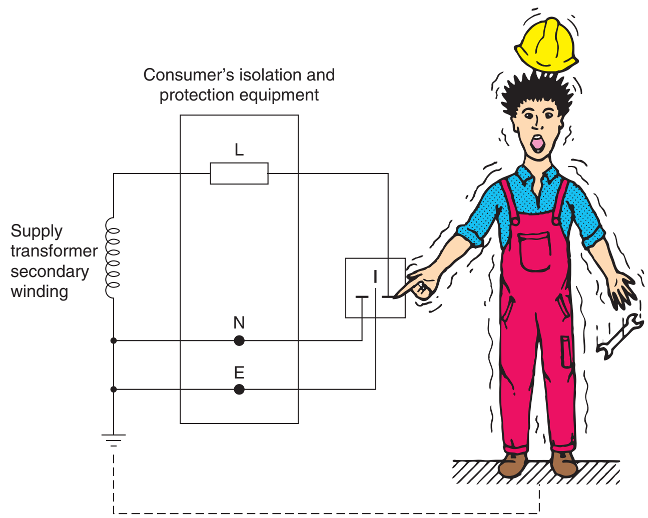


FIGURE 2.11
Touching live and earth or live and neutral makes a person part of the electrical circuit and can lead to an electric shock.

When this happens it is necessary to act quickly to prevent the electric shock becoming fatal. Actions to be taken upon finding a workmate receiving an electric shock are as follows:

- Switch off the supply if possible.
- Alternatively, remove the person from the supply *without touching him*, for example, push him off with a piece of wood, pull him off with a scarf, dry towel or coat.
- If breathing or heart has stopped, immediately call professional help by dialling 999 or 112 and asking for the ambulance service. Give precise directions to the scene of the accident. The casualty stands the best chance of survival if the emergency services can get a rapid-response paramedic team quickly to the scene. They have extensive training and will have specialist equipment with them.
- Only then should you apply resuscitation or cardiac massage until the patient recovers, or help arrives.
- Treat for shock.

To reduce the risk of an electric shock at work we should:

- Avoid contact with live parts by insulating all live parts and placing them out of reach by using barriers or temporary barriers.
- Check and inspect all cables and equipment for damage before using them.
- PAT test all portable equipment.
- Use only low voltage or battery tools.
- Use a secure electrical isolation procedure before beginning work as described earlier in this chapter.

Dangerous occurrences and hazardous malfunctions

Dangerous occurrence – is a 'near miss' that could easily have led to serious injury or loss of life. Dangerous occurrences are defined in the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995. Near miss accidents occur much more frequently than injury accidents and are, therefore, a good indicator of hazard, which is why the HSE collects this data. As I write this in January 2008 a BA passenger aeroplane lost power to both engines as it prepared to land at Heathrow airport. The pilots glided the plane into a crash landing on the grass just short of the runway. This is one example of a dangerous occurrence which could so easily have been a disaster.

Definition

Dangerous occurrence – is a 'near miss' that could easily have led to serious injury or loss of life. Near miss accidents occur much more frequently than injury accidents and are, therefore, a good indicator of hazard, which is why the HSE collects this data.

Consider another example – On a wet and windy night a large section of scaffold around a town centre building collapses. Fortunately this happens about midnight when no one was around because of the time and the bad weather. However, if it had occurred at midday, workers would have been using the scaffold and the streets would have been crowded with shoppers. This would be classified as a dangerous occurrence and must be reported to the HSE, who will investigate the cause and, using their wide range of powers, would either:

- stop all work,
- demand the dismantling of the structure,
- issue an Improvement Notice,
- issue a Prohibition Notice,
- prosecute those who have failed in their health and safety duties.

Other reportable dangerous occurrences are:

- the collapse of a lift,
- plant coming into contact with overhead power lines,
- any unexpected collapse which projects material beyond the site boundary,
- the overturning of a road tanker,
- a collision between a car and a train.

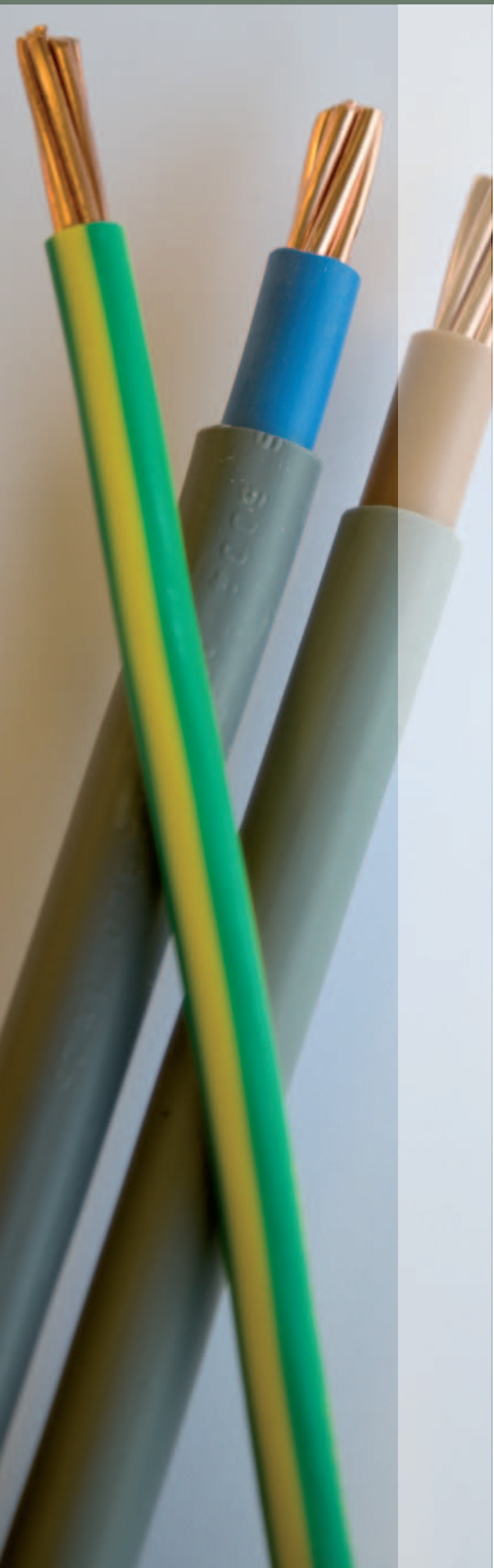
Hazardous malfunction – if a piece of equipment was to fail in its function, that is fail to do what it is supposed to do and, as a result of this failure have the potential to cause harm, then this would be defined as a hazardous malfunction. Consider an example – if a 'materials lift' on a construction site was to collapse when the supply to its motor failed, this would be a hazardous malfunction. All the Regulations concerning work equipment state that it must be:

Definition

Hazardous malfunction – if a piece of equipment was to fail in its function, that is fail to do what it is supposed to do and, as a result of this failure have the potential to cause harm, then this would be defined as a hazardous malfunction.

- suitable for its intended use;
- safe in use;
- maintained in a safe condition;
- used only by instructed persons;
- provided with suitable safety measures, protective devices and warning signs.

Check your Understanding



When you have completed these questions check out the answers at the back of the book.

Note: more than one multiple choice answer may be correct.

1. All equipment designed to be worn or held to protect against a risk to health and safety is one definition of:
   a. hazard
   b. risk
   c. PPE
   d. IEE.

2. Identify from the list below the potentially most dangerous work activity:
   a. isolating a live circuit
   b. working inside a grain silo
   c. fixing a socket outlet
   d. fixing a luminaire.

3. Some work situations are so potentially hazardous that you **must never:**
   a. work live
   b. work in isolation
   c. work above ground level
   d. work in the dark.

4. A type of safe system to work procedure used in potentially dangerous plant process situations is one definition of:
   a. PPE
   b. safe isolation
   c. permit-to-work
   d. working alone.

5. To avoid back injury when manually lifting heavy weights from ground level workers should:
   a. bend both legs and back
   b. bend legs but keep back straight
   c. keep legs straight but bend back
   d. keep both legs and back straight.

6. For any fire to continue to burn, three components must be present. These are:
   a. fuel, wood, cardboard
   b. petrol, oxygen, bottled gas
   c. flames, fuel, heat
   d. fuel, oxygen, heat.

7. The initial assistance given to a casualty for any sudden injury or illness is one definition of:
   a. assembly point
   b. nominated person
   c. first aider
   d. first aid.

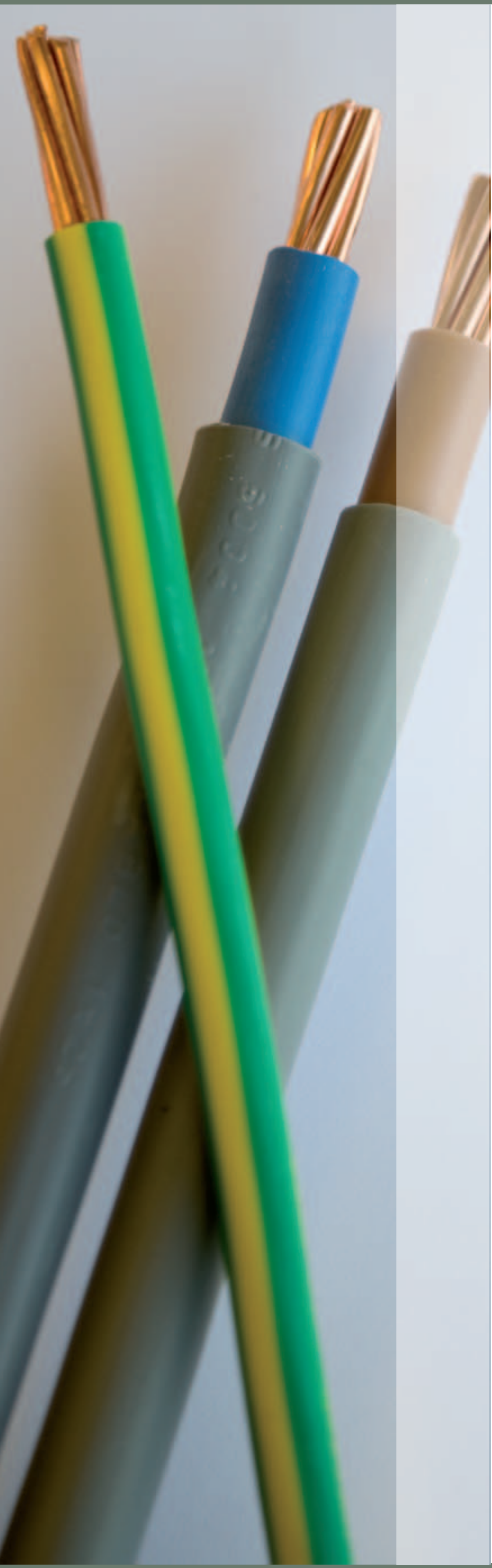
8. Someone who has undertaken a training course in basic medical procedures is one definition of:
   a. assembly point
   b. nominated person
   c. first aider
   d. first aid.

9. Someone who will take charge when someone becomes ill or is injured at work is one definition of:
   a. assembly point
   b. nominated person
   c. first aider
   d. first aid.

10. A place where people come together following a fire alarm sounding is:
    a. assembly point
    b. nominated person
    c. first aider
    d. first aid.

11. A condition caused by a lack of air in the lungs is called:
    a. asphyxiation
    b. bleeding
    c. resuscitation
    d. winded.

12. A ‘near miss’ accident that would easily have led to serious injury or loss of life is called a:
    a. collapse
    b. disaster
    c. dangerous occurrence
    d. hazardous malfunction.



13. When working alone in a confined space there is a risk of:
    a. boredom
    b. becoming trapped
    c. asphyxiation
    d. hazardous malfunction.

14. Consider three types of PPE which you have used at work. For each one, sketch the symbol, state what it is called and what it is used for.

15. State six situations when it is more hazardous to work alone.

16. List four things that a worker can do to reduce the hazard of working at height as recommended by the Regulations.

17. List three of the potential risks when working in confined spaces.

18. Use bullet points to describe a secure system of electrical isolation.

19. Briefly explain what a 'permit-to-work' is and where it would be used.

20. Briefly explain a safe manual handling procedure. Perhaps use bullet points to identify the most important points.

21. Why does any fire continue to burn? How would you put out a fire at work. Highlight the most important personal safety considerations.

22. Why do workers need to go to the assembly point following the sounding of a fire alarm?

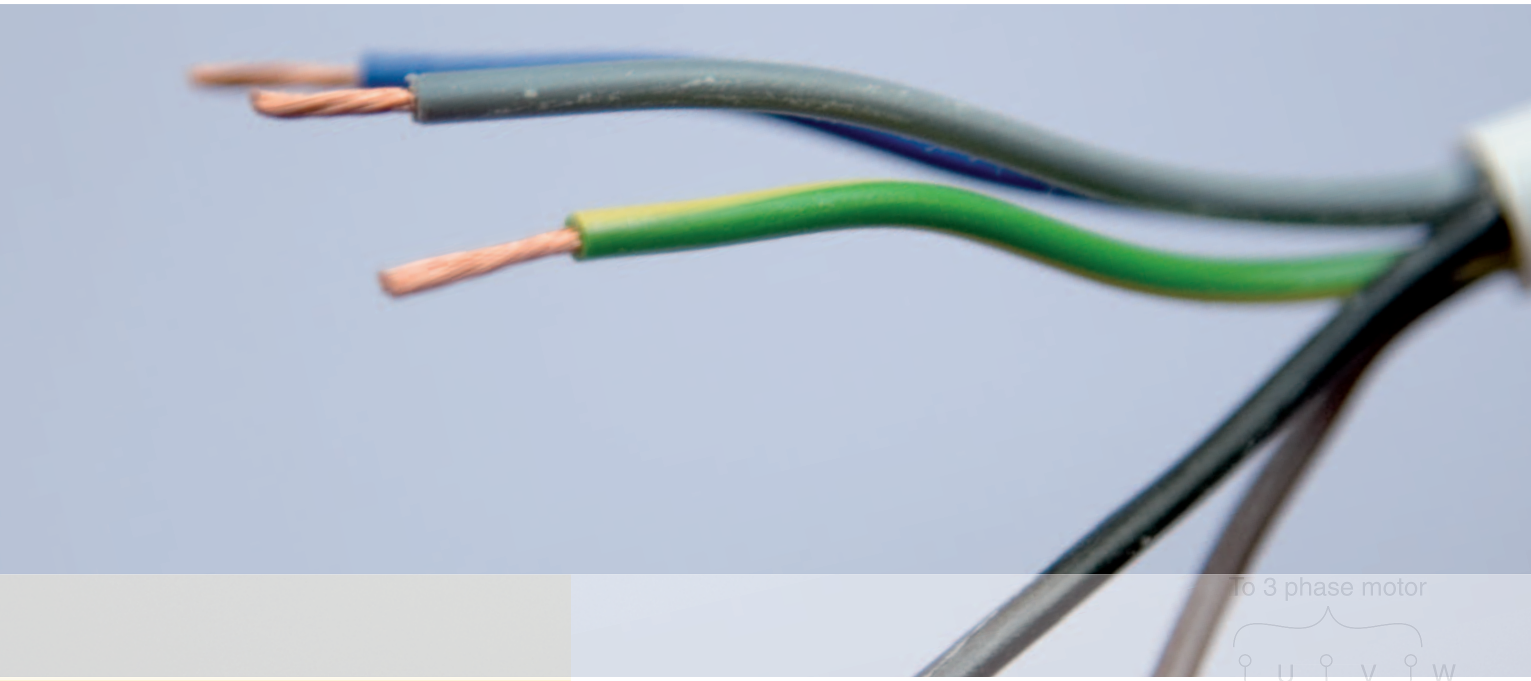
23. Briefly state the first aid provision provided by your employer for his workers.

24. List the procedure to be followed if you were to find a work colleague receiving an electric shock.

25. List five things that we can do to reduce the risk of an electric shock at work.

26. Very briefly describe the meaning of a 'dangerous occurrence' and a 'hazardous malfunction'.

Effective working practices



Unit 1 - Application of health and safety and electrical principles – Outcome 3

Underpinning knowledge: when you have completed this chapter you should be able to:

- state the meaning of team working
- explain employment legislation in terms of rights and responsibilities
- describe how to carry out electrotechnical activities safely and efficiently
- describe the quality standards of ISO 9000 and IiP
- describe the benefits of improving working practice

Effective working practices

Quality systems

When purchasing goods and services these days the customer is increasingly looking for good performance and reliability. Good performance means that a product will do what the customer wants it to do and reliability means that it will perform well for an acceptable period of time. Poor product reliability has been identified as one of the chief causes of customer dissatisfaction. Customers also look for durability and quality. Durability is closely linked to reliability and is a measure of the amount of use a customer receives from the product before it deteriorates.

Definition

Quality generally refers to the level of excellence, but in the business sense it means meeting the customer's expectations regarding performance, reliability and durability.

Quality generally refers to the level of excellence, but in the business sense it means meeting the customer's expectations regarding performance, reliability and durability. Quality is also a customer's subjective impression of a product or service which has been formed by images, advertisements, brand names or reputation. It is inferred from various tangible and intangible aspects of the product or service and may, in part, be due to the reputation built up by the particular company. Marks & Spencer, for example, have built up a formidable reputation from providing good-quality products and services.

In the early 1950s a motorcycle made in Japan was considered inferior to one made in Britain. Today the opposite is true. Japanese companies have used quality to become the leading producers of cars, televisions, photocopiers, radios, watches and cameras. After watching the Japanese capture the major share of these world markets, European and American companies have finally responded to the challenge and introduced the quality standards used so successfully by Japanese industry.

The customer's impression of quality is difficult to pin down but companies can work towards providing a quality product or service by introducing quality systems. There are four fundamental approaches to managing quality: quality control, quality assurance, total quality control and total quality management.

QUALITY CONTROL

Post-production inspection is the traditional form of quality control. It was introduced in the 1920s to improve the quality of mass-produced goods. Statistical sampling of the finished product took place, where, for example, one part in every hundred was tested. If the sample was found to be faulty then all 100 parts would be scrapped. If the sample was found to be acceptable it was assumed that all 100 parts were satisfactory. The problem with quality control is that the focus of attention is on the finished product rather than on the manufacturing process. Quality control never deals with the cause of the problem and, as a result, many defective products roll off the assembly line. Also, any scrapped products become built-in costs which reduce company profits and increase the product price in the shops. Defects and malfunctions have become acceptable within certain tolerance limits, but how often these days do we buy a faulty video, television or camera? Hardly ever, because Japanese industry has moved to a 'zero defects' quality management system.

QUALITY ASSURANCE

Unlike quality control, which focuses upon post-production inspection, quality assurance emphasizes defect prevention through statistical quality control and by monitoring processes to eliminate the production of bad parts.

Each part of a process has procedures written down which have been found to be the most effective. The procedures and standard forms of documentation are followed implicitly to ensure product conformity. These written procedures, used in conjunction with one of the recognized quality standards such as BS 5750 or ISO 9000, have become synonymous with quality assurance.

TOTAL QUALITY CONTROL

Total quality control attempts to expand the quality assurance philosophy to encompass all company activities. It focuses upon the elimination of waste and views the continuous improvement of systems and procedures as essential to an organization's survival. It was slow to be adopted by Western companies because it did not easily fit the organizational structures. Typically, European companies had strong vertical management structures with little opportunity for the workers' voice to be heard. Also, managers themselves tended to work independently of each other and, as a result, efforts to address company-wide issues such as quality were often met with indifference or resistance by the individuals involved.

This attitude is in sharp contrast to that of the Japanese people. They embraced the word 'total' and introduced quality assurance throughout their organizations. They have also introduced a new term 'company-wide quality control' which seeks to achieve continuous quality improvements throughout the entire organization. In the West, this company-wide quality management philosophy is known as 'total quality management'.

