a), (b) and (c) in the circuit diagram below. (3)

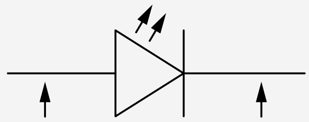
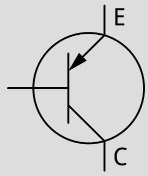
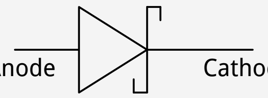


(a) *Resistor*

(b) *LED*

(c) *Transistor*

4.2 Complete the following table with reference to electronic components. (3)

COMPONENT	IEC SYMBOL
4.2.1 *LED*	
NPN Transistor	***4.2.2*** 
4.2.3 *Schottky diode (fast-switching)*	

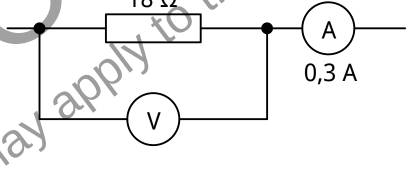
4.3 Discuss the advantages of building a circuit on a breadboard as opposed to a Veroboard. (2)

A circuit built on a breadboard can be taken apart – the components are not fixed onto the board permanently. If you make a mistake, you can correct the circuit. A Veroboard is used to build permanent, soldered circuits.

4.4 Why should a soldering iron always be switched off after use? (1)

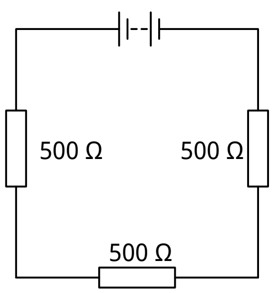
It helps to preserve the element and the soldering tip ***and/or*** *it prevents accidents – the soldering iron gets very hot and touching it can cause serious burns.*

4.5 The diagram below shows part of a circuit. What will the voltmeter reading be given this resistance and current readings? (1)



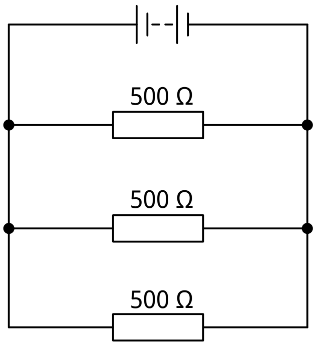
5,4 V

4.6 With reference to the circuit below, state whether the resistors are connected in *parallel* or in *series*? Motivate your answer. (2)



Series connection: the resistors are connected head to tail following one another.

4.7 Study the circuit below and answer the questions that follow.



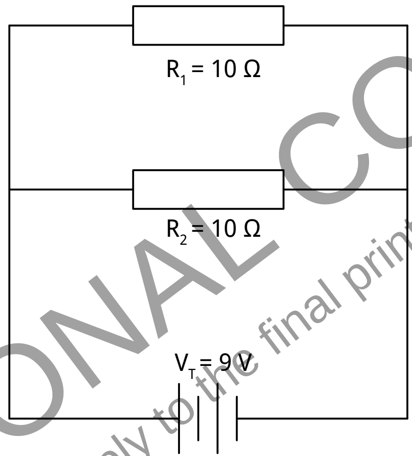
4.7.1 If a fourth resistor is inserted into the circuit in parallel, how will it influence the total resistance of the circuit? (1)

4.7.2 How will the addition of this fourth resistance impact on the total current through the circuit? (1)

4.7.1 *The total resistance of the circuit will decrease.*

4.7.2 *The total current through the circuit will increase.*

4.8 The questions that follow refer to the circuit shown below:
$R_1 = R_2 = 10\ \Omega$ each and $V_T = 9$ V.



4.8.1 Calculate the total resistance of this circuit. (3)

4.8.2 Calculate the total current flowing through the circuit. (3)

4.8.1

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{10}$$

$$\frac{1}{R_T} = \frac{2}{10}$$

$$R_T = 5\ \Omega$$

4.8.2

$$I_T = \frac{V_T}{R_T}$$

$$I_T = \frac{9}{5}$$

$$I_T = 1{,}8\ A$$

QUESTION 5: Electronic tools and equipment

5.1 State what can be measured by using each of the following measuring instruments:

5.1.1 Multimeter

5.1.2 Oscilloscope

5.1.3 Function generator (3)

5.1.1 *Multimeter*

Voltage, current, resistance (could also mention diode testing, transistor testing, temperature)

5.1.2 *Oscilloscope*

Voltage, phase angle, frequency, relationship between waves (Important to note that an oscilloscope cannot measure current).

5.1.3 *Function generator*

A function generator cannot measure anything at all. It simply supplies a signal to the circuit.

5.2 Explain what the *calibration* of a measuring equipment means. (1)

Calibration is the comparison of measurement values delivered by a device under test with those of a calibration standard of known accuracy.

5.3 State whether the following statements are TRUE or FALSE.

5.3.1 An analogue multimeter uses a needle to indicate readings on a calibrated scale.

5.3.2 An oscilloscope can show the phase displacement between two waveforms.

5.3.3 A digital multimeter cannot measure a greater variety of values than an analogue meter. (3)

5.3.1 *True*

5.3.2 *True*

5.3.3 *False*

5.4.1 What is a *parallax error* with reference to measuring instruments? (1)

5.4.2 State how this error can be prevented. (1)

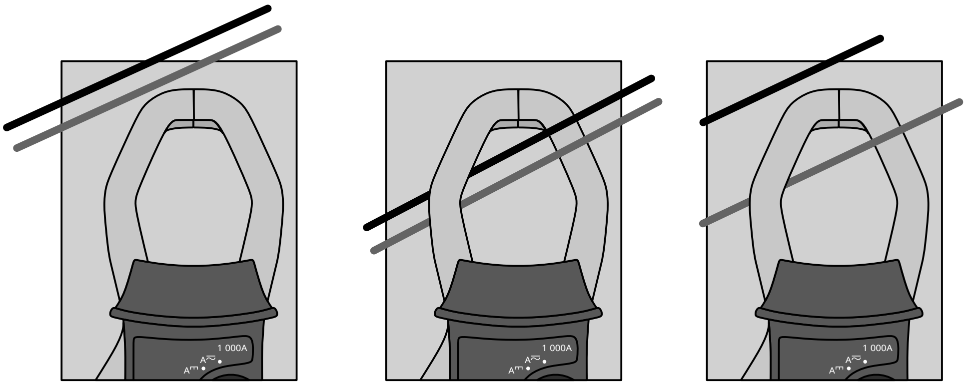
5.4.1 *It is an error in reading when the eye is positioned at an angle to the measurement markings while you are taking a reading.*

5.4.2 *To avoid this error, position your eyes directly above the needle on the meter's display.*

5.5 A clamp-on meter is used to measure the current flowing in a single-phase system with a live and a neutral conductor.

5.5.1 Identify the correct method from the figures shown below. Motivate your answer. (1)

5.5.2 Briefly discuss the problems with the other two methods. (2)



A B C

5.5.1 *Method C is the correct one. Only the current-carrying conductor must be clamped.*

5.5.2 *Method A: No current would be measured as the conductors do not go through the detection coil.*

Method B: No current would be measured as the current in the live and the neutral conductors are flowing in opposite directions and will cancel each other out, resulting a zero reading.