TOTAL QUALITY MANAGEMENT

Total quality management makes quality a way of life. It is no longer 'inspected in', 'built in' or even 'organized in': quality is 'managed in' at all levels. It is based upon four principles: meeting the customer's requirements; striving to do error-free work; managing by prevention and measuring the cost of non-quality.

Meeting the customer's requirements is the simple driving force behind total quality management. Many companies focus on meeting the needs of external customers, that is, those who buy the product or service, but this system accords equal importance to internal customers: other workers, supervisors, salesmen and managers all depend upon each other to provide a quality product or service.

Striving to do error-free work means providing a quality product or service first time, every time. A total quality management company strives to create an environment which seeks perfection at all levels of the operation, a corporate attitude which encourages the workforce to ask why an error has occurred, to track down the root cause and then take action to prevent it from happening again.

Managing by prevention means that workers at all levels must be encouraged to anticipate problems and be given the power to make permanent changes to procedures to prevent future errors. As the emphasis on preventing errors grows, the ability to meet a customer's requirements first time, every time, increases.

The cost of non-quality is the money a company would otherwise spend on detecting, correcting and preventing errors. The real benefits of a total quality management system are to be found in the education and training of the individuals, the improvement in contentment expressed by the workforce and the quality of the finished product or service.

BRITISH STANDARD QUALITY

British Standard (BS) 5750 (published in 1979) and the ISO 9000 series, the world standard for quality assurance (published in 1987), have become synonymous with quality assurance and are at the heart of most quality management systems in Europe. They specify the organizational framework for the quality management of systems, for product design, development, production, installation and servicing.

Definition

A *BS 5750/ISO 9000 certificate* provides a framework for a company to establish quality procedures and identify ways of improving its particular product or service. An essential part of any quality system is accurate record-keeping and detailed documentation which ensures that procedures are being followed and producing the desired results.

A **BS 5750/ISO 9000 certificate** provides a framework for a company to establish quality procedures and identify ways of improving its particular product or service. An essential part of any quality system is accurate record-keeping and detailed documentation which ensures procedures are being followed and producing the desired results.

Many electrotechnical companies are now accredited to ISO 9001: 2000 which means all of the company's standard systems and procedures have been documented into an approved quality management system. All procedures are internally audited throughout the year on a rolling programme to make sure that they are working effectively. Once a year an external audit of the systems takes place by an inspector nominated by ISO 9001. If the inspector is assured that the system is being operated effectively, then the company continues to use the quality system for a further year and is entitled to display the Quality Management ISO 9001 logo on vehicles and stationery. This says to potential customers 'we are a serious professional company working to the best standards of our industry and providing a quality service'.

Another quality system dedicated to improving a company's performance through the development of its employees is 'Investors in People'.

Investors in people

Most people would agree that the people an organization employs are the most valuable asset of the business. Conscientious workers are hard to find and difficult to keep. For any business to succeed, everyone must perform to the best of their ability from the youngest trainee to the Managing Director.

Definition

Investors in People is a National Quality Standard that focuses on the needs of the people working within an organization.

It recognizes that a company or business is investing some of its profits in its workforce in order to improve the efficiency and performance of the organization.

Investors in People (IiP) is a National Quality Standard that focuses on the needs of the people working within an organization.

It recognizes that a company or business is investing some of its profits in its workforce in order to improve the efficiency and performance of the organization. The objective is to create an environment where what people can do and are motivated to do, matches what the company needs them to do to improve.

The IiP standard lays down a set of 'principles' and 'indicators' of good practice which the participating organization must meet. The IiP standards are the same for all types of organization, large and small, and recognizes that each company must find its own way of achieving success through the development of its employees.

The IiP was started in 1990 and was driven by a partnership between leading businesses and organizations such as the Confederation of British Industry (CBI), Trade Union Councils (TUC), the Institute of Personnel and Development and the National Training Task Force. It is now a nationally recognized quality standard with over 36,000 qualifying organizations able to display the coveted 'IiP' UK Charter mark on their vehicles and stationery.

For more information on IiP go to www.investorsinpeople.co.uk

The benefits of improving working practices and procedures are:

- improved customer satisfaction,
- improved productivity,
- more efficient use of resources,
- increased profitability for the electrotechnical organization.

Try This

Quality Mark

- Does your Company hold ISO 9000 accreditation or IiP?
- Do they display the logo on company vehicles?
- How does this accreditation affect your work?

Definition

Team working is about working with other people.

TEAM WORKING

Team working is about working with other people, probably with other employees from the company you work for. Working together, helping each other, sharing the load in order to get the job done to a good standard of workmanship in the time allowed. All the separate parts of the job have to be finished and eventually brought together at completion. The team can also be much larger than just those people who work for the same company. We are often dependent on other trades completing their work before we can start ours. The ceiling fitters must install the suspended ceiling before we can drop the recessed modular fluorescent fittings in place and connect them. So, in this case, two different trades are interdependent, working as a team to complete a suspended ceiling job.

A lot of research has been done over the years about what makes a good team and how the relationship of individual members of a team develop over time. One such model is called 'Forming, Storming, Norming and Performing'.

Forming is the first stage of the developing team where the separate individuals come together. They behave as individuals, their responsibility to the team is unclear and they feel confused about what they should be doing. At this stage the team leader will be telling everyone what to do for the collective good because they are all acting as individuals.

Storming is the stage where people begin to see a role for themselves within the team. They will challenge other team members and the team leader, who must become less dominant and more encouraging.

Norming is the stage where team members have generally reached an agreement upon their individual roles and responsibilities to the group. They discuss together and reach agreement upon the best way to perform a task together. The team may share the leadership role.

Performing is the final stage of the development of the team. Everyone knows what they are doing and how their input fits into everyone else's work in the team. The team leaders role is to oversee the project. There is no requirement for instruction or assistance because everyone knows what they have to do to be successful. The individual members support each other, jollying each other along if necessary, giving help when required and generally looking after each other. They have a shared vision and goal.

To work safely in a busy electrotechnical environment alongside other workers we must, in the words of the Health and Safety Act:

- not interfere with or misuse anything provided to protect our health and safety and
- take reasonable care to avoid injury to ourselves and other people as a result of our work activities.

To complete an electrotechnical project successfully, safely and efficiently it will require careful planning. The planning process should involve the following activities:

- Check the drawings, instructions and specifications to make sure that all the specified work is carried out but not more than that which was specified.
- Check that the work area is suitable and safe at all times.
- Create a logical sequence for all work activities and identify tasks remaining to be done before completion of the project.

- Make a list of tools, materials and equipment required to complete the project. Will the project require specialist equipment that needs to be hired from another contractor or specially purchased. Make sure everything is available on site when it is required.
- Make an assessment of the skill that will be required of the electrotechnical staff. Do some work tasks require a specialist's knowledge or skill or someone with greater experience?
- Co-ordinate the work tasks with other trades on site when necessary. For example, a suspended ceiling must be finished before the recessed modular fittings can be installed.
- Make sure that everyone in the electrotechnical team observes all safety procedures and practices.
- When the project is completed make sure that the customer's specified requirements have been met and those of BS 7671 through the process of commissioning, inspection, testing and certification.

Laws protecting people

In Chapter 1 of this book we looked at some of the major pieces of legislation that affect our working environment and some of the main pieces of environmental law. Let us now look at some of the laws and regulations that protect and affect us as individuals, and our human rights and responsibilities.

Employment Rights Act 1996

If you work for a company you are an employee and you will have a number of legal rights under the Employment Rights Act 1996.

As a trainee in the electrotechnical industry you are probably employed by a company and, therefore, are an employee. There are strict guidelines regarding those who are employed and those who are self-employed. Indicators of being employed are listed below:

- You work wholly or mainly for one company and work is centred upon the premises of the company.
- You do not risk your own money.
- You have no business organization such as a storage facility or stock in trade.
- You do not employ anyone.
- You work a set number of hours in a given period and are paid by the hour and receive a weekly or monthly wage or salary.
- Someone else has the right to control what you do at work even if such control is rarely practised.

Indicators of being self-employed are as follows:

- You supply the materials, plant and equipment necessary to do the job.
- You give a price for doing a job and will bear the consequences if your price is too low or something goes wrong.
- You have the right to hire other people who will answer to you and are paid by you to do a job.
- You may be paid an agreed amount for a job regardless of how long it takes or be paid according to some formula, for example, a fee to 'first fix' a row of houses.
- Within an overall deadline, you have the right to decide how and when the work will be done.

The titles 'employed' or 'self-employed' are not defined by statute but have emerged through cases coming before the courts. The above points will help in deciding the precise nature of the working relationship.

Home working is a growing trend which prompts the question as to whether home workers are employed or self-employed. As in any circumstance, it will depend upon the specific conditions of employment, and the points mentioned above may help to decide the question.

The Inland Revenue look with concern at those people who claim to be self-employed but do all or most of their work for one company. There is a free leaflet available from local Inland Revenue Offices, IR 56 – titled 'Employed or Self-Employed' – which will give further guidance if required.

If you are an employee you have a special relationship in law with your employer which entitles you to the following benefits:

- A written statement of the particulars of your employment. It is clearly in the interests of both parties to understand at the outset of their relationship the terms and conditions of employment. The legal relationship between employer and employee is one of contract. Both parties are bound by the agreed terms but the contract need not necessarily be in writing, although contracts of apprenticeship must be in writing.
- The date your employment started.
- The continuity of service, that is, whether employment with a previous employer is to count as part of an employee's continuous service. Continuous service is normally with one employer but there are exceptions, for example, if a business is transferred or taken over or there is a change of partners or trustees. This is important because many employees rights depend on the need to show that he or she has worked for the 'appropriate period' and this is known as '**continuous service**'.
- The job title.
- The normal place from which you work.
- A brief description of your work.

- The hours to be worked.
- Holiday entitlement and holiday pay.
- Sick pay entitlement.
- Pension scheme arrangements.
- The length of notice which an employee is obliged to give and is entitled to receive to terminate his contract of employment.
- Where the employment is not intended to be permanent, the period for which it is expected to continue and the date when it is to end.
- Disciplinary and grievance procedures.
- The rate of pay and frequency, weekly or monthly.
- An itemized pay statement showing
  - the gross amount of the wage or salary;
  - the amounts of any deductions and the purpose for which they have been made. This will normally be tax and National Insurance contributions, but may also include payments to professional bodies or Trade Unions;
  - the net amount of salary being paid.

An **employer** has responsibilities to all employees. Even if the responsibilities are not written down in the contract of employment, they are implied by law. Case histories speak of a relationship of trust, confidence and respect. These responsibilities include:

- The obligation to pay an employee for work done.
- The obligation to treat an employee fairly.
- The obligation to take reasonable care of an employee's health and safety.
- An obligation to provide equal treatment both for men and women.

An **employee** also has responsibilities to his employer. These include:

- Carrying out the tasks for which you are employed with all reasonable skill and care.
- Conducting yourself in such a way as would best serve your employer's interests.
- Carrying out all reasonable orders.

An employee is not expected to carry out any order that is plainly illegal or unreasonable. 'Illegal' is quite easy to define – anything which is against the law, for example, driving a vehicle for which you do not hold a licence or falsifying documents or accounts. 'Unreasonable' is more difficult to define, what is reasonable to one person may be quite unreasonable to another person.

Finally, employees are under a general duty not to disclose confidential information relating to their employer's affairs that they might obtain in the course of their work. Employees are also under a general duty not to assist a competitor of their employer. This is one aspect of the employee's duty to ensure that the relationship between employer and employee is one of trust. Even when an employee has left an employer, confidential information is not to be disclosed.

Health and Safety (First Aid) Regulations 1981

People can suffer an injury or become ill whilst at work. It does not matter whether the injury or illness is caused by the work they do or not, what is important is that they are able to receive immediate attention by a competent person or that an ambulance is called in serious cases. First aid at work covers the arrangements that an employer must make to ensure that this happens. It can save lives and prevent a minor incident becoming a major one.

The Health and Safety (First Aid) Regulations 1981 requires employers to provide '**adequate**' and '**appropriate**' equipment, facilities and personnel to enable first aid to be given to employees if they are injured or become ill at work. What is adequate and appropriate will depend upon the type of work being carried out by the employer. The minimum provision is a suitably stocked first aid box and a competent person to take charge of first aid arrangements.

Employers must consider:

- How many people are employed and, therefore, how many first aid boxes will be required?
- What is the pattern of working hours, shift work, night work, is a 'first aider' available for everyone at all times?
- How many trained 'first aiders' will be required?
- Where will first aid boxes be made available?
- Do employees travel frequently or work alone?
- Will it be necessary to issue personal first aid boxes if employees travel or work away from the company's main premises?
- How hazardous is the work being done – what are the risks?
- Are different employees at different levels of risk?
- What has been the accident or sickness record of staff in the past?

Although there is no legal responsibility for employers to make provision for non-employees, the HSE strongly recommends that they are included in any first aid provision.

We looked at first aid provision at work in the last chapter of this book, Chapter 2.

Data Protection Act 1998

The right to privacy is a fundamental human right and one that many of us take for granted. Most of us, for instance, would not want our medical records freely circulated, and many people are sensitive about revealing their age, religious beliefs, family circumstances or academic qualifications. In the United Kingdom, even the use of name and address files for mail shots is often felt to be an invasion of privacy.

With the advent of large computerized databases it is now possible for sensitive personal information to be stored without the individual's knowledge and accessed by, say, a prospective employer, credit card company or insurance company in order to assess somebody's suitability for employment, credit or insurance.

The Data Protection Act 1984 grew out of public concern about personal privacy in the face of rapidly developing computer technology.

The act covers 'personal data' which is 'automatically processed'. It works in two ways, giving individuals certain rights whilst requiring those who record and use personal information on computer, to be open about that use and to follow proper practices.

The Data Protection Act 1998 was passed in order to implement a European Data Protection Directive. This Directive sets a standard for data protection throughout all the countries of the European Union, and the new act was brought into force in March 2000. The act gives the following useful definitions:

- *Data subjects*: the individuals to whom the personal data relate – we are all data subjects.
- *Data users*: those who control the contents and use a collection of personal data. They can be any type of company or organization, large or small, within the public or private sector.
- *Personal data*: information about living, identifiable individuals. Personal data does not have to be particularly sensitive information and can be as little as a name and address.
- *Automatically processed*: processed by computer or other technology such as document image processing systems. The act does not currently cover information which is held on manual records, for example, in ordinary paper files.

Registered data users must comply with the eight Data Protection principles of good information handling practice contained in the act. Broadly these state that data must be:

1. obtained and processed fairly and lawfully;
2. held for the lawful purposes described in the data users' register entry;
3. used for the purposes and disclosed only to those people described in the register entry;
4. adequate, relevant and not excessive in relation to the purposes for which they are held;
5. accurate and, where necessary, kept up to date;

6. held no longer than is necessary for the registered purpose;
7. accessible to the individual concerned who, where appropriate, has the right to have information about themselves corrected or erased;
8. surrounded by proper security.

EXEMPTIONS FROM THE ACT

- The act does not apply to payroll, pensions and accounts data, nor to names and addresses held for distribution purposes.
- Registration may not be necessary if the data is for personal, family, household or recreational use.
- Data subjects do not have a right to access data if the sole aim of collecting it is for statistical or research purposes.
- Data can be disclosed to the data subject's agent (e.g. lawyer or accountant), to persons working for the data user, and in response to urgent need to prevent injury or damage to health.

Additionally, there are exemptions for special categories, including data held:

- in connection with national security,
- for prevention of crime,
- for the collection of tax or duty.

THE RIGHTS OF DATA SUBJECTS

The Data Protection Act allows individuals to have access to information held about themselves on computer and where appropriate to have it corrected or deleted.

As an individual you are entitled, on making a written request to a data user, to be supplied with a copy of any personal data held about yourself. The data user may charge a fee of up to £10 for each register entry for supplying this information but in some cases it is supplied free.

Usually the request must be responded to within 40 days. If not, you are entitled to complain to the Registrar or apply to the courts for correction or deletion of the data.

Apart from the right to complain to the Registrar, data subjects also have a range of rights which they may exercise in the civil courts. These are:

- Right to compensation for unauthorized disclosure of data.
- Right to compensation for inaccurate data.
- Right of access to data and to apply for rectification or erasure where data is inaccurate.
- Right to compensation for unauthorized access, loss or destruction of data.

For more information see www.dataprotection.gov.uk

Prejudice and discrimination

It is because we are all different to each other that life is so interesting and varied. Our culture is about the way of life that we have, the customs, ideas and experiences that we share and the things that we find acceptable and unacceptable. Different groups of people have different cultures. When people have a certain attitude towards you, or the group of people to which you belong, or a belief about you that is based upon lack of knowledge, understanding or myth, this is prejudice.

When prejudice takes form or action it becomes discrimination and this often results in unfair treatment of people. Regardless of our age, ability, sex, religion, race or sexuality we should all be treated equally and with respect. If we are treated differently because of our differences, we are being discriminated against.

If you are being discriminated against or you see it happening to someone else, you do not have to put up with it. Stay calm and do not retaliate but report it to someone, whoever is the most appropriate person, your supervisor, trainer or manager. If you are a member of a Trade Union you may be able to get help from them if it is an employment related matter.

There are three areas covered by legislation at the moment, these are race, sex and disability. In the next few years the law will change to make it unlawful to discriminate in the training or workplace on the grounds of sexual orientation, religious belief and age.

The Race Relations Act 1976 and Amendment Act 2000

The 1976 Race Relations Act (RRA) made employers liable for acts of racial discrimination committed by their employees in the course of their employment. However, police officers are office holders, not employees, and, therefore, Chief Officers of the police were not liable under the 1976 Act for acts of racial discrimination. The Commission for Racial Equality proposed that the act be extended to include all public services and the amendment came into force in 2000.

It is illegal to discriminate against someone because of their race, colour, nationality, citizenship or ethnic origin.

Institutional racism is when the policies or practices of an organization or institution results in its failure to provide an appropriate service to people because of their colour, culture or ethnic origin. It may mean that the organization or institution does, or does not do something, or that someone is treated less favourably. This includes public services as well as educational institutions.

There are some exceptions in the RRA. It does not apply to certain jobs where people from a certain ethnic or racial background are required for authenticity. These are known as ‘genuine occupational qualifications’ and might apply to actors and restaurants.

The Commission for Racial Equality website can be found at www.cre.gov.uk

Sex Discrimination Act 1975

'Sexism' takes place every time a person, usually a woman, is discriminated against because of their sex. The Sex Discrimination Act of 1975 makes it unlawful to discriminate against people on sexual grounds in areas relating to recruitment, promotion or training. Job advertisements must not discriminate in their language but they can make it clear that they are looking for people of a particular sex. If, though, a person of either sex applies then they must be treated equally and fairly.

There are some exceptions in the Sex Discrimination Act (SDA) known as '**genuine occupational qualifications**' that might apply to artists, models, actors and some parts of the priesthood in the church. Some exceptions can also apply when appointing people to occupations where 'decency' is required, for example, in changing room attendants in swimming pools, gymnasiums, etc., and women are not allowed to work underground.

Sex discrimination is when someone is treated less favourably because of sex or marital status. It includes sexual harassment and unfavourable treatment because a woman is pregnant. Employers fear a high level of absenteeism, often unjustified, from a mother who is trying to juggle the conflicting demands of work and motherhood. This is known as 'direct sex discrimination'.

'Indirect sex discrimination' occurs when a condition of the job is applied to both sexes but excludes or disadvantages a larger proportion of one sex and is not justifiable. For example, an unnecessary height requirement of 180 cm (5′ 10″) would discriminate against women because less women would be able to meet this requirement.

The Equal Opportunities Commission has published a Code of Practice that gives guidance on best practice in the promotion of equality of opportunity in employment. Further information can be found on the SDA website at www.eoc.org.uk

Disability Discrimination Act 1995

There are more than 8.5 million disabled people in the United Kingdom. The Disability Discrimination Act (DDA) makes it unlawful to discriminate against a disabled person in the areas of employment, access to goods and services and buying or renting land or property.

It is now unlawful for employers of more than 15 people to discriminate against employees or job applicants on the grounds of disability. Reasonable adjustments must be made for people with disabilities and employers must ensure that discrimination does not occur in the workplace.

Under Part 111 of the DDA, from 1 October 2004, service providers will have to take reasonable steps to remove, alter or provide reasonable means of avoiding physical features that make it impossible or unreasonably difficult for disabled people to use their services. The duty requires service providers to make '**reasonable**' adjustments to their premises so that disabled people can use the service and are not restricted by physical barriers. If this is not possible then the service should be provided by means of a reasonable alternative such as bringing goods to the disabled person or helping the person to find items.

All organizations which provide goods, facilities or services to the public are covered by the DDA including shops, offices, public houses, leisure facilities, libraries, museums, banks, cinemas, churches and many more, in fact there are few exemptions.

Some service providers will need to incur significant capital expenditure in order to comply with the DDA. What is '**reasonable**' will depend upon the state and condition of the service provider's premises. A subjective standard will apply when determining what is reasonable under the circumstances at a given location. Whether or not an adjustment is reasonable will ultimately be a question of fact for the courts.

Further information can be found on the DDA website at www.disability.gov.uk

The Human Rights Act 1998

The Human Rights Act (HRA) 1998 came into force on 2 October 2000 bringing the European Convention on Human Rights into UK law. It means that if you think your human rights have been violated, you can take action through the British court system, rather than taking it to the European Court of Human Rights. The act makes it unlawful for a '**Public Authority**' to act in a way that goes against any of the rights laid down in the convention unless an Act of Parliament meant that it could not have acted differently. The basic human rights in the Human Rights Act are:

- the right to life,
- the right to a fair trial,
- the right to respect for your private and family life,
- the right to marry,
- the right to liberty and security,
- prohibition of torture,
- prohibition of slavery and forced labour,
- prohibition of discrimination,
- prohibition of the abuse of rights,
- freedom of thought, conscience and religion,
- freedom of expression,
- freedom of assembly and association,
- no punishment without law.

If you feel that your human rights have been violated, you should seek advice from a solicitor. Rights under the act can only be used against a public authority such as the police or a local authority. They cannot be used against a private company. For more information see www.humanrights.gov.uk

Check your Understanding

When you have completed these questions check out the answers at the back of the book.

Note: more than one multiple choice answer may be correct.

1. Meeting the customer's expectations regarding performance, reliability and durability is one definition of:
   a. team working
   b. quality
   c. ISO 9000 system
   d. IiP standard.
2. A system which provides a framework for a company to establish quality procedures that improves its product and services is one definition of:
   a. team working
   b. quality
   c. ISO 9000 system
   d. IiP standard.
3. A system which focuses upon the need of the people working within an organization is one definition of:
   a. team working
   b. quality
   c. ISO 9000 system
   d. IiP standard.
4. Working together with other people to get the job done to the best standards is one definition of:
   a. team working
   b. quality
   c. ISO 9000 system
   d. IiP standard.
5. In five short bullet point statements describe an ISO 9000 quality system.
6. In four short bullet point statements describe the IiP standard.
7. In four bullet point statements describe the benefits of improving working practices and procedures.
8. Give a very brief description or definition of the following words – team working, forming, storming, norming and performing.
9. State eight activities which lead to the successful planning and completion of an electrotechnical project.

10. Make a list of the legal rights which we all have as individuals under the various laws protecting people.

11. Make a list of the responsibilities which we as individuals have in order to ensure other people's rights.

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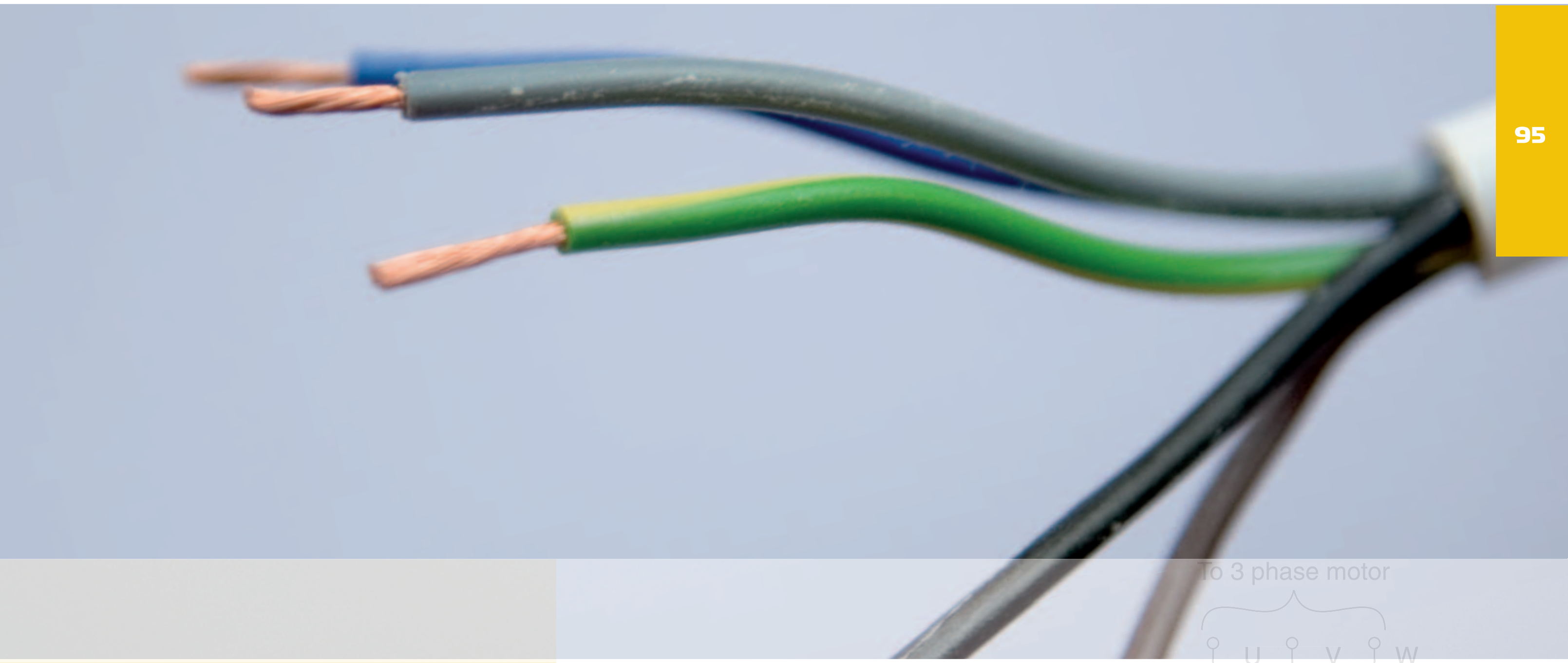
CH 4

Electrical systems and components



Unit 1 – Application of health and safety and electrical principles – Outcome 4

Underpinning knowledge: when you have completed this chapter you should be able to:

- describe resistance and Ohm's Law
- describe magnetism and magnetic circuits
- describe inductance and inductive components
- describe capacitors and their construction
- state the effect of resistance, inductance, capacitance and impedance in a.c. circuits
- describe basic electronic circuits
- describe luminaires and calculate lighting levels

Electrical science

All matter is made up of atoms which arrange themselves in a regular framework within the material. The atom is made up of a central, positively charged nucleus, surrounded by negatively charged electrons. The electrical properties of a material depend largely upon how tightly these electrons are bound to the central nucleus.

Definition

A *conductor* is a material in which the electrons are loosely bound to the central nucleus and are, therefore, free to drift around the material at random from one atom to another.

A **conductor** is a material in which the electrons are loosely bound to the central nucleus and are, therefore, free to drift around the material at random from one atom to another, as shown in Fig. 4.1(a). Materials which are good conductors include copper, brass, aluminium and silver.

Definition

An *insulator* is a material in which the outer electrons are tightly bound to the nucleus and so there are no free electrons to move around the material.

An **insulator** is a material in which the outer electrons are tightly bound to the nucleus and so there are no free electrons to move around the material. Good insulating materials are PVC, rubber, glass and wood.

If a battery is attached to a conductor as shown in Fig. 4.1(b), the free electrons drift purposefully in one direction only. The free electrons close to the positive plate of the battery are attracted to it since unlike charges attract, and the free electrons near the negative plate will be repelled from it. For each electron entering the positive terminal of the battery, one will be ejected from the negative terminal, so the number of electrons in the conductor remains constant.

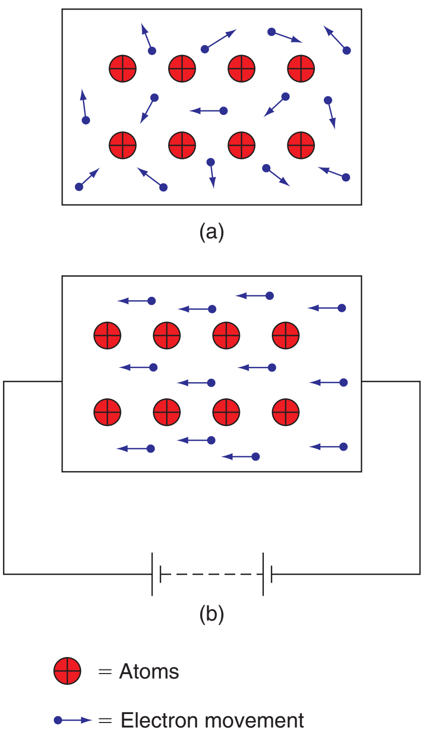


FIGURE 4.1
Atoms and electrons on a material.

This drift of electrons within a conductor is known as an electric *current*, measured in amperes (symbol I). For a current to continue to flow, there must be a complete circuit for the electrons to move around. If the circuit is broken by opening a switch, for example, the electron flow and therefore the current will stop immediately.

To cause a current to flow continuously around a circuit, a driving force is required, just as a circulating pump is required to drive water around a central heating system. This driving force is the *electromotive force* (abbreviated as emf). Each time an electron passes through the source of emf, more energy is provided to send it on its way around the circuit.

An emf is always associated with energy conversion, such as chemical to electrical in batteries and mechanical to electrical in generators. The energy introduced into the circuit by the emf is transferred to the load terminals by the circuit conductors. The *potential difference* (abbreviated as p.d.) is the change in energy levels measured across the load terminals. This is also called the volt drop or terminal voltage, since emf and p.d. are both measured in volts. Every circuit offers some opposition to current flow, which we call the circuit *resistance*, measured in ohms (symbol Ω), to commemorate the famous German physicist George Simon Ohm, who was responsible for the analysis of electrical circuits.

Ohm's law

Definition

Ohm's law, which says that the current passing through a conductor under constant temperature conditions is proportional to the potential difference across the conductor.

In 1826, George Ohm published details of an experiment he had done to investigate the relationship between the current passing through and the potential difference between the ends of a wire. As a result of this experiment, he arrived at a law, now known as **Ohm's law**, which says that the current passing through a conductor under constant temperature conditions is proportional to the potential difference across the conductor. This may be expressed mathematically as:

$$V = I \times R \text{ (V)}$$

Transposing this formula, we also have:

$$I = \frac{V}{R} \text{ (A)} \quad \text{and} \quad R = \frac{V}{I} \text{ }(\Omega)$$

Example 1

An electric heater, when connected to a 230 V supply, was found to take a current of 4 A. Calculate the element resistance.

$$R = \frac{V}{I}$$

$$\therefore \; R = \frac{230 \text{ V}}{4 \text{ A}} = 57.5 \; \Omega$$

Example 2

The insulation resistance measured between phase conductors on a 400 V supply was found to be 2 MΩ. Calculate the leakage current.

$$I = \frac{V}{R}$$

$$\therefore I = \frac{400 \text{ V}}{2 \times 10^6 \; \Omega} = 200 \times 10^{-6} \text{ A} = 200 \; \mu\text{A}$$

Example 3

When a 4 Ω resistor was connected across the terminals of an unknown d.c. supply, a current of 3 A flowed. Calculate the supply voltage.

$$V = I \times R$$

$$\therefore \; V = 3 \text{ A} \times 4 \; \Omega = 12 \text{ V}$$

Resistivity

The resistance or opposition to current flow varies for different materials, each having a particular constant value. If we know the resistance of, say, 1 m of a material, then the resistance of 5 m will be five times the resistance of 1 m.

Definition

The *resistivity* (symbol ρ – the Greek letter 'rho') of a material is defined as the resistance of a sample of unit length and unit cross-section.

The **resistivity** (symbol ρ – the Greek letter 'rho') of a material is defined as the resistance of a sample of unit length and unit cross-section. Typical values are given in Table 4.1. Using the constants for a particular material we can calculate the resistance of any length and thickness of that material from the equation.

$$R = \frac{\rho l}{a} \ (\Omega)$$

where

ρ = the resistivity constant for the material (Ω m)

l = the length of the material (m)

a = the cross-sectional area of the material (m^2).

Key Fact

Resistance

- If the length is doubled, resistance is doubled.
- If the thickness is doubled, resistance is halved.

Table 4.1 gives the resistivity of silver as $16.4 \times 10^{-9}\,\Omega$m, which means that a sample of silver 1 m long and 1 m in cross-section will have a resistance of $16.4 \times 10^{-9}\,\Omega$.

Example 1

Calculate the resistance of 100 m of copper cable of 1.5 mm^2 cross-sectional area if the resistivity of copper is taken as $17.5 \times 10^{-9}\,\Omega$m.

$$R = \frac{\rho l}{a} \ (\Omega)$$

$$\therefore R = \frac{17.5 \times 10^{-9}\,\Omega \times 100 \text{ m}}{1.5 \times 10^{-6} \text{m}^2} = 1.16\ \Omega$$

Example 2

Calculate the resistance of 100 m of aluminium cable of 1.5 mm^2 cross-sectional area if the resistivity of aluminium is taken as $28.5 \times 10^{-9}\,\Omega$m.

$$R = \frac{\rho l}{a} \ (\Omega)$$

$$\therefore R = \frac{28.5 \times 10^{-9}\,\Omega\text{m} \times 100 \text{ m}}{1.5 \times 10^{-6} \text{m}^2} = 1.9\ \Omega$$

The above examples show that the resistance of an aluminium cable is some 60% greater than a copper conductor of the same length and cross-section.

Table 4.1 Resistivity Values

Material	Resistivity (Ω m)
Silver	16.4×10^{-9}
Copper	17.5×10^{-9}
Aluminium	28.5×10^{-9}
Brass	75.0×10^{-9}
Iron	100.0×10^{-9}

Therefore, if an aluminium cable is to replace a copper cable, the conductor size must be increased to carry the rated current as given by the tables in Appendix 4 of the *IEE Regulations* and Appendix 6 of the *On Site Guide*.

The other factor which affects the resistance of a material is the temperature, and we will consider this next.

Temperature coefficient

The resistance of most materials changes with temperature. In general, conductors increase their resistance as the temperature increases and insulators decrease their resistance with a temperature increase. Therefore, an increase in temperature has a bad effect on the electrical properties of a material.

Each material responds to temperature change in a different way, and scientists have calculated constants for each material which are called the *temperature coefficient of resistance* (symbol α – the Greek letter 'alpha'). Table 4.2 gives some typical values.

Using the constants for a particular material and substituting values into the following formulae the resistance of a material at different temperatures may be calculated. For a temperature increase from 0°C

$$R_t = R_0(1 + \alpha t)\ (\Omega)$$

Table 4.2 Temperature Coefficient Values

Material	Temperature coefficient (Ω/Ω°C)
Silver	0.004
Copper	0.004
Aluminium	0.004
Brass	0.001
Iron	0.006

where

R_t = the resistance at the new temperature t°C

R_0 = the resistance at 0°C

α = the temperature coefficient for the particular material.

For a temperature increase between two intermediate temperatures above 0°C:

$$\frac{R_1}{R_2} = \frac{(1+\alpha t_1)}{(1+\alpha t_2)}$$

where

R_1 = the resistance at the original temperature

R_2 = the resistance at the final temperature

α = the temperature coefficient for the particular material.

If we take a 1 Ω resistor of, say, copper, and raise its temperature by 1°C, the resistance will increase to 1.004 Ω. This increase of 0.004 Ω is the temperature coefficient of the material.

Example 1

The field winding of a d.c. motor has a resistance of 100 Ω at 0°C. Determine the resistance of the coil at 20°C if the temperature coefficient is 0.004 Ω/Ω°C.

$$\begin{aligned} R_t &= R_0\,(1+\alpha t)\ (\Omega) \\ \therefore R_t &= 100\ \Omega\,(1+0.004\ \Omega/\Omega°\text{C}\times 20°\text{C}) \\ R_t &= 100\ \Omega\,(1+0.08) \\ R_t &= 108\ \Omega \end{aligned}$$

Example 2

The field winding of a shunt generator has a resistance of 150 Ω at an ambient temperature of 20°C. After running for some time the mean temperature of the generator rises to 45°C. Calculate the resistance of the winding at the higher temperature if the temperature coefficient of resistance is 0.004 Ω/Ω°C.

$$\frac{R_1}{R_2} = \frac{(1+\alpha t_1)}{(1+\alpha t_2)}$$

$$\frac{150\ \Omega}{R_2} = \frac{1+0.004\ \Omega/\Omega°\text{C}\times 20°\text{C}}{1+0.004\ \Omega/\Omega°\text{C}\times 45°\text{C}}$$

$$\frac{150\ \Omega}{R_2} = \frac{1.08}{1.18}$$

$$\therefore R_2 = \frac{150\ \Omega\times 1.18}{1.08} = 164\ \Omega$$

It is clear from the last two sections that the resistance of a cable is affected by length, thickness, temperature and type of material. Since Ohm's law tells us that current is inversely proportional to resistance, these factors must also influence the current carrying capacity of a cable. The tables of current ratings in Appendix 4 of the IEE Regulations contain correction factors so that current ratings may be accurately determined under defined installation conditions. Cable selection is considered in Chapter 7.

Resistors

In an electrical circuit resistors may be connected in series, in parallel, or in various combinations of series and parallel connections.

Key Fact

Resistance

When the temperature increases:

- conductor resistance increases
- insulator resistance decreases.

SERIES-CONNECTED RESISTORS

In any series circuit a current I will flow through all parts of the circuit as a result of the potential difference supplied by a battery V_T. Therefore, we say that in a series circuit the current is common throughout that circuit.

When the current flows through each resistor in the circuit, R_1, R_2 and R_3 for example in Fig. 4.2, there will be a voltage drop across that resistor whose value will be determined by the values of I and R, since from Ohm's law $V = I \times R$. The sum of the individual voltage drops, V_1, V_2 and V_3 for example in Fig. 4.2, will be equal to the total voltage V_T.