5.6 Complete the table below by: naming THREE tests that are performed on any new household installation before it is commissioned (switched on for the customer), providing the meter setting and stating the acceptable reading for the tests conducted.

TEST	METER SETTING	ACCEPTABLE READING
Continuity	*Ω scale*	*Low Ω, depending on the thickness and length of the conductor*
Insulation between conductors	*MΩ scale*	*Any reading above 1 MΩ*
Resistance between conductors and earth	*MΩ scale*	*Any reading above 1 MΩ*

(3)

[15]

QUESTION 6: Digital systems, PLCs and principles

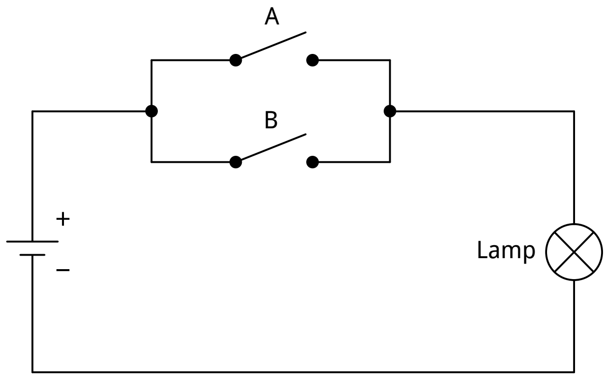
6.1 In your own words, define the term *truth table.* (2)

It is a mathematical table that shows all possible outcomes that may occur given all possible scenarios that are considered at the input.

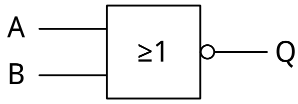
6.2 How many switching combinations are possible with *two inputs* into any logic gate? (1)

2^2 = 4 combinations

6.3 Draw a labelled switching diagram for a two-input OR gate. (2)



6.4 Identify the logic gate shown below and complete a truth table for this gate. (3)



NOR gate [1] *[½ mark for each correct row in truth table]*

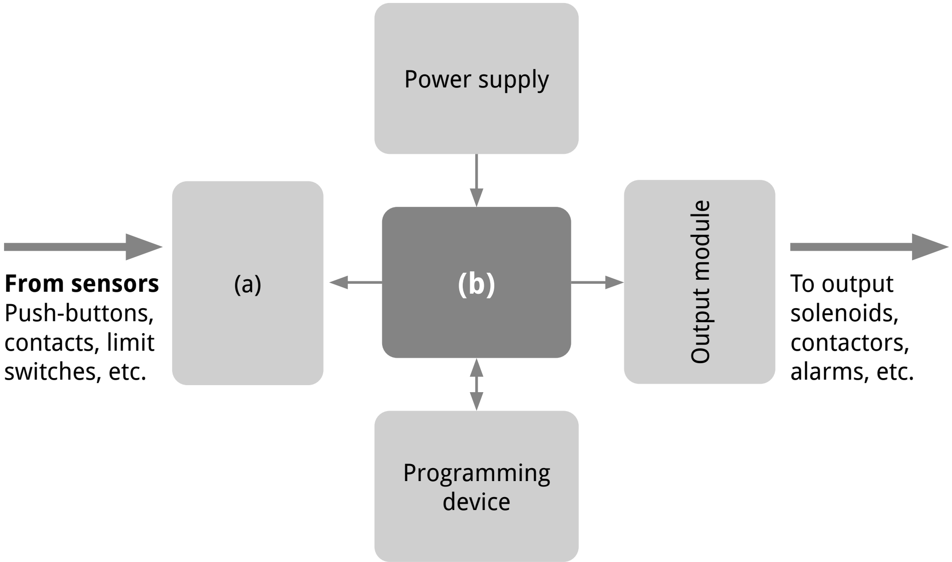
A	*B*	*OUTPUT (Q)*
0	*0*	*1*
0	*1*	*0*
1	*0*	*0*
1	*1*	*0*

6.5 Give TWO reasons why PLCs are better suited for industrial automation applications than relay logic. (2)

Any TWO of the following: PLCs

- *Are compact solid-state devices that are relatively small.*
- *Use about one tenth the amount of energy of relay system.*
- *Have a very long service life*
- *Need less maintenance*
- *Cost much less compared to relay logic system (one-time investment)*
- *Are more reliable because they have no moving parts*
- *Are very flexible because it is easy to change or modify (write a new program) programs*
- *Have a fast response time – can process thousands of items per second.*

6.6 Name the blocks labelled (a) and (b) with reference to the block diagram of the PLC given below. (2)

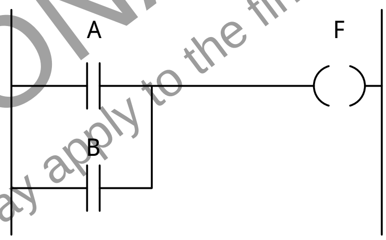


(a) *Processor or Central processing unit*

(b) *Input module*

6.7 Draw the ladder diagram that is represented by the truth table shown below. (3)

INPUT A	INPUT B	OUTPUT (F)
0	0	0
0	1	1
1	0	1
1	1	1



[15]

Exemplar Paper 2: Design related

Memorandum

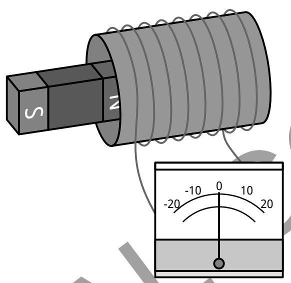
Total: 80
Time: 3 hours

QUESTION 1: Magnetism, electromagnetic circuits and related concepts (4)

1.2 Electromagnetic induction is the production of an electromotive force (emf) or voltage across an electrical conductor due to the movement between a conductor and a magnetic field (as shown in the figure below).

1.2.1 What needs to take place between the coil and the magnet to produce an emf? (1)

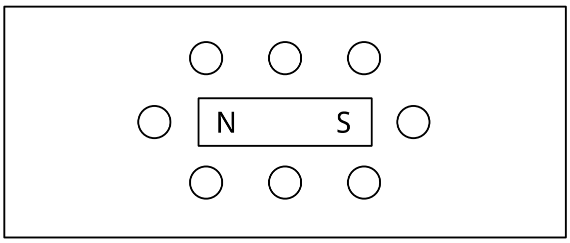
1.2.2 What can be done to increase the magnitude of the induced emf? (1)

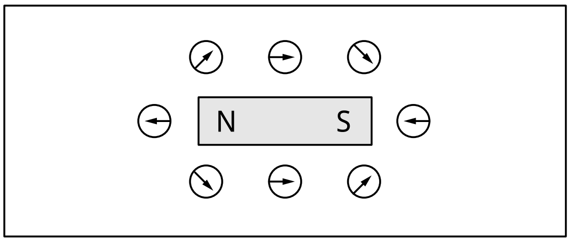


1.2.1 *There must be relative movement between the coil and the magnet.*

1.2.2 *Increase the speed at which the conductor is moved through the magnetic field*
Increase the strength of the magnetic field.
Increase the active length of the conductor

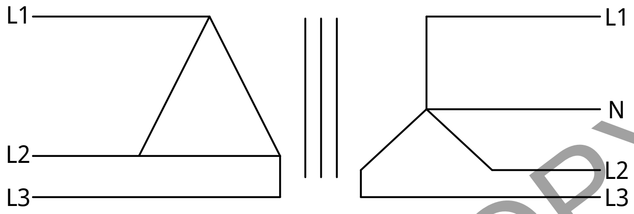
1.1 The sketch below indicates the experiment that was done to determine the direction of the magnetic fields around a bar magnet. Complete the drawing by indicating the direction of the compasses around the magnet. (2)