We can summarize these statements as follows. For any series circuit, I is common throughout the circuit and,

$$V_T = V_1 + V_2 + V_3 \tag{4.1}$$

Let us call the total circuit resistance R_T. From Ohm's law we know that $V = I \times R$ and therefore

$$\begin{aligned} \text{Total voltage } V_T &= I \times R_T \\ \text{Voltage drop across } R_1 \text{ is } V_1 &= I \times R_1 \\ \text{Voltage drop across } R_2 \text{ is } V_2 &= I \times R_2 \\ \text{Voltage drop across } R_3 \text{ is } V_3 &= I \times R_3 \end{aligned} \tag{4.2}$$

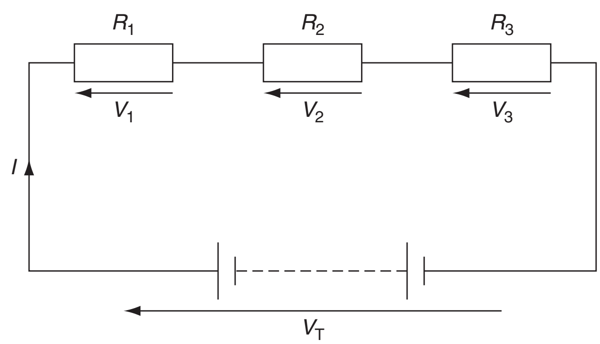


FIGURE 4.2
A series circuit.

We are looking for an expression for the total resistance in any series circuit and, if we substitute Equations (4.2) into Equation (4.1) we have:

$$V_T = V_1 + V_2 + V_3$$
$$\therefore\ I \times R_T = I \times R_1 + I \times R_2 + I \times R_3$$

Now, since I is common to all terms in the equation, we can divide both sides of the equation by I. This will cancel out I to leave us with an expression for the circuit resistance:

$$R_T = R_1 + R_2 + R_3$$

Note that the derivation of this formula is given for information only. Craft students need only state the expression $R_T = R_1 + R_2 + R_3$ for series connections.

PARALLEL-CONNECTED RESISTORS

In any parallel circuit, as shown in Fig. 4.3, the same voltage acts across all branches of the circuit. The total current will divide when it reaches a resistor junction, part of it flowing in each resistor. The sum of the individual currents, I_1, I_2 and I_3 for example in Fig. 4.3, will be equal to the total current I_T.

We can summarize these statements as follows. For any parallel circuit, V is common to all branches of the circuit and,

$$I_T = I_1 + I_2 + I_3 \tag{4.3}$$

Let us call the total resistance R_T.

From Ohm's law we know, that $I = \dfrac{V}{R}$, and therefore

$$\begin{aligned} \text{the total current } I_T &= \frac{V}{R_T} \\ \text{the current through } R_1 \text{ is } I_1 &= \frac{V}{R_1} \\ \text{the current through } R_2 \text{ is } I_2 &= \frac{V}{R_2} \\ \text{the current through } R_3 \text{ is } I_3 &= \frac{V}{R_3} \end{aligned} \tag{4.4}$$

Key Fact

Series resistors

The total resistance in a series circuit can be found from $R_T = R_1 + R_2$

We are looking for an expression for the equivalent resistance R_T in any *parallel* circuit and, if we substitute Equations (4.4) into Equation (4.3) we have:

$$I_T = I_1 + I_2 + I_3$$
$$\therefore\ \frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

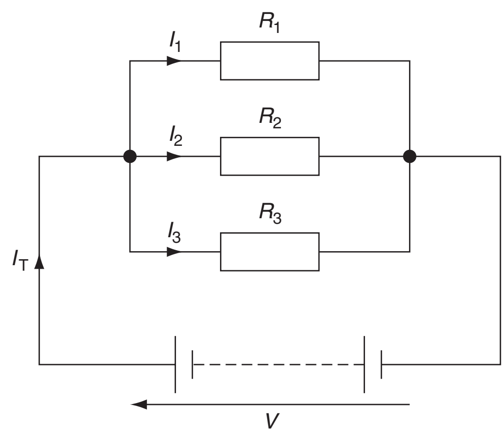


FIGURE 4.3
A parallel circuit.

Now, since V is common to all terms in the equation, we can divide both sides by V, leaving us with an expression for the circuit resistance:

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

Note that the derivation of this formula is given for information only. Craft students need only state the expression $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$ for parallel connections.

Example

Three 6 Ω resistors are connected (a) in series (see Fig. 4.4) and (b) in parallel (see Fig. 4.5), across a 12 V battery. For each method of connection, find the total resistance and the values of all currents and voltages.

For any series connection:

$$R_T = R_1 + R_2 + R_3$$
$$\therefore R_1 = 6\ \Omega + 6\ \Omega + 6\ \Omega = 18\ \Omega$$

$$\text{Total current } I_T = \frac{V}{R_T}$$
$$\therefore I_T = \frac{12\ \text{V}}{18\ \Omega} = 0.67\ \text{A}$$

The voltage drop across R_1 is:

$$V_1 = I \times R_1$$
$$\therefore V_1 = 0.67\ \text{A} \times 6\ \Omega = 4\ \text{V}$$

The voltage drop across R_2 is:

$$V_2 = I \times R_2$$
$$\therefore V_2 = 0.67\ \text{A} \times 6\ \Omega = 4\ \text{V}$$

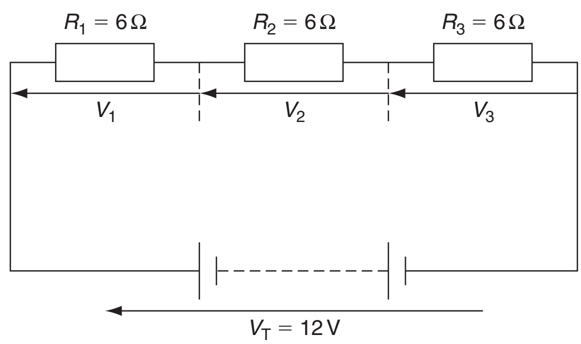


FIGURE 4.4
Resistors in series.

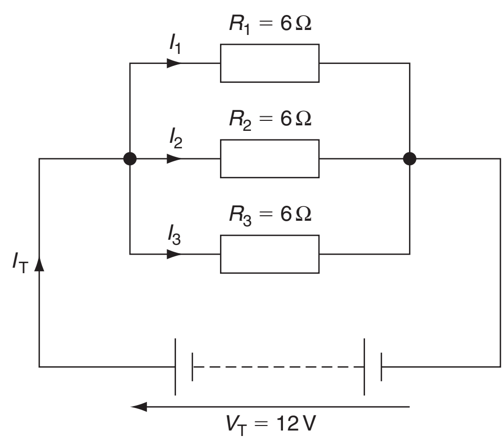


FIGURE 4.5
Resistors in parallel.

The voltage drop across R_3 is:

$$V_3 = I \times R_3$$

$$\therefore V_3 = 0.67\text{ A} \times 6\ \Omega = 4\text{ V}$$

For any parallel connection:

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

$$\therefore \frac{1}{R_T} = \frac{1}{6\ \Omega} + \frac{1}{6\ \Omega} + \frac{1}{6\ \Omega}$$

$$\frac{1}{R_T} = \frac{1+1+1}{6\ \Omega} = \frac{3}{6\ \Omega}$$

$$R_T = \frac{6\ \Omega}{3} = 2\ \Omega$$

$$\text{Total current } I_T = \frac{V}{R_T}$$

$$\therefore I_T = \frac{12\text{ V}}{2\ \Omega} = 6\text{ A}$$

The current flowing through R_1 is:

$$I_1 = \frac{V}{R_1}$$

$$\therefore I_1 = \frac{12\text{ V}}{6\ \Omega} = 2\text{ A}$$

The current flowing through R_2 is:

$$I_2 = \frac{V}{R_2}$$

$$\therefore I_2 = \frac{12\text{ V}}{6\ \Omega} = 2\text{ A}$$

The current flowing through R_3 is:

$$I_3 = \frac{V}{R_3}$$

$$\therefore I_3 = \frac{12\text{ V}}{6\ \Omega} = 2\text{ A}$$

SERIES AND PARALLEL COMBINATIONS

The most complex arrangement of series and parallel resistors can be simplified into a single equivalent resistor by combining the separate rules for series and parallel resistors.

Example 1

Resolve the circuit shown in Fig. 4.6 into a single resistor and calculate the potential difference across each resistor.

By inspection, the circuit contains a parallel group consisting of R_3, R_4 and R_5, and a series group consisting of R_1 and R_2 in series with the equivalent resistor for the parallel branch.

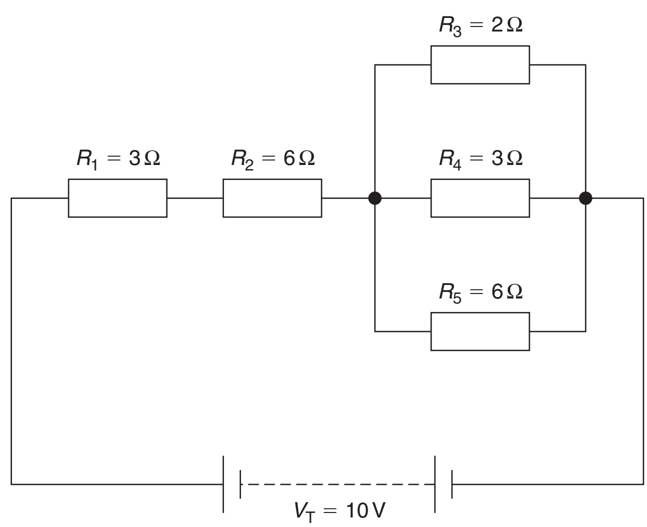


FIGURE 4.6
A series/parallel circuit.

Consider the parallel group. We will label this group R_P. Then,

$$\frac{1}{R_P} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_P} = \frac{1}{2\ \Omega} + \frac{1}{3\ \Omega} + \frac{1}{6\ \Omega}$$

$$\frac{1}{R_P} = \frac{3+2+1}{6\ \Omega} = \frac{6}{6\ \Omega}$$

$$R_P = \frac{6\ \Omega}{6} = 1\,\Omega$$

Figure 4.6 may now be represented by the more simple equivalent circuit is shown in Fig. 4.7

Since all resistors are now in series,

$$R_T = R_1 + R_2 + R_P$$
$$\therefore R_T = 3\ \Omega + 6\ \Omega + 1\ \Omega = 10\ \Omega$$

Thus, the circuit may be represented by a single equivalent resistor of value $10\,\Omega$ as shown in Fig. 4.8. The total current flowing in the circuit may be found by using Ohm's law:

$$I_T = \frac{V_T}{R_T} + \frac{10\ \text{V}}{10\ \Omega} = 1\ \text{A}$$

Key Fact

Parallel Resistors
The total resistance in a parallel circuit can be found from $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

The potential differences across the individual resistors are:

$$V_1 = I \times R_1 = 1\text{A} \times 3\Omega = 3\text{V}$$
$$V_2 = I \times R_2 = 1\text{A} \times 6\Omega = 6\text{V}$$
$$V_P = I \times R_P = 1\ \text{A} \times 1\Omega = 1\text{V}$$

Since the same voltage acts across all branches of a parallel circuit the same p.d. of 1 V will exist across each resistor in the parallel branch R_3, R_4 and R_5.

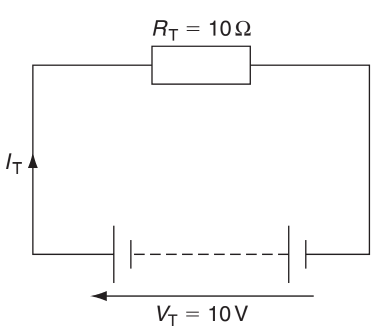


FIGURE 4.8
Single equivalent resistor for Fig. 4.6.

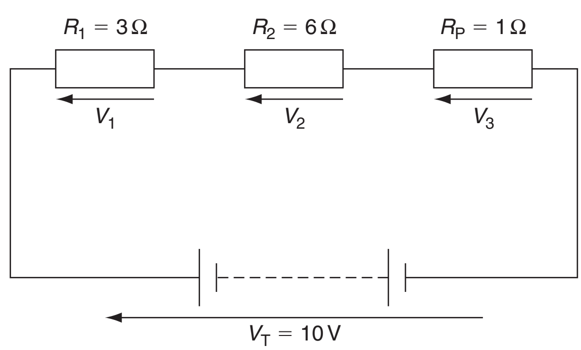


FIGURE 4.7
Equivalent series circuit.

Example 2

Determine the total resistance and the current flowing through each resistor for the circuit shown in Fig. 4.9.

By inspection, it can be seen that R_1 and R_2 are connected in series while R_3 is connected in parallel across R_1 and R_2. The circuit may be more easily understood if we redraw it as in Fig. 4.10.

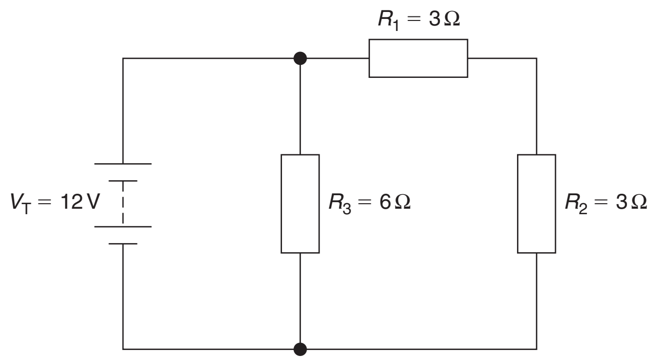


FIGURE 4.9
A series/parallel circuit for Example 2.

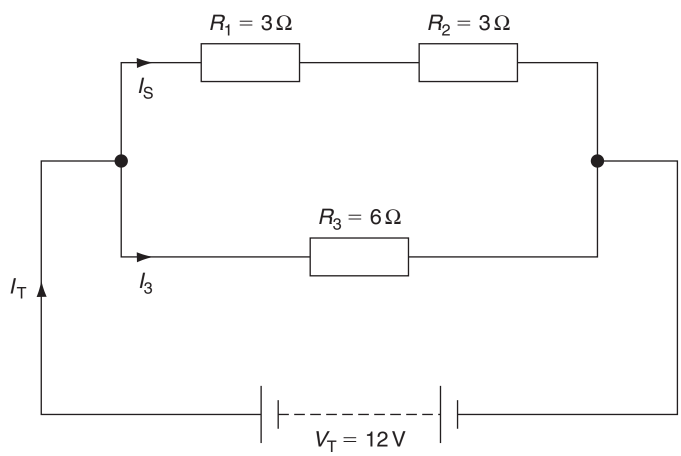


FIGURE 4.10
Equivalent circuit for Example 2.

For the series branch, the equivalent resistor can be found from:

$$R_S = R_1 + R_2$$
$$\therefore R_S = 3\ \Omega + 3\ \Omega = 6\ \Omega$$

Figure 4.10 may now be represented by a more simple equivalent circuit, as in Fig. 4.11.

Since the resistors are now in parallel, the equivalent resistance may be found from:

$$\frac{1}{R_T} = \frac{1}{R_S} + \frac{1}{R_3}$$

$$\therefore \frac{1}{R_T} = \frac{1}{6\ \Omega} + \frac{1}{6\ \Omega}$$

$$\frac{1}{R_T} = \frac{1+1}{6\ \Omega} = \frac{2}{6\ \Omega}$$

$$R_T = \frac{6\ \Omega}{2} = 3\ \Omega$$

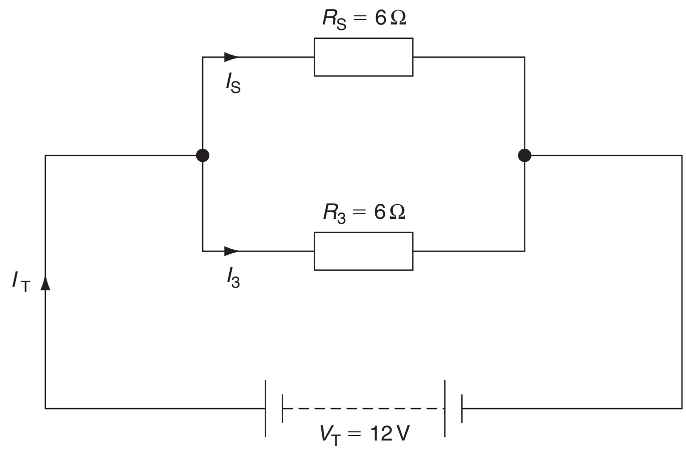


FIGURE 4.11
Simplified equivalent circuit for Example 2.

The total current is:

$$I_T = \frac{V}{R_T} = \frac{12\ \text{V}}{3\ \Omega} = 4\ \text{A}$$

Let us call the current flowing through resistor R_3 I_3:

$$\therefore I_3 = \frac{V}{R_3} = \frac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$$

Let us call the current flowing through both resistors R_1 and R_2, as shown in Fig. 4.10, I_S:

$$\therefore I_S = \frac{V}{R_S} = \frac{12\ \text{V}}{6\ \Omega} = 2\ \text{A}$$

Power and energy

POWER

Power is the rate of doing work and is measured in watts.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}\ (\text{W})$$

In an electrical circuit:

$$\text{Power} = \text{Voltage} \times \text{Current (W)} \qquad (4.5)$$

Now from Ohm's law:

$$\text{Voltage} = I \times R(\text{V}) \qquad (4.6)$$

$$\text{Current} = \frac{V}{R}\ (\text{A}) \qquad (4.7)$$

Substituting Equation (4.6) into Equation (4.5), we have:

$$\text{Power} = (I \times R) \times \text{Current} = I^2 \times R \text{ (W)}$$

and substituting Equation (4.7) into Equation (4.5), we have:

$$\text{Power} = \text{Voltage} \times \frac{V}{R} = \frac{V^2}{R} \text{ (W)}$$

We can find the power of a circuit by using any of the three formulae:

$$P = V \times I, \quad P = I^2 \times R, \quad P = \frac{V^2}{R}$$

ENERGY

Energy is a concept which engineers and scientists use to describe the ability to do work in a circuit or system.

$$\begin{aligned} \text{Energy} &= \text{Power} \times \text{Time} \\ \text{but, since Power} &= \text{Voltage} \times \text{Current} \\ \text{then Energy} &= \text{Voltage} \times \text{Current} \times \text{Time} \end{aligned}$$

The SI unit of energy is the joule, where time is measured in seconds. For practical electrical installation circuits this unit is very small and therefore the kilowatt-hour (kWh) is used for domestic and commercial installations. Electricity Board meters measure 'units' of electrical energy, where each 'unit' is 1 kWh. So,

$$\begin{aligned} \text{Energy in joules} &= \text{Voltage} \times \text{Current} \\ &\quad \times \text{Time in seconds} \\ \text{Energy in kWh} &= \text{kW} \times \text{Time in hours} \end{aligned}$$

Example 1

A domestic immersion heater is switched on for 40 minutes and takes 15 A from a 200 V supply. Calculate the energy used during this time.

$$\text{Power} = \text{Voltage} \times \text{Current}$$

$$\text{Power} = 200\text{ V} \times 15\text{ A} = 3000\text{ W or } 3\text{ kW}$$

$$\text{Energy} = \text{kW} \times \text{Time in hours}$$

$$\text{Energy} = 3\text{ kW} \times \frac{40\text{ min}}{60\text{ min/h}} = 2\text{ kWh}$$

This immersion heater uses 2 kWh in 40 minutes, or 2 'units' of electrical energy every 40 minutes.

Example 2

Two 50 Ω resistors may be connected to a 200 V supply. Determine the power dissipated by the resistors when they are connected (a) in series, (b) each resistor separately connected and (c) in parallel.

For (a), the equivalent resistance when resistors are connected in series is given by:

$$R_T = R_1 + R_2$$
$$\therefore R_T = 50\ \Omega + 50\ \Omega = 100\ \Omega$$

$$\text{Power} = \frac{V^2}{R_T}\ (\text{W})$$

$$\therefore \text{Power} = \frac{200\ \text{V} \times 200\ \text{V}}{100\ \Omega} = 400\ \text{W}$$

For (b), each resistor separately connected has a resistance of 50 Ω.

$$\text{Power} = \frac{V^2}{R}\ (\text{W})$$

$$\therefore \text{Power} = \frac{200\ \text{V} \times 200\ \text{V}}{50\ \Omega} = 800\ \text{W}$$

For (c), the equivalent resistance when resistors are connected in parallel is given by:

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

$$\therefore \frac{1}{R_T} = \frac{1}{50\ \Omega} + \frac{1}{50\ \Omega}$$

$$\frac{1}{R_T} = \frac{1+1}{50\ \Omega} = \frac{2}{50\ \Omega}$$

$$R_T = \frac{50\ \Omega}{2} = 25\ \Omega$$

$$\text{Power} = \frac{V^2}{R_T}\ (\text{W})$$

$$\therefore \text{Power} = \frac{200\ \text{V} \times 200\ \text{V}}{25\ \Omega} = 1600\ \text{W}$$

This example shows that by connecting resistors together in different combinations of series and parallel connections, we can obtain various power outputs: in this example, 400, 800 and 1600 W. This theory finds a practical application in the three heat switch used to control a boiling ring or cookes hotplate.

Alternating waveforms

The supply which we obtain from a car battery is a unidirectional or d.c. supply, whereas the mains electricity supply is alternating or a.c. (see Fig. 4.12).

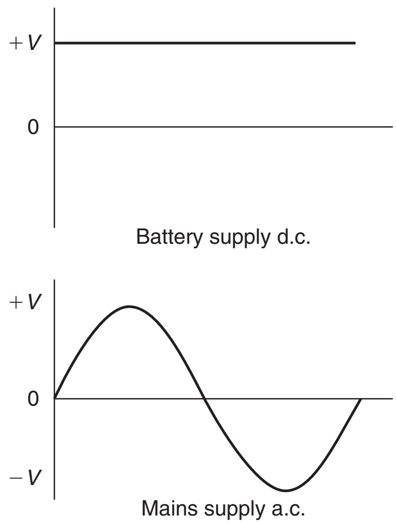


FIGURE 4.12
Unidirectional and alternating supply.

Most electrical equipment makes use of alternating current supplies, and for this reason a knowledge of alternating waveforms and their effect on resistive, capacitive and inductive loads is necessary for all practising electricians.

When a coil of wire is rotated inside a magnetic field a voltage is induced in the coil. The induced voltage follows a mathematical law known as the sinusoidal law and, therefore, we can say that a sine wave has been generated. Such a waveform has the characteristics displayed in Fig. 4.13.

In the United Kingdom we generate electricity at a frequency of 50 Hz and the time taken to complete each cycle is given by:

$$T = \frac{1}{f}$$

$$\therefore T = \frac{1}{50\,\text{Hz}} = 0.02\,\text{s}$$

An alternating waveform is constantly changing from zero to a maximum, first in one direction, then in the opposite direction, and so the instantaneous values of the generated voltage are always changing. A useful description of the electrical effects of an a.c. waveform can be given by the maximum, average and rms values of the waveform.

The maximum or peak value is the greatest instantaneous value reached by the generated waveform. Cable and equipment insulation levels must be equal to or greater than this value.

The average value is the average over one half-cycle of the instantaneous values as they change from zero to a maximum and can be found from the following formula applied to the sinusoidal waveform shown in Fig. 4.14:

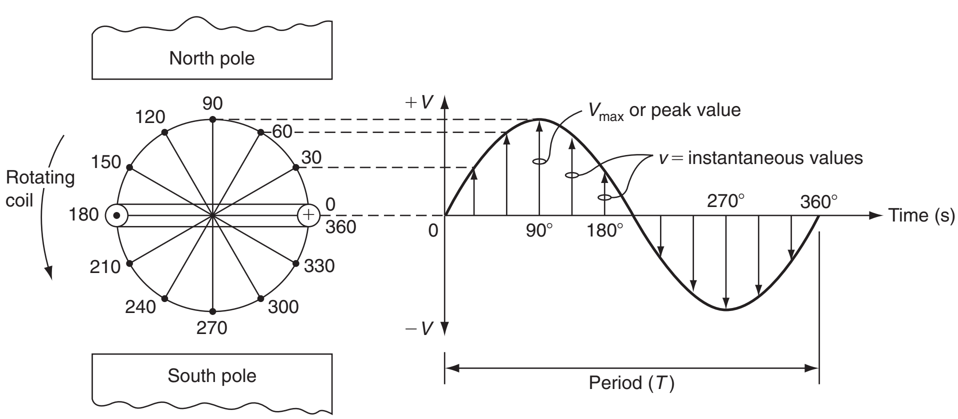


FIGURE 4.13
Characteristics of a sine wave.

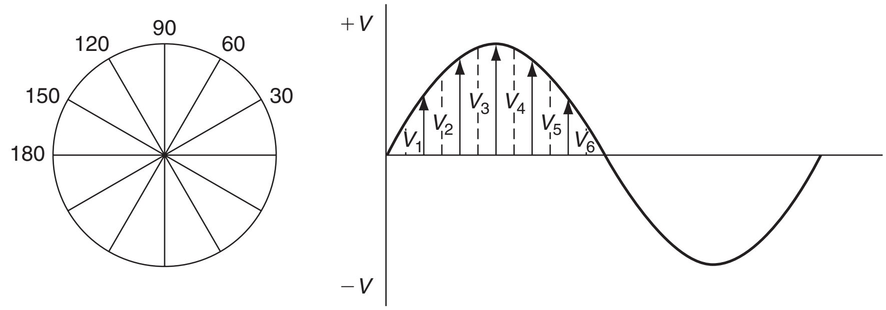


FIGURE 4.14
Sinusoidal waveform showing instantaneous values of voltage.

$$V_{av} = \frac{V_1 + V_2 + V_3 + V_4 + V_5 + V_6}{6}$$
$$= 0.637 V_{max}$$

For any sinusoidal waveform the average value is equal to 0.637 of the maximum value.

Key Fact

a.c. waveforms

- Maximum value = V_{max}
- Average value = $0.637 V_{max}$
- RMS value = $0.7071 V_{max}$

The rms value is the square root of the mean of the individual squared values and is the value of an a.c. voltage which produces the same heating effect as a d.c. voltage. The value can be found from the following formula applied to the sinusoidal waveform shown in Fig. 4.14.

$$V_{rms} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + V_5^2 + V_6^2}{6}}$$
$$= 0.7071\ V_{max}$$

For any sinusoidal waveform the rms value is equal to 0.7071 of the maximum value.

Example

The sinusoidal waveform applied to a particular circuit has a maximum value of 325.3V. Calculate the average and rms value of the waveform.

$$\text{Average value } V_{av} = 0.637 \times V_{max}$$
$$\therefore V_{av} = 0.637 \times 325.3 = 207.2\ \text{V}$$
$$\text{rms value } V_{rms} = 0.7071 \times V_{max}$$
$$V_{rms} = 0.7071 \times 325.3 = 230\ \text{V}$$

When we say that the main supply to a domestic property is 230V we really mean 230V rms. Such a waveform has an average value of about 207.2V and a maximum value of almost 325.3V but because the rms value gives the d.c. equivalent value we almost always give the rms value without identifying it as such.

Magnetism

The Greeks knew as early as 600 BC that a certain form of iron ore, now known as magnetite or lodestone, had the property of attracting small pieces of iron. Later, during the Middle Ages, navigational compasses were made using the magnetic properties of lodestone. Small pieces of lodestone attached to wooden splints floating in a bowl of water always came to rest pointing in a north–south direction. The word lodestone is derived from an old English word meaning 'the way', and the word magnetism is derived from Magnesia, the place where magnetic ore was first discovered.

Iron, nickel and cobalt are the only elements which are attracted strongly by a magnet. These materials are said to be *ferromagnetic*. Copper, brass, wood, PVC and glass are not attracted by a magnet and are, therefore, described as *non-magnetic*.

SOME BASIC RULES OF MAGNETISM

1. Lines of magnetic flux have no physical existence, but they were introduced by Michael Faraday (1791–1867) as a way of explaining the magnetic energy existing in space or in a material. They help us to visualize and explain the magnetic effects. The symbol used for magnetic flux is the Greek letter Φ (phi) and the unit of magnetic flux is the weber (symbol Wb), pronounced 'veber', to commemorate the work of the German physicist Wilhelm Weber (1804–1891).
2. Lines of magnetic flux always form closed loops.
3. Lines of magnetic flux behave like stretched elastic bands, always trying to shorten themselves.
4. Lines of magnetic flux never cross over each other.
5. Lines of magnetic flux travel along a magnetic material and always emerge out of the 'north pole' end of the magnet.
6. Lines of magnetic flux pass through space and non-magnetic materials undisturbed.
7. The region of space through which the influence of a magnet can be detected is called the *magnetic field* of that magnet.
8. The number of lines of magnetic flux within a magnetic field is a measure of the flux density. Strong magnetic fields have a high flux density. The symbol used for flux density is B, and the unit of flux density is the tesla (symbol T), to commemorate the work of the Croatian-born American physicist Nikola Tesla (1857–1943).
9. The places on a magnetic material where the lines of flux are concentrated are called the magnetic poles.
10. Like poles repel; unlike poles attract. These two statements are sometimes called the 'first laws of magnetism' and are shown in Fig. 4.16.

Example

The magnetizing coil of a radio speaker induces a magnetic flux of 360 μWb in an iron core of cross-sectional area 300 mm^2. Calculate the flux density in the core.

$$\text{Flux density } B = \frac{\Phi}{\text{area}} \text{ (tesla)}$$

$$B = \frac{360 \times 10^{-6} \text{ (Wb)}}{300 \times 10^{-6} \text{ (m}^2\text{)}}$$

$$B = 1.2\text{ T}$$

MAGNETIC FIELDS

If a permanent magnet is placed on a surface and covered by a piece of paper, iron filings can be shaken on to the paper from a dispenser. Gently tapping the paper then causes the filings to take up the shape of the magnetic field surrounding the permanent magnet. The magnetic fields around a permanent magnet are shown in Figs. 4.15 and 4.16.

Electromagnetism

Electricity and magnetism have been inseparably connected since the experiments by Oersted and Faraday in the early nineteenth century. An electric current flowing in a conductor produces a magnetic field 'around' the conductor which is proportional to the current. Thus a small current produces a weak magnetic field, while a large current will produce a strong magnetic field. The magnetic field 'spirals' around the conductor, as shown in Fig. 4.17 and its direction can be determined by the 'dot' or 'cross' notation and the 'screw rule'. To do this, we think of the current as being represented by a dart or arrow inside the conductor. The dot represents current coming towards us when we would see the point of the arrow or dart inside the conductor. The cross represents current going away from us when we

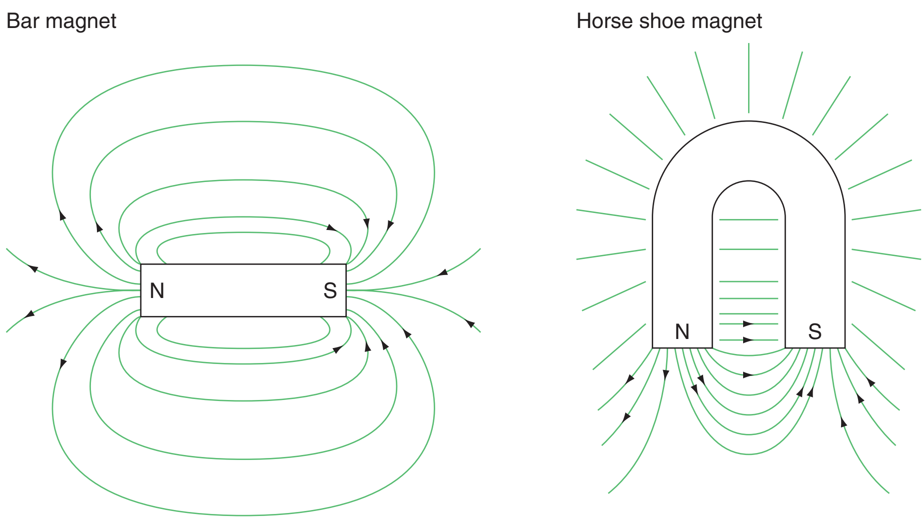


FIGURE 4.15
Magnetic fields around a permanent magnet.

would see the flights of the dart or arrow. Imagine a corkscrew or screw being turned so that it will move in the direction of the current. Therefore, if the current was coming out of the paper, as shown in Fig. 4.17(a), the magnetic field would be spiralling anticlockwise around the conductor. If the current was going into the paper, as shown in Fig. 4.17(b), the magnetic field would spiral clockwise around the conductor.

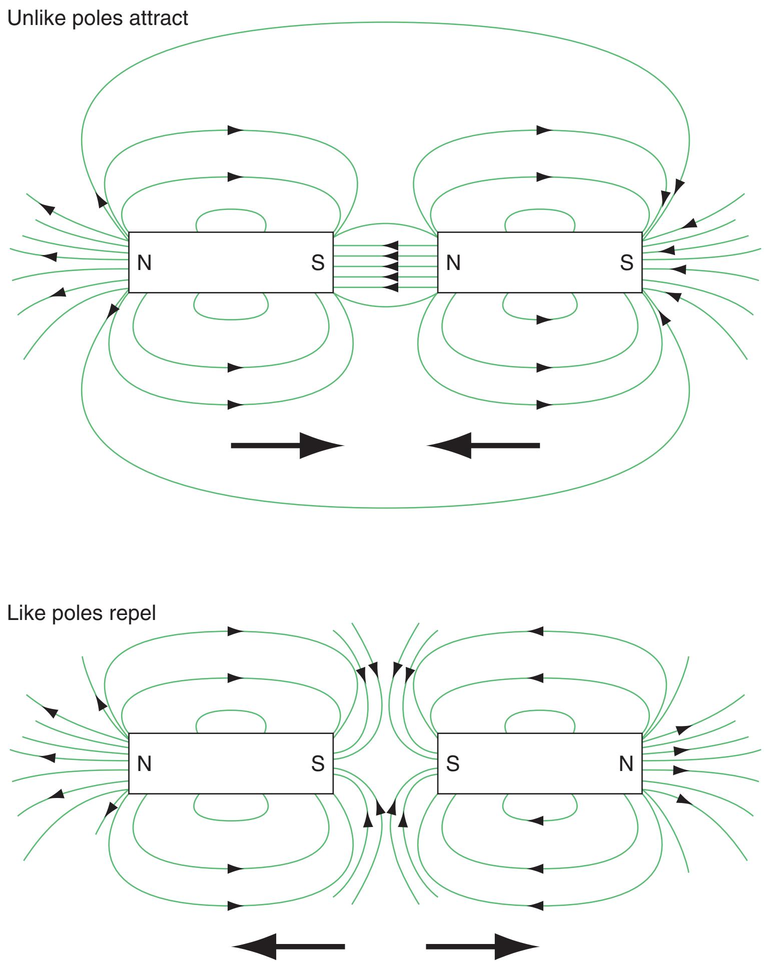


FIGURE 4.16
The first laws of magnetism.

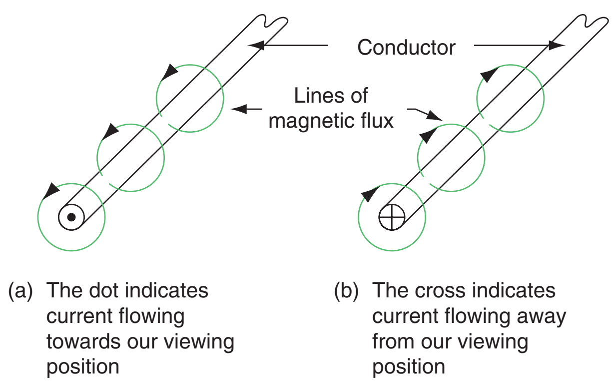


FIGURE 4.17
Magnetic fields around a current carrying conductor.

A current flowing in a *coil* of wire or solenoid establishes a magnetic field which is very similar to that of a bar magnet. Winding the coil around a soft iron core increases the flux density because the lines of magnetic flux concentrate on the magnetic material. The advantage of the electromagnet when compared with the permanent magnet is that the magnetism of the electromagnet can be switched on and off by a functional switch controlling the coil current. This effect is put to practical use in the electrical relay as used in a motor starter or alarm circuit. Fig. 4.18 shows the structure and one application of the solenoid.

A current carrying conductor maintains a magnetic field around the conductor which is proportional to the current flowing. When this magnetic field interacts with another magnetic field, forces are exerted which describe the basic principles of electric motors.

Definition

Michael Faraday demonstrated on 29 August 1831 that electricity could be produced by magnetism. He stated that *'When a conductor cuts or is cut by a magnetic field an emf is induced in that conductor. The amount of induced emf is proportional to the rate or speed at which the magnetic field cuts the conductor'.*

Michael Faraday demonstrated on 29 August 1831 that electricity could be produced by magnetism. He stated that **'When a conductor cuts or is cut by a magnetic field an emf is induced in that conductor. The amount of induced emf is proportional to the rate or speed at which the magnetic field cuts the conductor'**. This basic principle laid down the laws of present-day electricity generation where a strong magnetic field is rotated inside a coil of wire to generate electricity.

This law can be translated into a formula as follows:

$$\text{Induced emf} = Blv \text{ (V)}$$

where B is the magnetic flux density, measured in tesla, to commemorate Nikola Tesla (1856–1943) a famous Yugoslav who invented the two-phase and three-phase alternator and motor; l is the length of conductor in the magnetic field, measured in metres; and v is the velocity or speed at which the conductor cuts the magnetic flux (measured in metres per second).

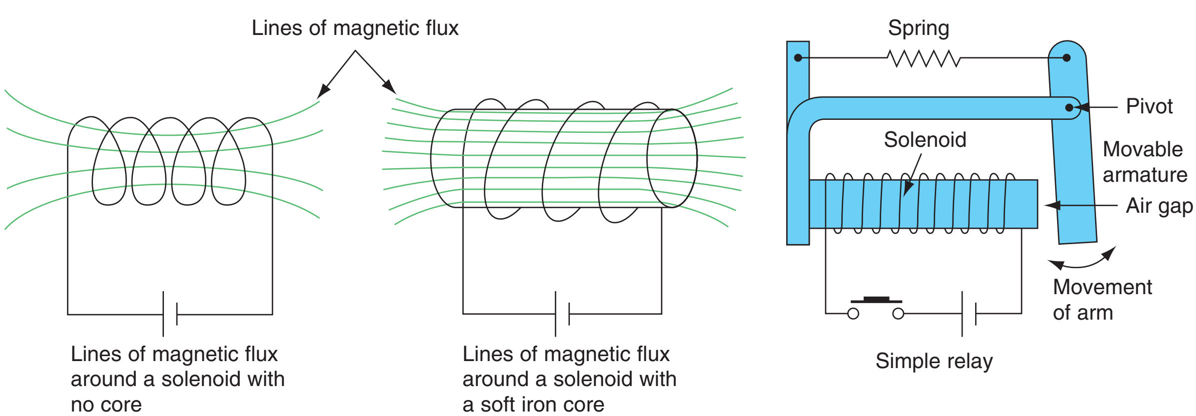


FIGURE 4.18
The solenoid and one practical application: the relay.

Example

A 15 cm length of conductor is moved at 20 m/s through a magnetic field of flux density 2T. Calculate the induced emf.

$$\text{emf} = Blv \text{ (V)}$$
$$\therefore \text{emf} = 2\text{ T} \times 0.15 \times 20 \text{ m/s}$$
$$\text{emf} = 6 \text{ V}$$

SELF AND MUTUAL INDUCTANCE

If a coil of wire is wound on to an iron core as shown in Fig. 4.19, a magnetic field will become established in the core when a current flows in the coil due to the switch being closed.