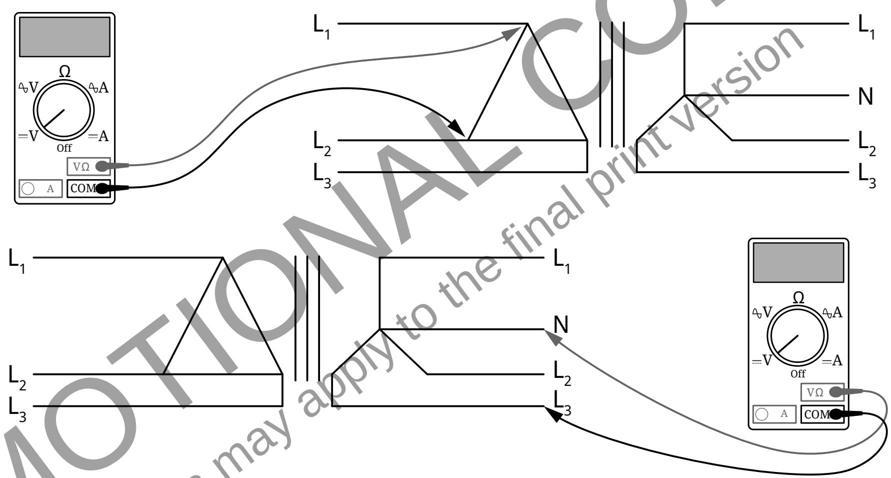




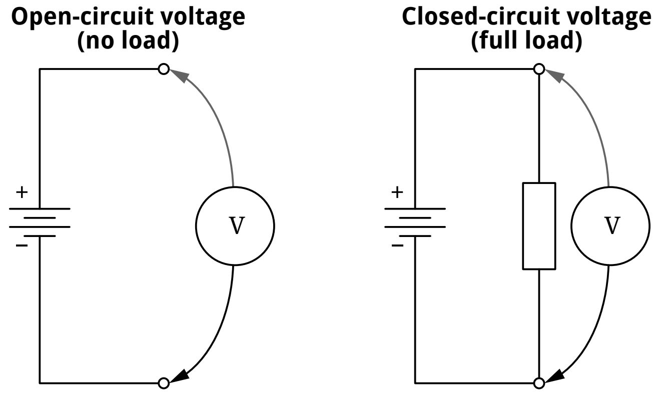
QUESTION 2: Electrical supply systems, Transformers, DC Machines, Series-parallel networked circuits

2.1 The following three-phase transformer was connected in delta-star and then connected to a supply. By means of two neat sketches, show how a multimeter, set to voltage scale, should be connected to measure any phase voltages (on the primary and on the secondary sides) of the three-phase transformer shown below. You must redraw the transformer. (4)





2.2 Before one uses a battery to power an inverter system, it is important to know which operating voltages should be used with no load as well as at full load. Show, by means of a neat sketch, how to measure the emf and the pd of a battery. (2)



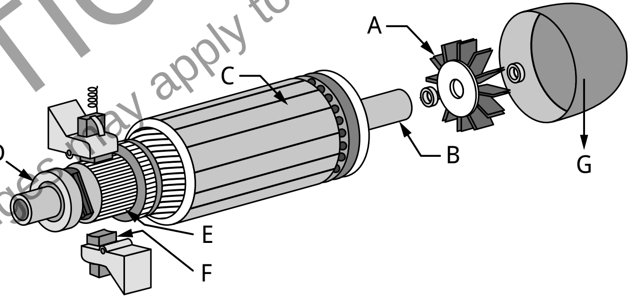
2.3 A car's battery is faulty. Keep in mind that the relative density of the electrolyte is the ratio of the mass of a unit volume of the electrolyte to the mass of the same volume of water (or specific gravity of the electrolyte). The relative density of a fully charged cell is specified by the manufacturer and is generally in the region of 1 230 to 1 280.

Explain how you would test whether the relative density level of the battery is acceptable. Refer to the density of the electrolyte as well as the instrument you would use. (3)

One would use a hydrometer. The nozzle of the hydrometer is inserted into the electrolyte through the filler caps at the top of the battery. Electrolyte is drawn up into the hydrometer. A sufficient amount should be drawn up to allow the float inside the glass tube to rise freely. The reading on the float will indicate the relative density of the electrolyte. The floater inside the hydrometer should be in the green section to indicate the density is at an acceptable level. The relative density of each cell must be tested in this manner.

2.4 An electric motor was disassembled to inspect the parts. Once the rotor section had been removed, the technician observed the parts as shown in the picture below.

Identify the parts labelled as A to F in the sketch of the rotor. (3)



A	*Fan*	*B*	*Shaft*
C	*Armature*	*D*	*Bearing*
E	*Commutator*	*F*	*Carbon brushes*

(½ marks each)

[12]

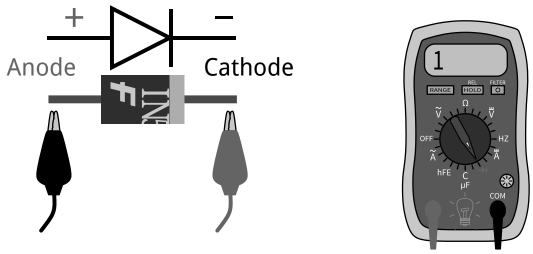
QUESTION 3: Electronic components and semiconductors

3.1 Before using a 1N4007 diode to build a rectifier circuit (or any other circuit), we need to perform certain tests to ensure the diode is fully functional.

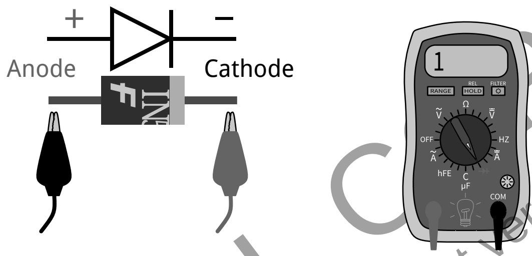
Use two neat sketches to demonstrate how you would use a multimeter to test the diode and state the acceptable as well as the unacceptable readings. (3)

Set the multimeter to the ohm scale (or the diode testing scale).

Step 1: Place the leads of the meter across the terminals of the diode and test it. Record the reading.



Step 2: Swop the diode around and test it again. Record the reading.