When the switch is opened the current stops flowing and, therefore, the magnetic flux collapses. The collapsing magnetic flux induces an emf into the coil and this voltage appears across the switch contacts. The effect is known as *self-inductance*, or just **inductance**, and is one property of any coil. The unit of inductance is the henry (symbol H), to commemorate the work of the American physicist Joseph Henry (1797–1878), and a circuit is said to possess an inductance of 1 H when an emf of 1 V is induced in the circuit by a current changing at the rate of 1 A/s.

Definition

Inductance is are property of any coil in which a current establishes a magnetic field and the storage of magnetic enegy.

Fluorescent light fittings contain a choke or inductive coil in series with the tube and starter lamp. The starter lamp switches on and off very quickly, causing rapid current changes which induce a large voltage across the tube electrodes sufficient to strike an arc in the tube.

When two separate coils are placed close together, as they are in a transformer, a current in one coil produces a magnetic flux which links with the second coil. This induces a voltage in the second coil and is the basic principle of the transformer action which is described later in this chapter. The two coils in this case are said to possess **mutual inductance**, as shown in Fig. 4.20. A mutual inductance of 1 H exists between two coils when a uniformly varying current of 1 A/s in one coil produces an emf of 1 V in the other coil.

Definition

A *mutual inductance* of 1 H exists between two coils when a uniformly varying current of 1 A/s in one coil produces an emf of 1 V in the other coil.

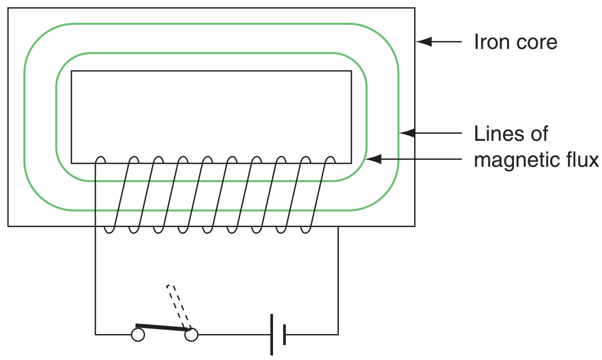


FIGURE 4.19
An inductive coil or choke.

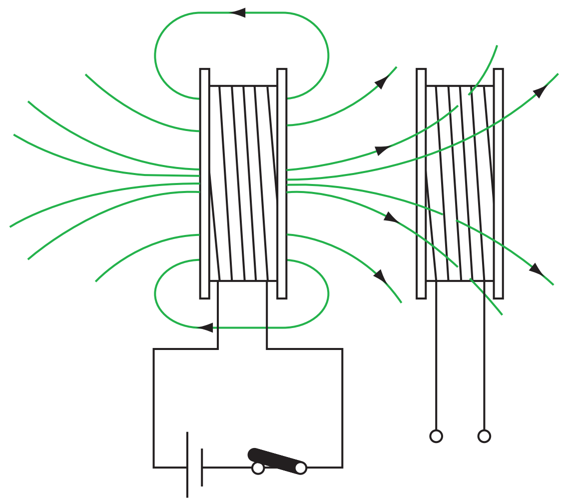


FIGURE 4.20
Mutual inductance between two coils.

The emf induced in the right-hand coil of Fig. 4.20 is dependent upon the rate of change of magnetic flux and the number of turns on the coil. The average induced emf is, therefore, given by:

$$\text{emf} = \frac{-(\Phi_2 - \Phi_1)}{t} \times N \ (V)$$

where Φ is the magnetic flux measured in webers, to commemorate the work of the German physicist, Wilhelm Weber (1804–1891), t is the time in seconds and N the number of turns. The minus sign indicates that the emf is a back emf opposing the rate of change of current as described later by Lenz's law.

Example

The magnetic flux linking 2000 turns of electromagnetic relay changes from 0.6 to 0.4 mWb in 50 ms. Calculate the average value of the induced emf.

$$\text{emf} = -\frac{(\Phi_2 - \Phi_1)}{\text{t}} \times N \ (V)$$

$$\therefore \text{emf} = -\frac{(0.6 - 0.4) \times 10^{-3}}{50 \times 10^{-3}} \times 2000$$

$$\text{emf} = -8 \text{ V}$$

ENERGY STORED IN A MAGNETIC FIELD

When we open the switch of an inductive circuit such as an electric motor or fluorescent light circuit the magnetic flux collapses and produces an arc across the switch contacts. The arc is produced by the stored magnetic energy being discharged across the switch contacts. The stored magnetic energy (symbol W) is expressed in joules and given by the following formula:

$$\text{Energy} = W = \tfrac{1}{2} LI^2 \text{ (J)}$$

where L is the inductance of the coil in henrys and I is the current flowing in amperes.

Example

The field windings of a motor have an inductance of 3 H and carry a current of 2 A. Calculate the magnetic energy stored in the coils.

$$W = \tfrac{1}{2} LI^2 \text{ (J)}$$
$$W = \tfrac{1}{2} \times 3\text{H} \times (2\text{A})^2$$
$$W = 6\text{J}$$

Definition

Some materials magnetize easily, and some are difficult to magnetize. Some materials retain their magnetism, while others lose it. The result will look like the graphs shown in Fig. 4.21 and are called *hysteresis loops*.

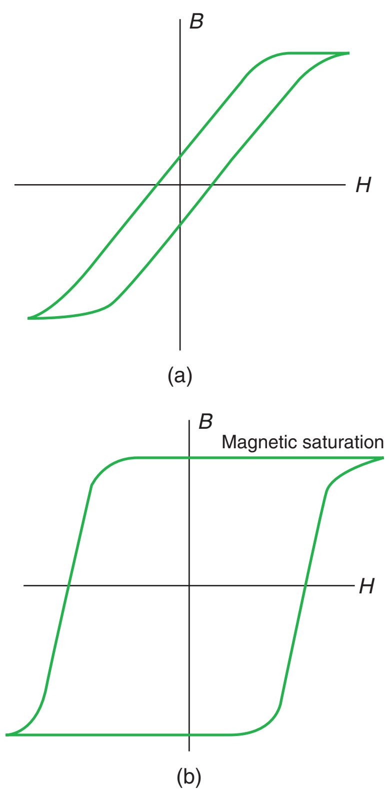


FIGURE 4.21
Magnetic hysteresis loops: (a) electromagnetic material; (b) permanent magnetic material.

MAGNETIC HYSTERESIS

There are many different types of magnetic material and they all respond differently to being magnetized. Some materials magnetize easily, and some are difficult to magnetize. Some materials retain their magnetism, while others lose it. The result will look like the graphs shown in Fig. 4.21 and are called **hysteresis loops**.

Materials from which permanent magnets are made should display a wide hysteresis loop, as shown by loop (b) in Fig. 4.21.

The core of an electromagnet is required to magnetize easily, and to lose its magnetism equally easily when switched off. Suitable materials will, therefore, display a narrow hysteresis loop, as shown in loop (a) in Fig. 4.21.

The hysteresis effect causes an energy loss whenever the magnetic flux changes. This energy loss is converted to heat in the iron. The energy lost during a complete cycle of flux change is proportional to the area enclosed by the hysteresis loop.

When an iron core is subjected to alternating magnetization, as in a transformer, the energy loss occurs at every cycle and so constitutes a continuous power loss, and, therefore, for applications such as transformers, a material with a narrow hysteresis loop is required.

Electrostatics

If a battery is connected between two insulated plates, the emf of the battery forces electrons from one plate to another until the p.d. between the plates is equal to the battery emf.

The electrons flowing through the battery constitute a current, I (in amperes), which flows for a time, t (in seconds). The plates are then said to be charged.

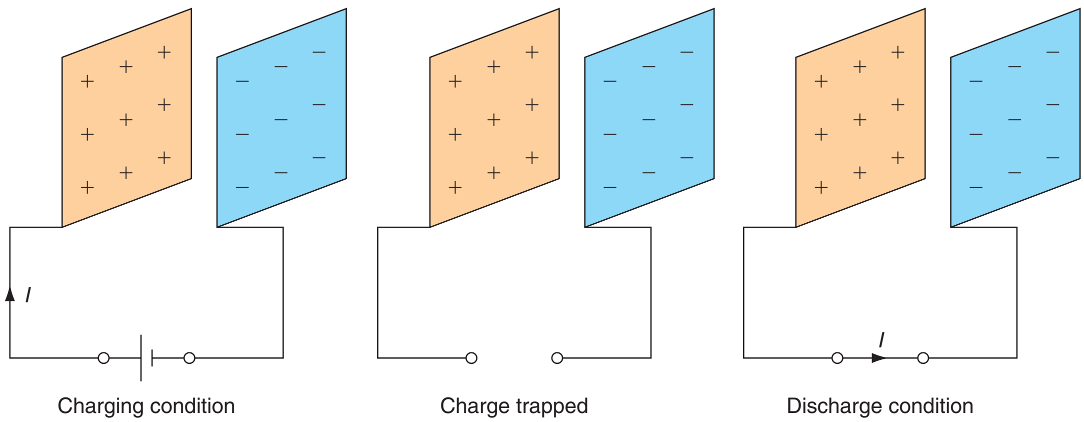


FIGURE 4.22
The charge on a capacitor's plates.

Definition

The property of a pair of plates to store an electric charge is called its *capacitance*.

Definition

By definition, a *capacitor* has a capacitance (C) of one farad (symbol F) when a p.d. of one volt maintains a charge of one coulomb on that capacitor.

The amount of charge transferred is given by:

$$Q = It \text{ (coulomb [Symbol C])}$$

Figure 4.22 shows the charges on a capacitor's plates.

When the voltage is removed the charge Q is trapped on the plates, but if the plates are joined together, the same quantity of electricity, $Q = It$, will flow back from one plate to the other, so discharging them. The property of a pair of plates to store an electric charge is called its **capacitance**.

By definition, a **capacitor** has a capacitance (C) of one farad (symbol F) when a p.d. of one volt maintains a charge of one coulomb on that capacitor, or

$$C = \frac{Q}{V} \text{ (F)}$$

Collecting these important formulae together, we have:

$$Q = It = CV$$

CAPACITORS

A capacitor consists of two metal plates, separated by an insulating layer called the dielectric. It has the ability of storing a quantity of electricity as an excess of electrons on one plate and a deficiency on the other.

Example

A 100 μF capacitor is charged by a steady current of 2 mA flowing for 5 seconds. Calculate the total charge stored by the capacitor and the p.d. between the plates.

$$Q = It \text{ (C)}$$
$$\therefore Q = 2 \times 10^{-3}\ \text{A} \times 5\,\text{s} = 10\,\text{mC}$$
$$Q = CV$$
$$\therefore V = \frac{Q}{C} \text{ (V)}$$
$$V = \frac{10 \times 10^{-3}\,\text{C}}{100 \times 10^{-6}\,\text{F}} = 100\,\text{V}$$

The p.d. or voltage which may be maintained across the plates of a capacitor is determined by the type and thickness of the dielectric medium. Capacitor manufacturers usually indicate the maximum safe working voltage for their products.

Capacitors are classified by the type of dielectric material used in their construction. Fig. 4.23 shows the general construction and appearance of some capacitor types to be found in installation work.

AIR-DIELECTRIC CAPACITORS

Air-dielectric capacitors are usually constructed of multiple aluminium vanes of which one section moves to make the capacitance variable. They are often used for radio-tuning circuits.

MICA-DIELECTRIC CAPACITORS

Mica-dielectric capacitors are constructed of thin aluminium foils separated by a layer of mica. They are expensive, but this dielectric is very

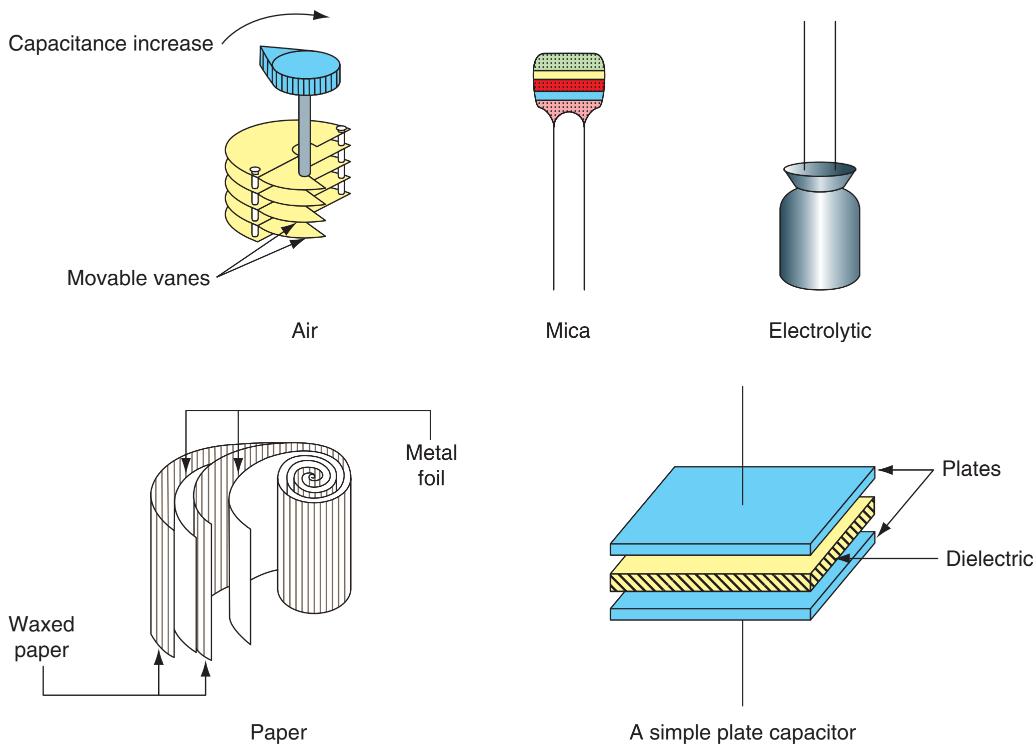


FIGURE 4.23
Construction and appearance of capacitors.

stable and has low dielectric loss. They are often used in high-frequency electronic circuits.

PAPER-DIELECTRIC CAPACITORS

Paper-dielectric capacitors usually consist of thin aluminium foils separated by a layer of waxed paper. This paper–foil sandwich is rolled into a cylinder and usually contained in a metal cylinder. These capacitors are used in fluorescent lighting fittings and motor circuits.

Key Fact

Capacitors

A capacitor is a device which stores an electric charge.

ELECTROLYTIC CAPACITORS

The construction of these is similar to that of the paper-dielectric capacitors, but the dielectric material in this case is an oxide skin formed electrolytically by the manufacturers. Since the oxide skin is very thin, a large capacitance is achieved for a small physical size, but if a voltage of the wrong polarity is applied, the oxide skin is damaged and the gas inside the sealed container explodes. For this reason electrolytic capacitors must be connected to the correct voltage polarity. They are used where a large capacitance is required from a small physical size and where the terminal voltage never reverses polarity.

The practical considerations of capacitors and the use of colour codes to determine capacitor values are dealt with later in this chapter.

Energy stored in a capacitor

Following a period of charge, the capacitor will store a small amount of energy as an electrostatic charge which, we will see later, can be made to do work. The energy stored (symbol *W*) in a capacitor is expressed in joules and given by the formula:

$$\text{Energy} = W = \tfrac{1}{2}CV^2 \text{ (J)}$$

where *C* is the capacitance of the capacitor and *V* is the applied voltage.

Example 1

A 60 μF capacitor is used for power-factor correction in a fluorescent luminaire. Calculate the energy stored in the capacitor when it is connected to the 230 V mains supply.

$$\text{Energy} = W = \tfrac{1}{2}CV^2 \text{ (J)}$$

$$\therefore\ W = \tfrac{1}{2} \times 60 \times 10^{-6}\ \text{F} \times (230\ \text{V})^2$$

$$W = 3.17\ \text{J}$$

Example 2

The energy stored in a certain capacitor when connected across a 400 V supply is 0.3 J. Calculate (a) the capacitance and (b) the charge on the capacitor.

For (a),

$$W = \tfrac{1}{2}CV^2 \text{ (J)}$$

Transposing,

$$C = \frac{2W}{V^2} \text{ (F)}$$

$$\therefore\ C = \frac{2 \times 0.3 \text{ J}}{(400 \text{ V})^2}$$

$$C = 3.75\ \mu\text{F}$$

For (b), the charge is given by:

$$Q = CV \text{ (C)}$$

$$\therefore\ Q = 3.75 \times 10^{-6} \text{ F} \times 400 \text{ V}$$

$$Q = 1500\ \mu\text{C}$$

CR CIRCUITS

As we have discussed earlier in this chapter, connecting a voltage to the plates of a capacitor causes it to charge up to the potential of the supply. This involves electrons moving around the circuit to create the necessary charge conditions and, therefore, this action does not occur instantly, but takes some time, depending upon the size of the capacitor and the resistance of the circuit. Such circuits are called capacitor–resistor (CR) circuits, and have many applications in electronics as timers and triggers and for controlling the time base sweeps of a cathode ray oscilloscope.

Figure 4.24 shows the circuit diagram for a simple CR circuit and the graphs drawn from the meter readings. It can be seen that:

(a) initially the current has a maximum value and decreases slowly to zero as the capacitor charges and

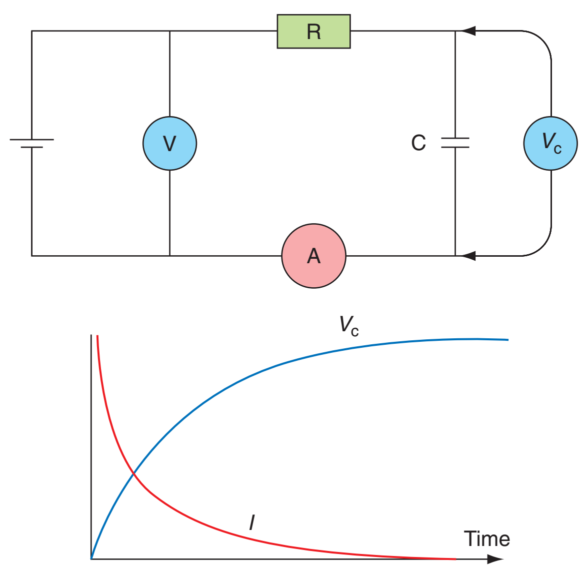


FIGURE 4.24
A CR circuit.

(b) initially the capacitor voltage rises rapidly but then slows down, increasing gradually until the capacitor voltage is equal to the supply voltage when fully charged.

The mathematical name for the shape of these curves is an *exponential* curve and, therefore, we say that the capacitor voltage is growing exponentially while the current is decaying exponentially during the charging period. The *rate* at which the capacitor charges is dependent upon the *size* of the capacitor and resistor. The bigger the values of C and R, the longer it will take to charge the capacitor. The time taken to charge a capacitor by a *constant* current is given by the time constant of the circuit which is expressed mathematically as $T = CR$, where T is the time in seconds.

Example 1

A 60 μF capacitor is connected in series with a 20 kΩ resistor across a 12 V supply. Determine the time constant of this circuit.

$$T = CR \text{ (s)}$$

$$\therefore \; T = 60 \times 10^{-6}\text{ F} \times 20 \times 10^{3}\ \Omega$$

$$T = 1.2\text{ s}$$

We have already seen that in practice the capacitor is not charged by a *constant* current but, in fact, charges exponentially. However, it can be shown by experiment that in one time constant the capacitor will have reached about 63% of its final steady value, taking about five times the time constant to become fully charged. Therefore, in 1.2 seconds the 60 μF capacitor of Example 1 will have reached about 63% of 12V and after 5 T, that is 6 seconds, will be fully charged at 12V.

GRAPHICAL DERIVATION OF CR CIRCUIT

The exponential charging and discharging curves of the CR circuit described in Example 1 may also be drawn to scale by following the procedure described below and is shown in Fig. 4.25.

1. We have calculated the time constant for the circuit (T) and found it to be 1.2 seconds.
2. We know that the maximum voltage of the fully charged capacitor will be 12V because the supply voltage is 12V.
3. To draw the graph we must first select suitable scales: 0–12 on the voltage axis would be appropriate for this example and 0–6 seconds on the time axis because we know that the capacitor must be fully charged in five time constants.
4. Next draw a horizontal dotted line along the point of maximum voltage, 12V in this example.
5. Along the time axis measure off one time constant (T), distance OA in Fig. 4.25. This corresponds to 1.2 seconds because in this example T is equal to 1.2 seconds.

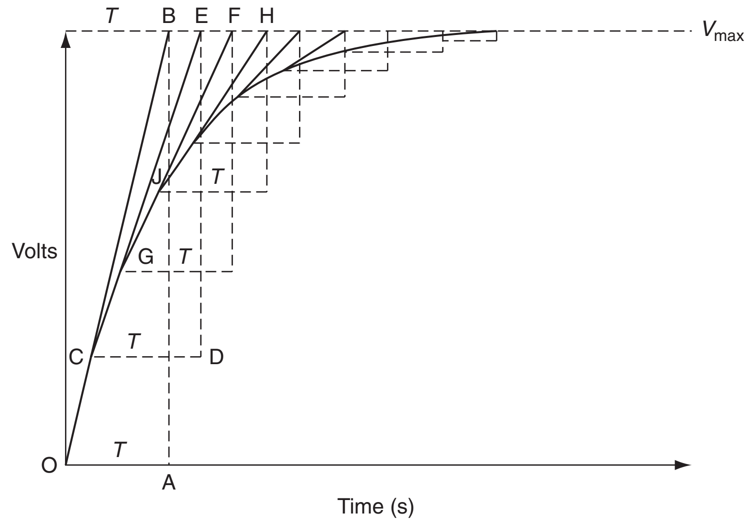


FIGURE 4.25
Graphical derivation of CR growth curve.

6. Draw the vertical dotted line AB.
7. Next, draw a full line OB; this is the start of the charging curve.
8. Select a point C, somewhere convenient and close to O along line OB.
9. Draw a horizontal line CD equal to the length of the time constant (T).
10. Draw the dotted vertical line DE.
11. Draw the line CE, the second line of our charging curve.
12. Select another point G close to C along line CE and repeat the procedures 9 to 12 to draw lines GF, JH and so on as shown in Fig. 4.25.
13. Finally, join together with a smooth curving line the points OCGJ, etc., and we have the exponential growth curve of the voltage across the capacitor.

Switching off the supply and discharging the capacitor through the 20 kΩ resistor will produce the exponential decay of the voltage across the capacitor which will be a mirror image of the growth curve. The decay curve can be derived graphically in the same way as the growth curve and is shown in Fig. 4.26.

SELECTING A CAPACITOR

There are two broad categories of capacitor, the non-polarized and the polarized type.

The non-polarized type is often found in electrical installation work for power-factor correction. A paper-dielectric capacitor is non-polarized and can be connected either way round.

The polarized type must be connected to the polarity indicated otherwise the capacitor will explode. Electrolytic capacitors are polarized and are used where a large value of capacitance is required in a relatively small

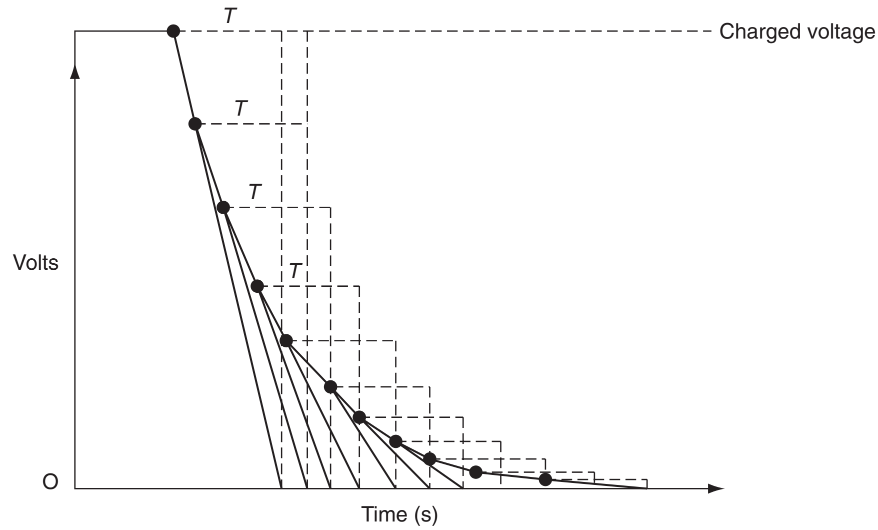


FIGURE 4.26
Graphical derivation of CR decay curve.

package. We therefore find polarized capacitors in electronic equipment such as smoothing or stabilized supplies, emergency lighting and alarm systems, so be careful when working on these systems.

When choosing a capacitor for a particular application, three factors must be considered: value, working voltage and leakage current.

The unit of capacitance is the *farad* (symbol F), to commemorate the name of the English scientist Michael Faraday. However, for practical purposes the farad is much too large and in electrical installation work and electronics we use fractions of a farad as follows:

$$\begin{aligned} 1 \text{ microfarad} &= 1\ \mu\text{F} = 1 \times 10^{-6}\ \text{F} \\ 1 \text{ nanofarad} &= 1\ \text{nF} = 1 \times 10^{-9}\ \text{F} \\ 1 \text{ picofarad} &= 1\ \text{pF} = 1 \times 10^{-12}\ \text{F} \end{aligned}$$

The p.f. correction capacitor used in a domestic fluorescent luminaire would typically have a value of 8 μF at a working voltage of 400 V. In an electronic filter circuit a typical capacitor value might be 100 pF at 63 V.

One microfarad is 1 million times greater than one picofarad. It may be useful to remember that:

$$1000\ \text{pF} = 1\ \text{nF}, \quad \text{and} \quad 1000\ \text{nF} = 1\ \mu\text{F}$$

The working voltage of a capacitor is the *maximum* voltage that can be applied between the plates of the capacitor without breaking down the dielectric insulating material. This is a d.c. rating and, therefore, a capacitor with a 200 V rating must only be connected across a maximum of 200 V d.c. Since a.c. voltages are usually given as rms values, a 200 V a.c. supply would have a maximum value of about 283 V which would damage the 200 V capacitor. When connecting a capacitor to the 230 V mains supply we must choose a working voltage of about 400 V because 230 V rms is approximately 325 V maximum. The 'factor of safety' is small and, therefore, the working voltage of the capacitor must not be exceeded.

An ideal capacitor which is isolated will remain charged forever, but in practice no dielectric insulating material is perfect, and the charge will slowly *leak* between the plates, gradually discharging the capacitor. The loss of charge by leakage through it should be very small for a practical capacitor. However, the capacitors used in electrical installation work for power-factor correction are often fitted with a high-value discharge resistor to encourage the charge to leak away safely when not in use. This is to prevent anyone getting a shock from touching the terminals of a charged capacitor.

Alternating current theory

Earlier in this chapter in Figs. 4.13 and 4.14 we looked at the generation of an a.c. waveform and the calculation of average and rms values. In this section we will first of all consider the theoretical circuits of pure resistance, inductance and capacitance acting alone in an a.c. circuit before going on to consider the practical circuits of resistance, inductance and capacitance acting together. Let us first define some of our terms of reference.

Definition

In any circuit, *resistance* is defined as opposition to current flow.

RESISTANCE

In any circuit, **resistance** is defined as opposition to current flow. From Ohm's law,

$$R = \frac{V_R}{I_R}\ (\Omega)$$

However, in an a.c. circuit, resistance is only part of the opposition to current flow. The inductance and capacitance of an a.c. circuit also cause an opposition to current flow, which we call *reactance*.

Definition

Inductive reactance (X_L) is the opposition to an a.c. current in an inductive circuit. It causes the current in the circuit to lag behind the applied voltage.

Inductive reactance (X_L) is the opposition to an a.c. current in an inductive circuit. It causes the current in the circuit to lag behind the applied voltage, as shown in Fig. 4.27. It is given by the formula

$$X_L = 2\pi fL\ (\Omega)$$

where

$\pi = 3.142$ a constant

$f =$ the frequency of the supply

$L =$ the inductance of the circuit

or by:

$$X_L = \frac{V_L}{I_L}$$

Definition

Capacitive reactance (X_C) is the opposition to an a.c. current in a capacitive circuit. It causes the current in the circuit to lead ahead of the voltage.

Capacitive reactance (X_C) is the opposition to an a.c. current in a capacitive circuit. It causes the current in the circuit to lead ahead of the voltage, as

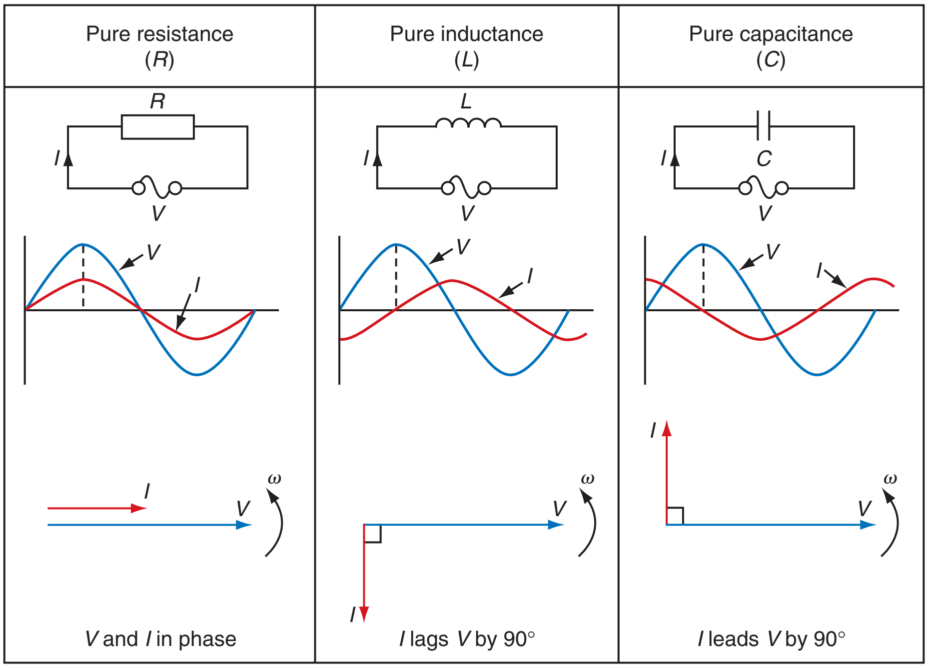


FIGURE 4.27
Voltage and current relationships in resistive, capacitive and inductive circuits.

shown in Fig. 4.27. It is given by the formula

$$X_C = \frac{1}{2\pi f C} \ (\Omega)$$

where π and f are defined as before and C is the capacitance of the circuit. It can also be expressed as:

$$X_C = \frac{V_C}{I_C}$$

Example

Calculate the reactance of a 150 μF capacitor and a 0.05 H inductor if they were separately connected to the 50 Hz mains supply.

For capacitive reactance:

$$X_C = \frac{1}{2\pi f C}$$

where $f = 50\,\text{Hz}$ and $C = 150\,\mu\text{F} = 150 \times 10^{-6}\,\text{F}$.

$$\therefore \ X_C = \frac{1}{2 \times 3.142 \times 50\,\text{Hz} \times 150 \times 10^{-6}} = 21.2\,\Omega$$

For inductive reactance:

$$X_L = 2\pi f L$$

where $f = 50$ Hz and $L = 0.05$ H.

$$\therefore\ X_L = 2 \times 3.142 \times 50\text{ Hz} \times 0.05\text{ H} = 15.7\ \Omega$$

Definition

The total opposition to current flow in an a.c. circuit is called *impedance* and given the symbol *Z*.

IMPEDANCE

The total opposition to current flow in an a.c. circuit is called **impedance** and given the symbol *Z*. Thus impedance is the combined opposition to current flow of the resistance, inductive reactance and capacitive reactance of the circuit and can be calculated from the formula

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$

or

$$Z = \frac{V_T}{I_T}$$

Example 1

Calculate the impedance when a 5 Ω resistor is connected in series with a 12 Ω inductive reactance.

$$Z = \sqrt{R^2 + X_L^2}\ (\Omega)$$
$$\therefore\ Z = \sqrt{5^2 + 12^2}$$
$$Z = \sqrt{25 + 144}$$
$$Z = \sqrt{169}$$
$$Z = 13\ \Omega$$

Example 2

Calculate the impedance when a 48 Ω resistor is connected in series with a 55 Ω capacitive reactance.

$$Z = \sqrt{R^2 + X_C^2}\ (\Omega)$$
$$\therefore\ Z = \sqrt{48^2 + 55^2}$$
$$Z = \sqrt{2304 + 3025}$$
$$Z = \sqrt{5329}$$
$$Z = 73\ \Omega$$

RESISTANCE, INDUCTANCE AND CAPACITANCE IN AN A.C. CIRCUIT

When a resistor only is connected to an a.c. circuit the current and voltage waveforms remain together, starting and finishing at the same time. We say that the waveforms are *in phase*.

When a pure inductor is connected to an a.c. circuit the current lags behind the voltage waveform by an angle of 90°. We say that the current *lags* the voltage by 90°. When a pure capacitor is connected to an a.c. circuit the current *leads* the voltage by an angle of 90°. These various effects can be observed on an oscilloscope, but the circuit diagram, waveform diagram and phasor diagram for each circuit are shown in Fig. 4.27.

Phasor diagrams

Phasor diagrams and a.c. circuits are an inseparable combination. Phasor diagrams allow us to produce a model or picture of the circuit under consideration which helps us to understand the circuit. A phasor is a straight line, having definite length and direction, which represents to scale the magnitude and direction of a quantity such as a current, voltage or impedance.

Try This

Definitions

To help you to remember definitions, try writing them down. Write down a definition of resistance, inductive reactance and capacitive reactance.

To find the combined effect of two quantities we combine their phasors by adding the beginning of the second phasor to the end of the first. The combined effect of the two quantities is shown by the resultant phasor, which is measured from the original zero position to the end of the last phasor.

Example

Find by phasor addition the combined effect of currents *A* and *B* acting in a circuit. Current *A* has a value of 4 A, and current *B* a value of 3 A, leading *A* by 90°. We usually assume phasors to rotate anticlockwise and so the complete diagram will be as shown in Fig. 4.28. Choose a scale of, for example, 1 A = 1 cm and draw the phasors to scale, that is $A = 4$ cm and $B = 3$ cm, leading *A* by 90°.

The magnitude of the resultant phasor can be measured from the phasor diagram and is found to be 5 A acting at a phase angle ϕ of about 37° leading *A*. We therefore say that the combined effect of currents *A* and *B* is a current of 5 A at an angle of 37° leading *A*.

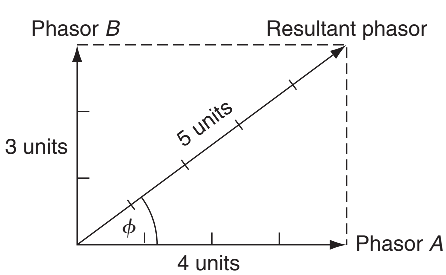


FIGURE 4.28
The phasor addition of currents A and B.

Phase angle ϕ

In an a.c. circuit containing resistance only, such as a heating circuit, the voltage and current are in phase, which means that they reach their peak and zero values together, as shown in Fig. 4.29(a).

In an a.c. circuit containing inductance, such as a motor or discharge lighting circuit, the current often reaches its maximum value after the voltage, which means that the current and voltage are out of phase with each other, as shown in Fig. 4.29(b). The phase difference, measured in degrees between the current and voltage, is called the phase angle of the circuit, and is denoted by the symbol ϕ, the Greek letter phi.

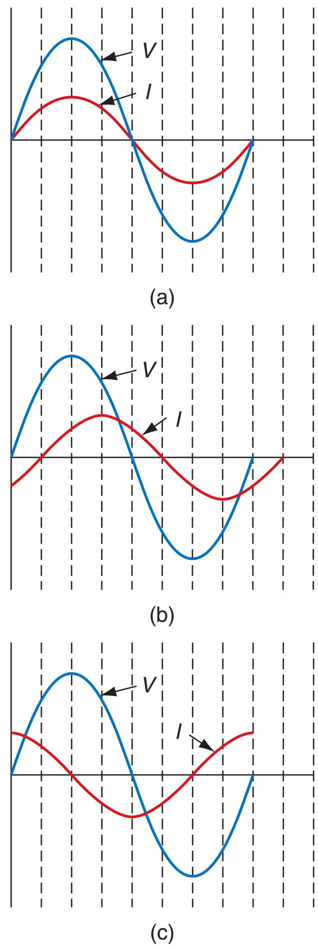


FIGURE 4.29

Phase relationship of a.c. waveform: (a) V and I in phase, phase angle $\phi = 0°$ and power factor (p.f.) = cos ϕ = 1; (b) V and I displaced by 45°, f = 45° and p.f. = 0.707; (c) V and I displaced by 90°, ϕ = 90° and p.f. = 0.

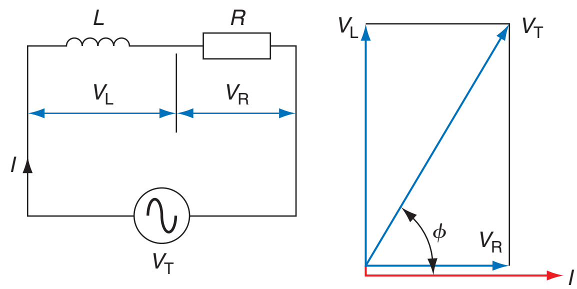


FIGURE 4.30

A series RL circuit and phasor diagram.

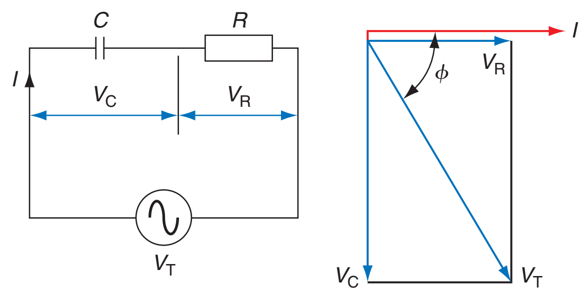


FIGURE 4.31

A series RC circuit and phasor diagram.

When circuits contain two or more separate elements, such as RL, RC or RLC, the phase angle between the total voltage and total current will be neither 0° nor 90° but will be determined by the relative values of resistance and reactance in the circuit. In Fig. 4.30 the phase angle between applied voltage and current is angle ϕ.

ALTERNATING CURRENT SERIES CIRCUIT

In a circuit containing a resistor and inductor connected in series as shown in Fig. 4.30, the current I will flow through the resistor and the inductor causing the voltage V_R to be dropped across the resistor and V_L to be dropped across the inductor. The sum of these voltages will be equal to the total voltage V_T but because this is an a.c. circuit the voltages must be added by phasor addition. The result is shown in Fig. 4.30, where V_R is drawn to scale and in phase with the current and V_L is drawn to scale and leading the current by 90°. The phasor addition of these two voltages gives us the magnitude and direction of V_T, which leads the current by angle ϕ.

In a circuit containing a resistor and capacitor connected in series as shown in Fig. 4.31, the current I will flow through the resistor and capacitor causing voltage drops V_R and V_C. The voltage V_R will be in phase with the current and V_C will lag the current by 90°. The phasor addition of these voltages is equal to the total voltage V_T which, as can be seen in Fig. 4.31, is lagging the current by some angle ϕ.