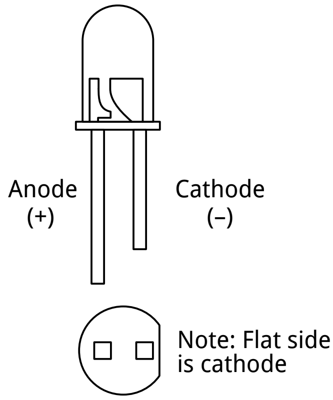


- ***Results:*** *If you only get a reading across the diode in one direction but not in the other direction, the diode is fully functional.*
- *If a reading is obtained in both directions the diode is defective.*
- *If no reading is obtained in either direction the diode is defective.*

3.2 Explain, with the aid of a neat, labelled sketch, the TWO methods used to identify the terminals of an LED correctly. (4)

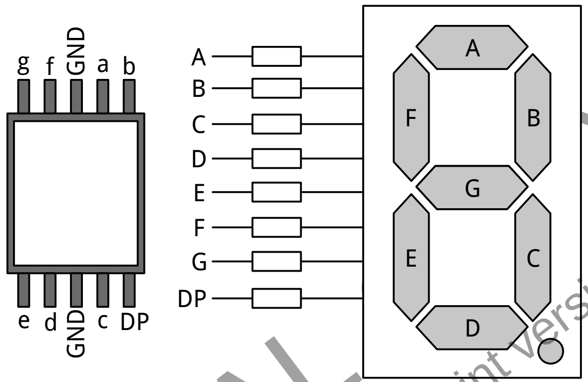
Method 1: *When viewed from the side, the long terminal is the anode (+) and the short terminal is the cathode (–)* *(1)*

Method 2: *When viewed from the bottom, the terminal closest to the flat side of the LED is the negative (–) and the one furthest away is the positive (+)* *(1)*

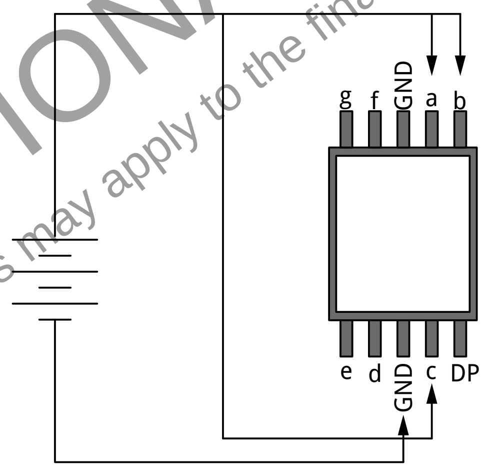


(2)

3.3 You have been asked to design an electronic circuit to display a digital number (to represent voltage or current) by means of a seven-segment display.
Using the integrated circuit given below, draw the circuit diagram needed to display the number seven (7) on the seven-segment display.
Include a battery in the circuit. (2)

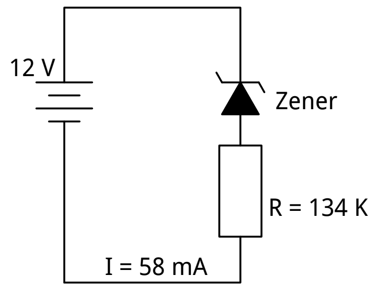


½ mark for each correct pin connection:



3.4 A Zener diode is required to regulate a set voltage cross it. In the circuit shown below, a 12-V battery is connected in series to the Zener diode and a 134-kΩ resistor.

3.4.1 Calculate the voltage drop across the diode. (5)



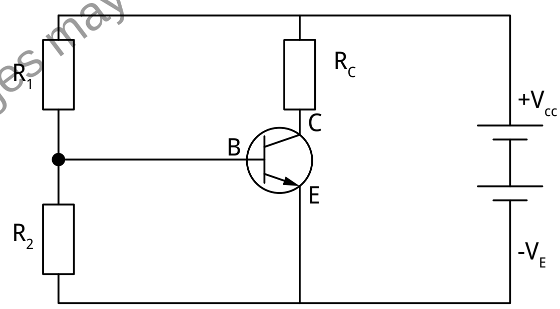
$V_R = I_R = (58\ mA)(134\ k\Omega) = 7{,}77\ V$
$V_Z = V_T - V_R = 12 - 7{,}77 = 4{,}23\ V$

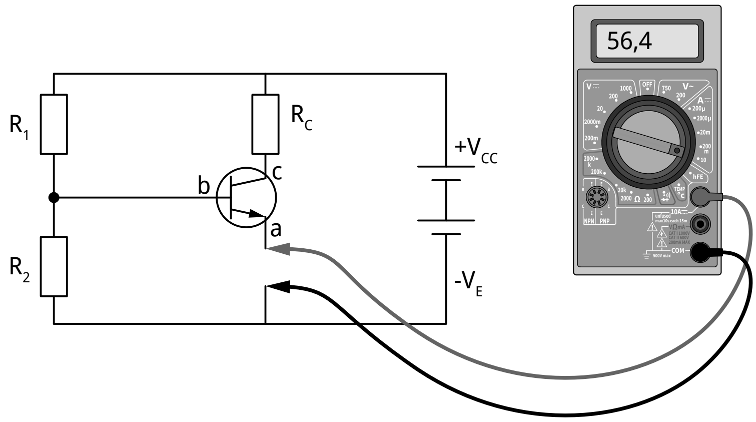
3.4.2 Select an appropriate Zener diode from the data sheet provided. (1)

ELECTRICAL CHARACTERISTICS (AT 25 °C, UNLESS OTHERWISE SPECIFIED)									
PART NUMBER	ZENER VOLTAGE	TEST CURRENT		REVERSE LEAKAGE CURRENT		DYNAMIC RESISTANCE f = 1 KHZ		SURGE CURRENT	REGULATOR CURRENT
	V_Z @ I_{ZT1}	I_{ZT1}	I_{ZT2}	I_R @ V_R		Z_{ZT} @ I_{ZT1}	Z_{ZK} @ I_{ZT2}	I_R	I_{ZM}
	V	mA	mA	µA	V	Ω		mA	mA
	NOM.			MAX.		TYP.	MAX.		MAX.
1N4728A	3,3	76	1	100	1	10	400	1380	276
1N4729A	3,3	69	1	50	1	10	400	1260	252
1N4730A	3,9	64	1	10	1	9	400	1190	234
1N4731A	4,3	58	1	10	1	9	400	1070	217
1N4732A	4,7	53	1	10	1	8	500	970	193

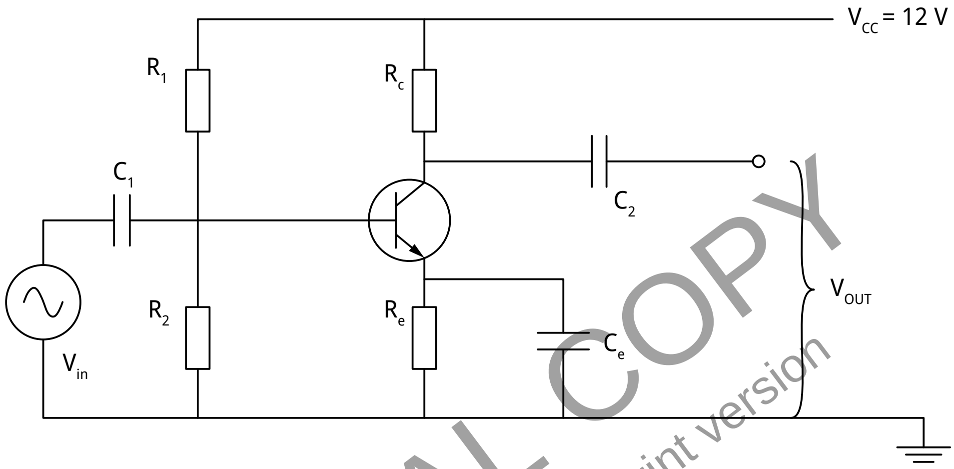
The 1N4731A which regulates 4,3 V is needed.

3.5 The following transistor circuit was built on a breadboard, but the value of the currents flowing in the circuit is not given.
Copy the circuit given below and show how you would connect a digital multimeter set to the milliampere scale to measure the current flowing out at the emitter terminal. (1)





3.6 A single-stage transistor amplifier with a collector resistor of 34 Ω is shown in the circuit diagram below.



3.6.1 Determine the maximum current that can flow through the transistor. (3)

$$I_c = \frac{Vcc}{Rc} = \frac{12}{34} = 352{,}94\ mA$$

3.6.2 From the data sheet shown below, select a suitable transistor for this circuit. Keep in mind the safety of the component when selecting the transistor. (1)

NPN TRANSISTORS								
CODE	STRUCTURE	CASE STYLE	I_C MAX.	V_{CE} MAX.	H_{FE} MAX.	P_{TOT} MAX.	CATEGORY (TYPICAL USE)	POSSIBLE SUBSTITUTES
BC107	NPN	TO18	100 mA	45 V	110	300 mW	Audio, low power	BC182 BC547
BC109	NPN	TO18	200 mA	20 V	200	300 mW	Audio (low noise), low power	BC184 BC549
BC182	NPN	TO92C	100 mA	50 V	100	350 mW	General purpose, low power	BC1077 BC182L
BC547B	NPN	TO92C	100 mA	45 V	200	500 mW	Audio, low power	BC107B
2N3053	NPN	TO39	700 mA	40 V	50	500 mW	General purpose, low power	BFY51
TIP31A	NPN	TO220	3 A	60 V	10	40 mW	General purpose, high power	TIP31C TIP41A

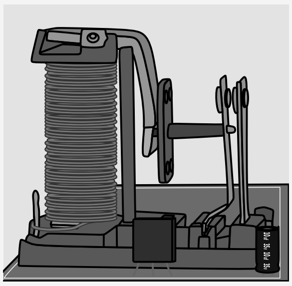
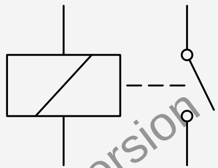
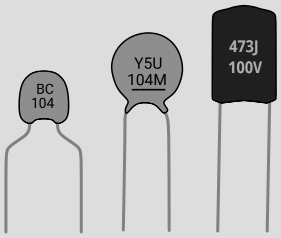
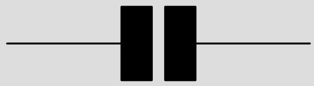
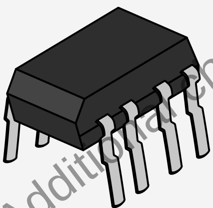
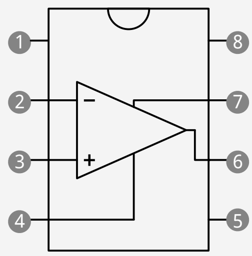
CODE	STRUCTURE	CASE STYLE	I_C MAX.	V_{CE} MAX.	H_{FE} MAX.	P_{TOT} MAX.	CATEGORY (TYPICAL USE)	POSSIBLE SUBSTITUTES
TIP41A	NPN	TO220	6 A	60 V	15	65 mW	General purpose, high power	
2N3055	NPN	TO3	15 A	60 V	20	117 mW	General purpose, high power	

The transistor needs to handle the current comfortably without overheating when conducting 352,94 mA, so double the current value: 352,94 mA × 2 = 705,88 mA. The selected transistor is the 2N3053 or the BFY 51.

[20]

QUESTION 4: Electrical components, symbols, circuit drawings, prototyping and design

4.1 In order to design simple electronic circuits, it is important to identify electronic components and know which symbols are used to represent each component.
Identify the components given in the table below and provide the symbol for each of them. (6)

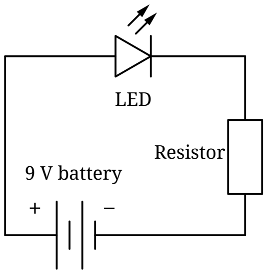
COMPONENT	NAME	IEC SYMBOL
	**4.1.1** Relay	**4.1.2** 
	**4.1.3** Non-polarised capacitors	**4.1.4** 
	**4.1.5** Integrated circuit operational amplifier	**4.1.6** 

4.2 You have been asked to design a simple series circuit consisting of a 9-V battery, a resistor and a LED.

4.2.1 Draw the series circuit you have designed. (3)

4.2.2 Calculate the value of the resistor that you must use in the circuit to protect the LED from blowing if it has a rating of 20 mA? (3)

a)

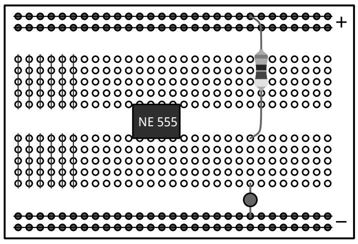


b) $R = \frac{V}{I}$

$R = \frac{9}{0{,}020}$

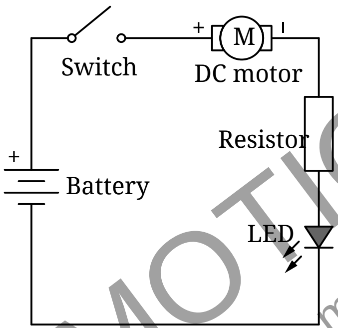
$R = 450\ \Omega$

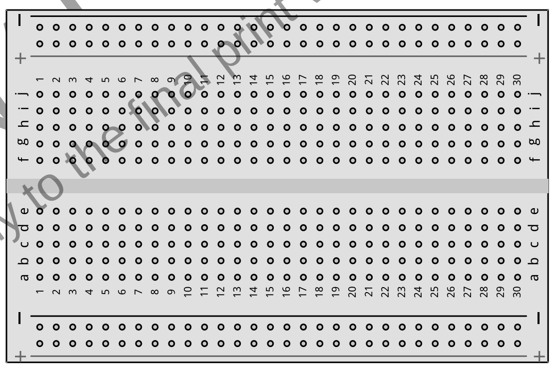
4.3 The figure below shows an IC connected onto a breadboard. Give a reason why the IC must be connected as illustrated. (1)

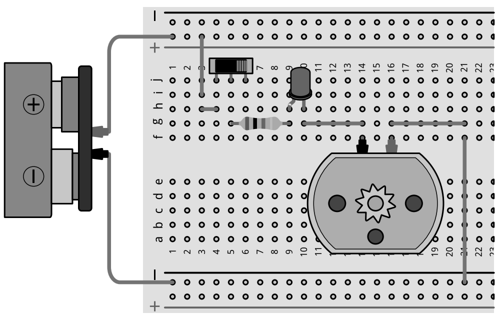


To prevent the IC pins from being shorted out. Connecting it in any other way will short out the pins because of the layout of the breadboard.

4.4 The given circuit must be built on a breadboard. Draw the breadboard layout for this circuit on the breadboard provided below. (5)

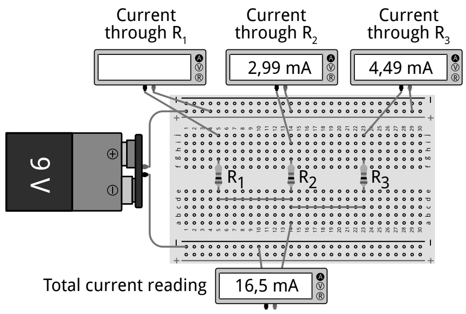






One possible layout. All designs must be checked for correctness.
One mark for the correct placement of each component.

4.5 The following circuit was built on a breadboard to prove Kirchhoff's current law. If the three resistors have the same values and the current readings are as given in the figure below, what will the current reading on the first meter be? (2)

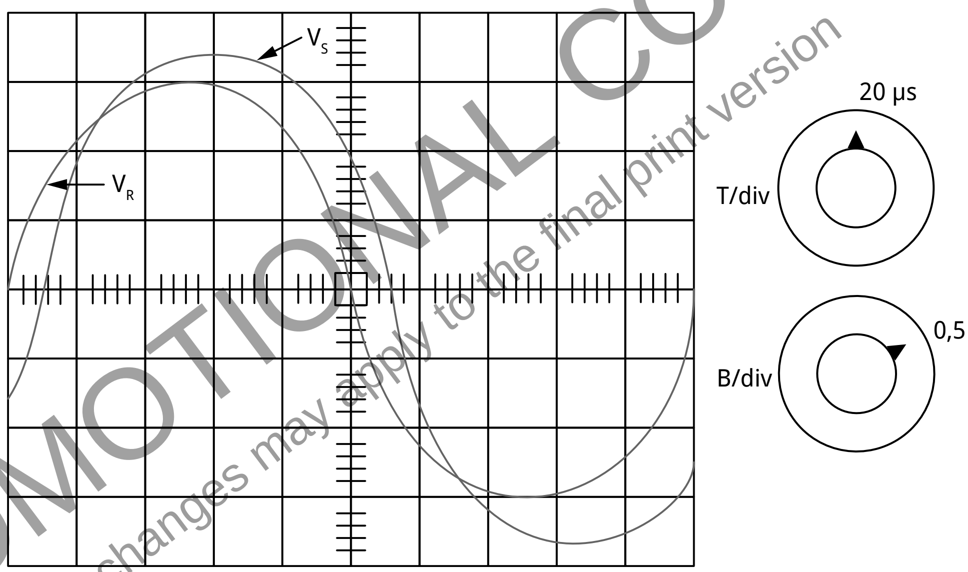


I_1 = 16,5 – 2,99 – 4,49
I_1 = 9,02 mA

QUESTION 5: Electronic tools and equipment (4)

5.1 A circuit was connected to an oscilloscope and the waveforms shown below were observed. The oscilloscope display with its time and voltage settings is given. Determine the following:

5.1.1 the voltage of both waveforms (2)
5.1.2 the frequency of the waveforms (1)
5.1.3 the phase angle between the two waveforms. (1)



[4]

5.1.1 V_R *= V/div × no. blocks × 0,707*
= 0,5 V/div × 3 blocks × 0,707 = 1,06 V

V_S *= V/div × no. blocks × 0,707*
= 0,5 V/div × 3,4 blocks × 0,707 = 1,2 V

5.1.2 $F = \frac{1}{T} = \frac{1}{20\ \mu s \times 10} = 5\ kHz$

5.1.3 $\theta = \frac{360}{50} \times 3 = 21{,}6°$

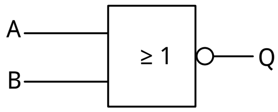
QUESTION 6: Digital systems, PLCs and principles

6.1 Logic gates are the building blocks of digital circuits. Logic gates will make decisions based on a combination of digital signals from their inputs. Draw the IEC symbols for the following logic gates and give the Boolean expression for each gate.

6.1.1 NOR gate (2)

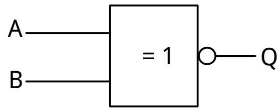
6.1.2 XNOR gate (2)

6.1.1



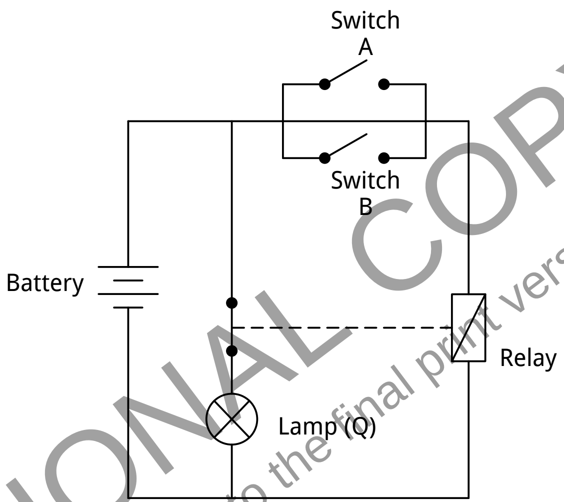
$Q = \overline{A + B}$

6.1.2



$Q = \overline{A}.B + A.\overline{B}$ or $Q = A \oplus B$

6.2 The following switching circuit was built on a breadboard. Identify the gate represented by this circuit diagram and draw the truth table for this logic gate. (3)

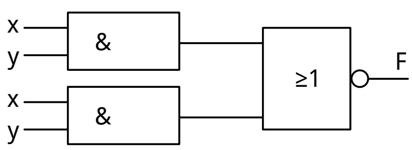


NOR gate

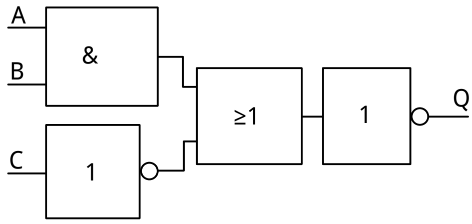
SWITCH A (INPUT)	SWITCH B (INPUT)	LAMP (Q)
0	*0*	*1*
0	*1*	*0*
1	*0*	*0*
1	*1*	*0*

6.3 Design a simple logic circuit that will match the following Boolean expression:

$F = \overline{X.Y + X.Z}$ (4)



6.4 The figure below represents a simple logic circuit. Answer the questions that follow.



6.4.3 How many input combination will a truth table for this circuit have? (1)

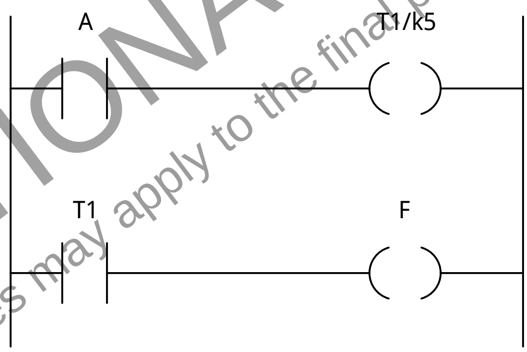
6.4.4 Draw the truth table for this logic circuit. (4)

6.4.1 *2^3 = 8 combinations*

6.4.2

INPUT A	INPUT B	INPUT C	OUTPUT Q
0	*0*	*0*	*0*
0	*0*	*1*	*1*
0	*1*	*0*	*0*
0	*1*	*1*	*1*
1	*0*	*0*	*0*
1	*0*	*1*	*1*
1	*1*	*0*	*0*
1	*1*	*1*	*0*

6.5 You have designed a ladder diagram. Explain the operation of this diagram to a friend. (4)



When contact A is closed, the timer coil is energised (T_1) and the counter starts counting. After five seconds (indicated by k5), the timer contact (T_1) closes and, at the same time, activates the coil (F). The output (F) will now be high or logic 1. This is an example of an on-delay timer.

[80]

Glossary

A

AC (alternating current) – an electric current that reverses its direction many times per second at regular intervals

Ampere – a measure of electric current; the amount of electric charge in motion per unit time

Amplifiers – electronic devices for increasing the amplitude of electrical signals, used chiefly in sound reproduction

Amplitude – the value of the induced voltage represented on a graph as the measurement that describes the vertical distance between the peak and the *x*-axis

Analogue – using the deflection of a pointer (or a needle) on a scale to indicate the measurement taken

Analogue input – varying signal between two limits, e.g. 1 to 5 V DC or 4 to 20 mA

Armature – the rotor and the wire windings or coils around the rotor of a DC motor

Armature reaction – the distortion of the main flux entering and leaving the armature caused by the flux set up by armature conductors when they carry current

Audio amplifier – differential amplifiers with a very high amplification (ideally infinite), a non-inverting input and an inverting input

Automatic – operates completely independently, i.e. without human intervention

Automation – the creation and application of technology to monitor and control the production and delivery of products and services

Auto-polarity – automatic interchanging of connections to a digital meter when polarity is wrong; a minus sign appears ahead of the value on the digital display if the reading is negative

Autotransformer – an electrical transformer with only one coil that has a tapping point (or points) for the secondary winding

B

Back emf – the electromotive force or voltage that opposes the change in the current that induced it

Biasing – an arrangement made in a diode or other electrical device to allow a larger flow of current in a certain direction

Binary inputs – input that represents one of two possible states, generally referred to as *logic 1 (high)* and *logic 0 (low)*

Block diagram – a chart representing complicated information in an easy-to-understand way

BNC – a miniature, quick connect/disconnect radio frequency (RF) connector developed for low-frequency applications

Boolean logic – a form of algebra where all values are either true or false

Breadboard – thin, plastic board with tiny holes for building an experimental model of an electric circuit

Brush (electric) – a sliding electrical contact between a moving part and a stationary part

Buchholz relay – a mechanical protection device used in transformers

C

Calibration – process of comparing a measurement made by an instrument with the value of the same measurement as defined by an accepted standard to check the accuracy of the instrument

Capacitance – the amount of electric charge stored on the plates of a capacitor

Capacitor – a device that stores electrical energy in an electric field by virtue of accumulating electric charges on two close surfaces

Carbon footprint – a measure of the amount of carbon dioxide released into the atmosphere

Ceramic capacitor – a fixed-value capacitor where the ceramic material acts as the dielectric

Charge controller – a device that regulates the voltage and current flow from the PV to the battery to prevent overcharging the battery

Comparator – device that compares two input voltages and outputs a binary signal indicating which is larger

Compound – a combination of both series and shunt connections

Controller – a device that uses electrical signals and digital algorithms to perform its receptive, comparative and corrective functions

Coulomb – the SI unit of electric charge, equal to the quantity of electricity conveyed in one second by a current of one ampere

CRT (cathode-ray tube) – a high-vacuum tube in which cathode rays produce a luminous image on a fluorescent screen, used in television and computer terminals

Crystal transducers – electronic devices that use quartz crystal which is made from silicon and oxygen arranged in crystalline structure (SiO_2)

Cycle – each repetition of a variable quantity, recurring at equal intervals

D

Data sheet (also ***datasheet*** **or** ***spec sheet*****)** – a document that summarises the performance and other characteristics of a product, machine or component

DC (direct current) – an electric current that flows in one direction only around a circuit from positive to negative

Delta – an electrical connection where the three coils are connected in series to form a closed loop

Depletion layer (region) – region between N-type and P-type materials where there is neither an excess of electrons nor of holes

Dielectric – a material that is a poor conductor of electricity (an insulator) but an efficient supporter of electrostatic fields

Differentiator – a circuit configuration (the inverse of the integrator circuit) that produces an output signal where the instantaneous amplitude is proportional to the rate of change of the applied input voltage

Digital – having numeric displays in easily readable format

Discreet – the presence (on) or absence (off) of an electrical signal

Distribution board (DB) – component of an electricity supply system that divides an electrical power feed into subsidiary circuits while providing a protective fuse or circuit breaker for each circuit in a common enclosure

Double-throw (DT) switch – electric switch with moving blades that may engage either of two different sets of fixed contacts

E

Eddy-current losses – a conductive I^2R loss produced by circulating currents induced in response to AC flux linkage, flowing against the internal resistance of the core

Efficiency – the ratio between power output (mechanical) and power input (electrical)

Electrical circuit – a closed path that consists of circuit components through which electrons from a voltage or current source can flow

Electricity consumer – any person who legally buys electricity for their own use and, possibly, for a sub-consumer connected to the installations

Electricity generation – the process of generating electrical power from sources of primary energy

Electrolyte – a substance that conducts electrical current as a result of a dissociation into positively and negatively charged particles called ions

Electrolytic capacitor – a type of capacitor that uses an electrolyte to obtain greater capacitance

Electromagnetic induction – the production of an electromotive force (emf) or voltage across an electrical conductor due to the relative movement between a conductor and a magnetic field

Electromagnetism – a fundamental force of nature; magnetism that is developed by electrical current

Electromotive force (emf or EMF) – a difference in potential energy between two points when the power source supplies no current to a circuit

Excited (excitation) – the process of generating a magnetic field by means of an electric current

F

Flux – often referred to as magnetic field but may also mean the magnetic field strength

Flux density – the amount of magnetic flux in an area taken perpendicular to the direction of the magnetic flux

Frequency – refers to the number of full waves that pass a fixed point in unit time, i.e. the number of cycles measured in one second

Functional block diagram – a diagram that describes the functions and interrelationships of a system

G

Gassing – destructive gas generation in batteries commonly resulting from self-discharge or from the electrolysis of water in the electrolyte during charging

Generator – a device used to convert mechanical energy into electrical energy

H

Half adder – a logic circuit used to add two single-bit binary numbers, giving a sum (S) and a carry (C) bit on the output

hFE (*hybrid parameter forward current-gain common emitter*) – a unit of measurement for determining the amount of current gain (amplification) that a transistor can produce

Humanoids –robots designed to look like humans for intuitive collaboration

Hygrometer – an instrument for measuring the humidity of the air or a gas

Hz – SI unit of frequency (the change in state or cycle in a sound wave, AC or other cyclical waveform per second); *kHz* is equivalent to 1 000 cycles per second

Hysteresis loss – a loss of heat caused by the magnetisation and demagnetisation of a core as current flows in reverse directions

I

Inductance – the tendency of an electrical conductor to oppose a change in the electric current flowing through it

Interface – the way a computer program presents information to a user or receives information from a user, in particular the layout of the screen and the menus

Input field devices – start/stop, overloads and various sensors that can be connected to the inputs of a PLC

Input impedance – the measure of the opposition to current (impedance) both static (resistance) and dynamic (reactance)

Inverter – a device that converts direct current (DC) electricity to alternating current (AC)

Irradiance – the energy per unit time that strikes a unit horizontal area per unit wavelength interval

L

Ladder diagram – specialised graphical representation of the programming language used to develop software for PLCs

Ladder logic – a programming language that creates and represents a program through ladder diagrams that are based on circuit diagrams

LCD (liquid-crystal display) – type of flat panel display which uses liquid crystals in its primary form of operation

Lenz's law – the direction of the induced current is such that it opposes the change that produced it

Loading effect – the extent to which an instrument affects the electrical properties (such as voltage, current and resistance) of the circuit being tested

Logic diagram – a graphical representation that shows the interconnection of the logic symbols and gates that are combined to achieve a specific output

M

Magnet(s) – object(s) capable of producing a magnetic field that attract(s) unlike poles and repel(s) like poles

Magnetic field – region in space where another magnet or ferromagnetic material will experience a force that can attract or repel objects

Magnetic field lines – three-dimensional representation of a magnetic field

Magnetic field strength (H) – a measure of the intensity of a magnetic field; the ratio of the mmf which is required to create a certain flux density within a certain material per unit length of that material

Magnetic flux (Φ) – the number of magnetic lines produced by a magnet perpendicular to a given surface

Magnetic flux density (β) – the number of magnetic lines per unit area

Magnetism – the force exerted by magnets when they attract or repel each other

Magnetomotive force (mmf) – the force responsible for the creation of a magnetic field in a magnetic circuit

Mains – the electrical power that is delivered to homes and businesses through the national electric grid

Mica – shiny silicate mineral with a layered structure used as an insulator

Microcontroller – a compact integrated circuit designed to control other parts of an electronic system

Monocrystalline – made of silicon with a single, constant crystal assembly

Motor – a device that converts electrical energy to mechanical energy

MPPT (maximum power point tracking) – an electronic DC to DC converter that optimises the match between the solar array (PV panels) and the battery

Multimeter – an electronic measuring instrument that combines several measurement functions, such as measuring voltage, current, and resistance, in one unit

N

NTC (negative temperature coefficient) – describes a ceramic-based component with temperature-dependent resistance, in this case the resistance decreases exponentially with rising temperature

O

Op-amp (operational amplifier) – a three-terminal device that can amplify weak electrical signals

Opto-isolator – a semiconductor device that uses light to transfer an electrical signal between circuits while keeping them electrically isolated from each other

Oscilloscope – type of electronic test instrument that graphically displays electrical signals and shows how these signals change over time

Output field devices – main contactors that can be connected to the outputs of a PLC

P

Parallel – a circuit that has more than one path for current flow, set up in such a way that current can flow through different branches at the same time

Parity bit – an additional bit that is added to digital data to make the number of logic 1s in the data either even or odd

Passive (device) – a component that does not generate power but instead dissipates, stores and/or releases it

Period – the time that it takes to complete one cycle

Phase angle – the number of degrees separating two sine waves of the same frequency

Photovoltaic – specialised semiconductor device that converts light energy into electrical energy

Piezoelectric – relating to electric polarisation resulting from the application of mechanical stress

Plastic-film capacitor – a capacitor that uses plastic film as the dielectric and aluminum or zinc as the electrodes to store electric charge

PLC (programmable logic controller) – a digital computer used to automate different industrial processes

Polarised component – component that has polarity, i.e., two distinct and opposite poles, and can therefore only be connected to a circuit in one direction

Polycrystalline – consisting of many small crystals that are randomly angled with respect to each other

Power supply – a source of power to an electrical system, which could be AC of DC

Printed circuit board (PCB) – a non-conductive material with thin strips of conducting material, such as copper, etched onto it to provide a path for electrical components

Processor – the device that makes decisions according to the program it is running at that time

Protective earthed neutral (PEN) – a single conductor that has the combined function of providing the neutral and protective earth conductor in a TN-C-S earthing arrangement; a PEN conductor is normally, but not exclusively, used with an LV PME supply service earthing system

PTC (positive temperature coefficient) – describes a ceramic-based component with temperature-dependent resistance, in this case the resistance increases with rising temperature

Pulse-width modulation – method of controlling the average power delivered by an electrical signal

R

Relative density – the ratio of the mass of a unit volume of a substance (the electrolyte) to the mass of the same volume of a given reference material (water)

Relay system (relay logic) – system that uses electromechanical relays to perform specific functions such as switching, timing, counting and logic operations

Residual magnetism – the amount of magnetisation left behind after the removal of the external magnetic field from the circuit

Resistance – amount of resistance the circuit offers to the current flowing through it; standard unit of measurement is ohm (θ)

Resistivity – the ability of a material to resist electrical conduction, also known as *specific resistance*

Rotor – a rotating part of an electrical or mechanical device

Rung – horizontal line representing a unique parallel-circuit branch between the poles of the power supply in a ladder diagram

S

Scalar – a quantity described only by its magnitude

Series – a circuit that has all components connected end-to-end to form a single path for current flow

Short circuit – an electrical circuit that allows a current to travel along an unintended path with no or very low electrical impedance

Shunt – connection that consists of multiple paths along which current can flow

Sine wave – a geometric waveform that represents periodic oscillations (up, down or side-to-side movements) of constant amplitude (size)

Single-pole single-throw switch – simple electric switch that has a single input and can connect only to one output

Silver-mica capacitor – capacitors that use mica as the dielectric

Slew rate – the maximum rate of voltage change that can be generated by the output circuitry of an op-amp

Solar cells – any device that directly converts the energy of light into electrical energy through the photovoltaic effect

Solder – alloy (usually with a lead, brass, tin or silver base) with a low melting point, used to join metals

Solenoid – cylindrical coil of wire acting as a magnet when carrying electric current

Solid-state device – an electronic device made up of mainly semiconductors such as ICs, transistors and diodes

Star – an electrical connection where the three common ends of the coils are connected together to form a terminal called the neutral (N)

Step-down transformer – takes a high voltage and converts it to a lower voltage value

Step-up transformer – takes a lower voltage and converts it into a higher voltage

Sun hours – any hour of the day when the sunlight's intensity is an average of 1 000 watts of energy per square metre, usually peaking from noon until early afternoon

T

Tantalum capacitor – an electrolytic capacitor that consists of a pellet of porous tantalum metal as an anode, covered by an insulating oxide layer that forms the dielectric, surrounded by liquid or solid electrolyte as a cathode

Temperature coefficient of resistance – the increase in unit resistance of a substance, per unit rise in temperature

Tesla – the unit of magnetic flux density which is equivalent to 1 weber per square metre

Thermistor – temperature-dependent resistors, changing resistance with changes in temperature

Toggle – electric switch operated by means of a projecting lever that is moved up and down

Torque – a force that causes rotation about an axis

Toxic –poisonous or causing damage to health

Transducer – an electronic device that converts energy from one form to another

Transformer – an electrical device that uses the principle of electromagnetic induction to transfer energy from one electric circuit to another

Transmission – the transport of electricity via high-voltage, interconnected systems for delivery to consumers

Truth table – a mathematical table that shows all possible outcomes that would occur from all possible scenarios that are considered at the input

Turns ratio – the relationship between the number of turns on the primary winding and the number of turns on the secondary winding, i.e. the number of turns of the primary winding divided by the number of turns of the secondary winding

V

Vector – a quantity described by both its magnitude and direction

Veroboard – a board used to build electronic circuits; some of the electrical connections are formed by strips of copper on the underside of the board

Voltage regulator – an electrical or electronic device that maintains the voltage of a power source within acceptable limits

W

Weber (Wb) – the unit of magnetic flux which, when cut at a uniform rate by a conductor in 1 second, generates an emf of 1 volt

Acknowledgements

Back emf: 'Back Emf and Torque Equation for DC Motor'. Studocu. https://www.studocu.com/ph/document/rizal-technological-university/bs-electrical-engineering/back-emf-and-torque-equation-for-dc-motor/23123488

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