THE IMPEDANCE TRIANGLE

We have now established the general shape of the phasor diagram for a series a.c. circuit. Figures 4.30 and 4.31 show the voltage phasors, but we know that $V_R = IR$, $V_L = IX_L$, $V_C = IX_C$ and $V_T = IZ$, and therefore the phasor diagrams (a) and (b) of Fig. 4.32 must be equal. From Fig. 4.32(b), by the theorem of Pythagoras, we have:

$$(IZ)^2 = (IR)^2 + (IX)^2$$
$$I^2Z^2 = I^2R^2 + I^2X^2$$

If we now divide throughout by I^2 we have:

$$Z^2 = R^2 + X^2$$
$$\text{or } Z = \sqrt{R^2 + X^2}\ \Omega$$

The phasor diagram can be simplified to the impedance triangle given in Fig. 4.32(c).

Example 1

A coil of 0.15 H is connected in series with a 50 Ω resistor across a 100 V 50 Hz supply. Calculate (a) the reactance of the coil, (b) the impedance of the circuit and (c) the current.

For (a),

$$X_L = 2\pi fL\ (\Omega)$$
$$\therefore\ X_L = 2 \times 3.142 \times 50\text{ Hz} \times 0.15\text{ H} = 47.1\ \Omega$$

For (b),

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$
$$\therefore\ Z = \sqrt{(50\ \Omega)^2 + (47.1\ \Omega)^2} = 68.69\ \Omega$$

For (c),

$$I = V/Z(\text{A})$$
$$\therefore\ I = \frac{100\text{ V}}{68.69\ \Omega} = 1.46\text{ A}$$

Example 2

A 60 μF capacitor is connected in series with a 100 Ω resistor across a 230 V 50 Hz supply. Calculate (a) the reactance of the capacitor, (b) the impedance of the circuit and (c) the current.

For (a),

$$X_C = \frac{1}{2\pi fC}\ (\Omega)$$
$$\therefore\ X_C = \frac{1}{2\pi \times 50\text{Hz} \times 60 \times 10^{-6}\text{ F}} = 53.05\ \Omega$$

For (b),

$$Z = \sqrt{R^2 + X^2}\ (\Omega)$$

$$\therefore\ Z = \sqrt{(100\,\Omega)^2 + (53.05\,\Omega)^2} = 113.2\,\Omega$$

For (c),

$$I = V/\,Z(\text{A})$$

$$\therefore\ I = \frac{230\,\text{V}}{113.2\,\Omega} = 2.03\,\text{A}$$

POWER AND POWER FACTOR

Power factor (p.f.) is defined as the cosine of the phase angle between the current and voltage:

$$\text{p.f.} = \cos\phi$$

If the current lags the voltage as shown in Fig. 4.30, we say that the p.f. is lagging, and if the current leads the voltage as shown in Fig. 4.31, the p.f. is said to be leading. From the trigonometry of the impedance triangle shown in Fig. 4.32, p.f. is also equal to:

$$\text{p.f.} = \cos\phi = \frac{R}{Z} = \frac{V_R}{V_T}$$

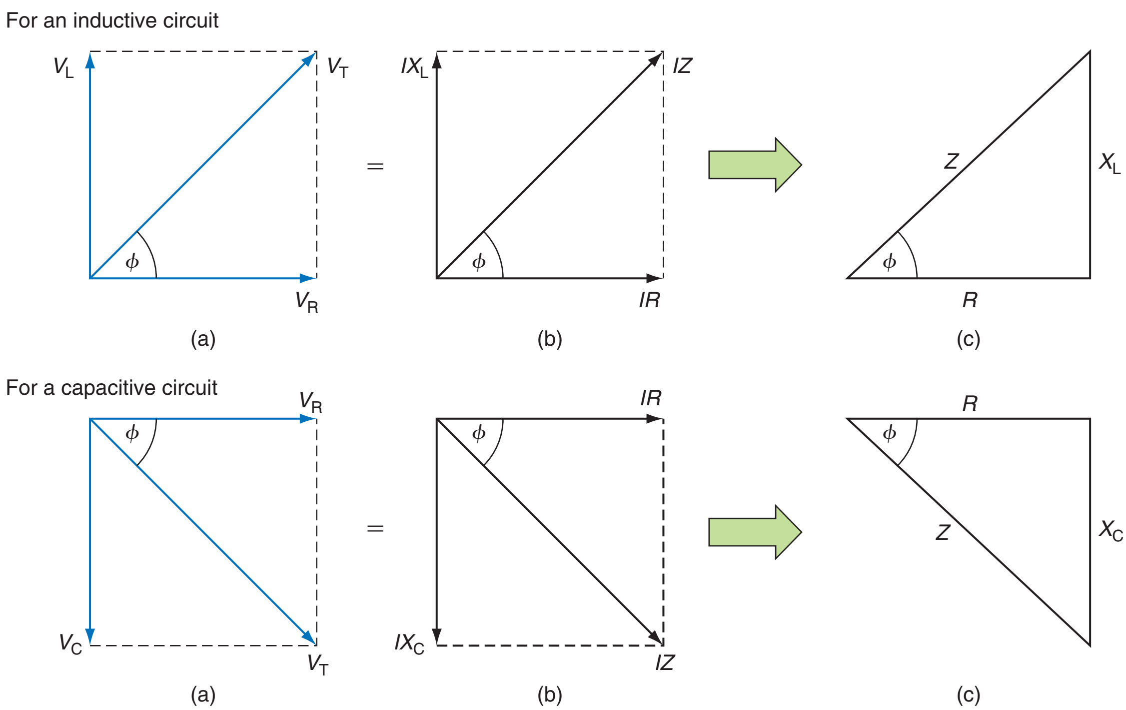
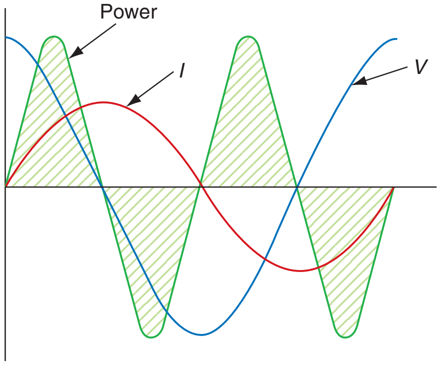


FIGURE 4.32
Phasor diagram and impedance triangle.



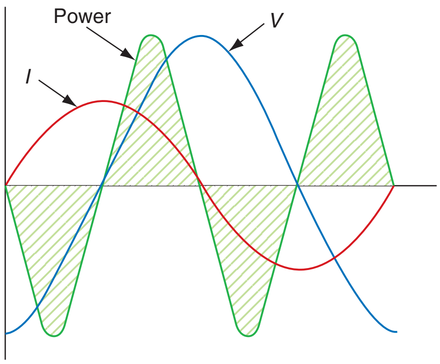


FIGURE 4.33
Waveform for the a.c. power in purely inductive and purely capacitive circuits.

The electrical power in a circuit is the product of the instantaneous values of the voltage and current. Fig. 4.33 shows the voltage and current waveform for a pure inductor and pure capacitor. The power waveform is obtained from the product of V and I at every instant in the cycle. It can be seen that the power waveform reverses every quarter cycle, indicating that energy is alternately being fed into and taken out of the inductor and capacitor. When considered over one complete cycle, the positive and negative portions are equal, showing that the average power consumed by a pure inductor or capacitor is zero. This shows that inductors and capacitors store energy during one part of the voltage cycle and feed it back into the supply later in the cycle. Inductors store energy as a magnetic field and capacitors as an electric field.

In an electric circuit more power is taken from the supply than is fed back into it, since some power is dissipated by the resistance of the circuit, and therefore:

$$P = I^2R \text{ (W)}$$

In any d.c. circuit the power consumed is given by the product of the voltage and current, because in a d.c. circuit voltage and current are in phase. In an a.c. circuit the power consumed is given by the product of the current and that part of the voltage which is in phase with the current. The in-phase component of the voltage is given by $V \cos \phi$, and so power can also be given by the equation:

$$P = VI \cos \phi \text{ (W)}$$

Example 1

A coil has a resistance of 30 Ω and a reactance of 40 Ω when connected to a 250 V supply. Calculate (a) the impedance, (b) the current, (c) the p.f. and (d) the power.

For (a),

$$Z = \sqrt{R^2 + X^2} \ (\Omega)$$

$$\therefore \ Z = \sqrt{(30\ \Omega)^2 + (40\ \Omega)^2} = 50\ \Omega$$

For (b),

$$I = V/Z(\text{A})$$

$$\therefore \ I = \frac{250\text{ V}}{50\ \Omega} = 5\text{ A}$$

For (c),

$$\text{p.f.} = \cos\phi = \frac{R}{Z}$$

$$\therefore \ \text{p.f.} = \frac{30\ \Omega}{50\ \Omega} = 0.6 \text{ lagging}$$

For (d),

$$P = VI \cos \phi \text{ (W)}$$
$$\therefore \; P = 250 \text{ V} \times 5 \text{ A} \times 0.6 = 750 \text{ W}$$

Example 2

A capacitor of reactance 12 Ω is connected in series with a 9 Ω resistor across a 150 V supply. Calculate (a) the impedance of the circuit, (b) the current, (c) the p.f. and (d) the power.

For (a),

$$Z = \sqrt{R^2 + X^2} \; (\Omega)$$
$$\therefore \; Z = \sqrt{(9 \; \Omega)^2 + (12 \; \Omega)^2} = 15 \; \Omega$$

For (b),

$$I = V/Z \text{(A)}$$
$$\therefore \; I = \frac{150 \text{ V}}{15 \; \Omega} = 10 \text{ A}$$

For (c),

$$\text{p.f.} = \cos \phi = \frac{R}{Z}$$
$$\therefore \; \text{p.f.} = \frac{9 \; \Omega}{15 \; \Omega} = 0.6 \text{ leading}$$

For (d),

$$P = VI \cos \phi \text{ (W)}$$
$$\therefore \; P = 150 \text{ V} \times 10 \text{ A} \times 0.6 = 900 \text{ W}$$

The power factor of most industrial loads is lagging because the machines and discharge lighting used in industry are mostly inductive. This causes an additional magnetizing current to be drawn from the supply, which does not produce power, but does need to be supplied, making supply cables larger.

Example 3

A 230 V supply feeds three 1.84 kW loads with power factors of 1, 0.8 and 0.4. Calculate the current at each power factor.

The current is given by:

$$I = \frac{P}{V \cos \phi}$$

where $\boldsymbol{P}$ = 1.84 kW = 1840 W and $\boldsymbol{V}$ = 230 V. If the p.f. is 1, then:

$$I = \frac{1840 \text{ W}}{230 \text{ V} \times 1} = 8 \text{ A}$$

For a p.f. of 0.8,

$$I = \frac{1840 \text{ W}}{230 \text{ V} \times 0.8} = 10 \text{ A}$$

For a p.f. of 0.4,

$$I = \frac{1840\ \text{W}}{230\ \text{V} \times 0.4} = 20\ \text{A}$$

It can be seen from these calculations that a 1.84 kW load supplied at a power factor of 0.4 would require a 20 A cable, while the same load at unity power factor could be supplied with an 8 A cable. There may also be the problem of higher voltage drops in the supply cables. As a result, the supply companies encourage installation engineers to improve their power factor to a value close to 1 and sometimes charge penalties if the power factor falls below 0.8.

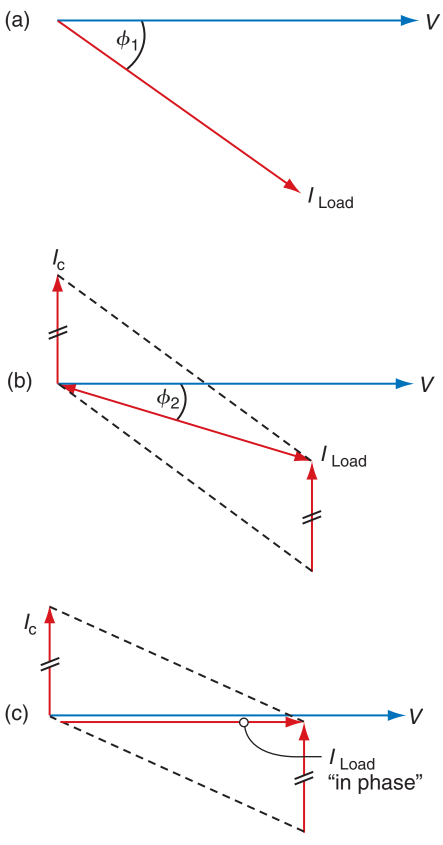


FIGURE 4.34
Power-factor improvement using capacitors.

Power-factor improvement

Most installations have a low or bad power factor because of the inductive nature of the load. A capacitor has the opposite effect of an inductor, and so it seems reasonable to add a capacitor to a load which is known to have a lower power factor.

Figure 4.34(a) shows an industrial load with a low power factor. If a capacitor is connected in parallel with the load, the capacitor current I_C leads the applied voltage by 90°. When this capacitor current is added to the load current as shown in 4.34(b) the resultant current has a much improved power factor. However, using a slightly bigger capacitor, the load current can be pushed up until it is 'in phase' with the voltage as can be seen in Fig. 4.34(c).

Capacitors may be connected across the main busbars of industrial loads in order to provide power-factor improvement, but smaller capacitors may also be connected across an individual piece of equipment, as is the case for fluorescent light fittings or a small electric motor.

Basic electronics

There are numerous types of electronic component – diodes, transistors, thyristors and integrated circuits (ICs) – each with its own limitations, characteristics and designed application. When repairing electronic circuits it is important to replace a damaged component with an identical or equivalent component. Manufacturers issue comprehensive catalogues with details of working voltage, current, power dissipation, etc., and the reference numbers of equivalent components, and some of this information is included in the Appendices. These catalogues of information, together with a high-impedance multimeter should form a part of the extended tool-kit for anyone in the electrotechnical industries proposing to repair electronic circuits.

Electronic circuit symbols

The British Standard BS EN 60617 recommends that particular graphical symbols should be used to represent a range of electronic components on circuit diagrams. The same British Standard recommends a range of symbols suitable for electrical installation circuits with which electricians will already be familiar. Figure 4.35 shows a selection of electronic symbols.

Definition

All materials have some resistance to the flow of an electric current but, in general, the term *resistor* describes a conductor specially chosen for its resistive properties.

Resistors

All materials have some resistance to the flow of an electric current but, in general, the term **resistor** describes a conductor specially chosen for its resistive properties.

Resistors are the most commonly used electronic component and they are made in a variety of ways to suit the particular type of application. They

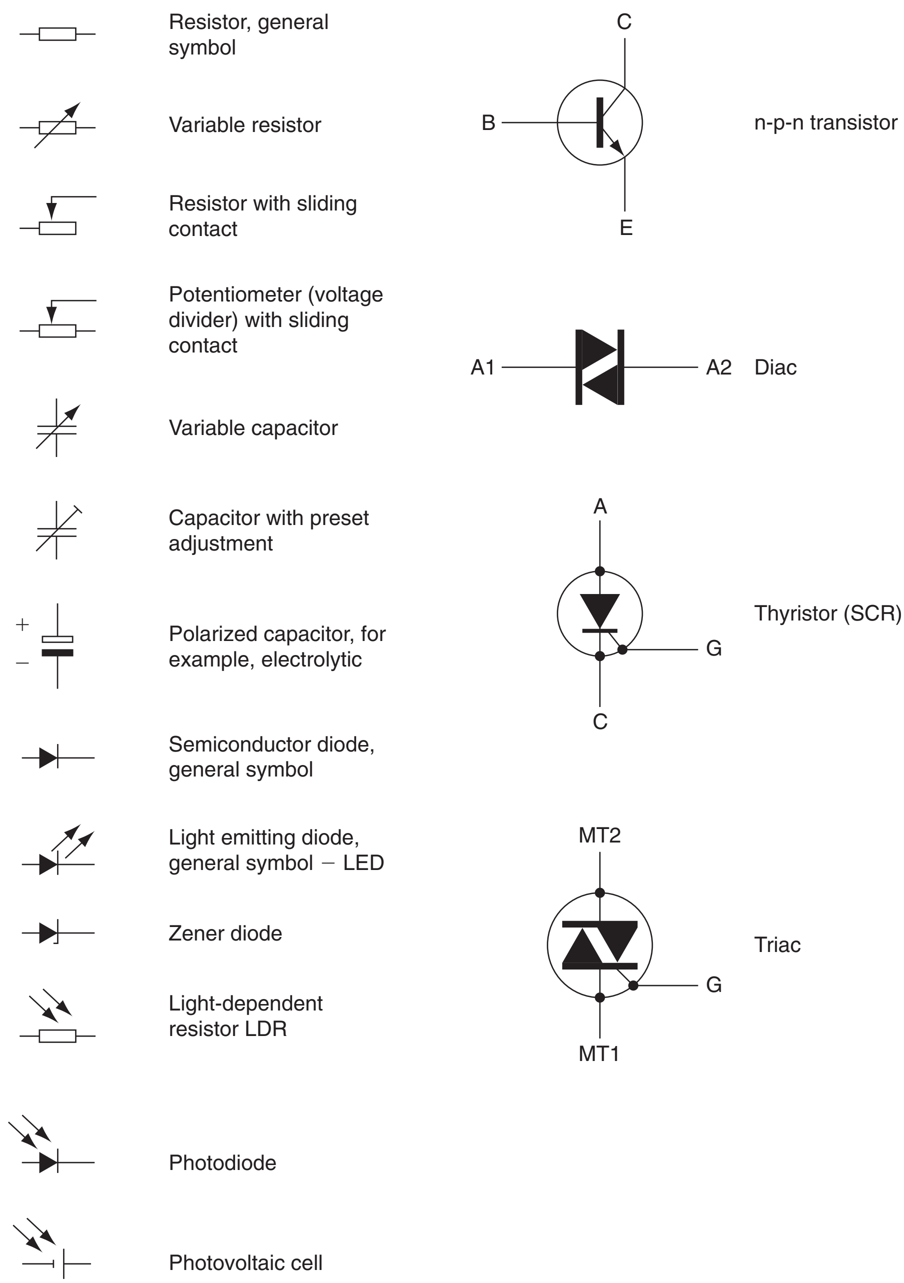


FIGURE 4.35
Some BS EN 60617 graphical symbols used in electronics.

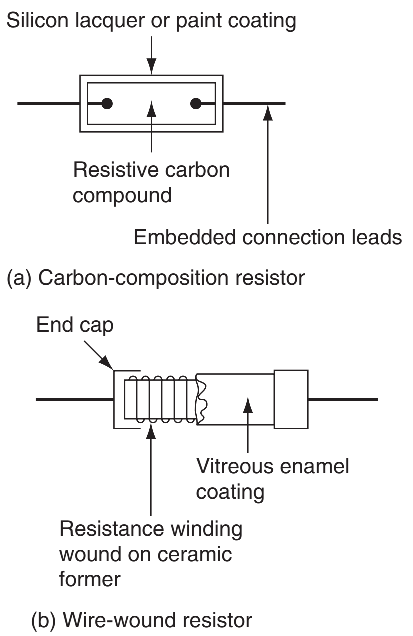


FIGURE 4.36
Construction of resistors.

FIGURE 4.37
Types of variable resistor.

are usually manufactured as either carbon composition or carbon film. In both cases the base resistive material is carbon and the general appearance is of a small cylinder with leads protruding from each end, as shown in Fig. 4.36(a).

If subjected to overload, carbon resistors usually decrease in resistance since carbon has a negative temperature coefficient. This causes more current to flow through the resistor, so that the temperature rises and failure occurs, usually by fracturing. Carbon resistors have a power rating between 0.1 and 2W, which should not be exceeded.

When a resistor of a larger power rating is required a wire-wound resistor should be chosen. This consists of a resistance wire of known value wound on a small ceramic cylinder which is encapsulated in a vitreous enamel coating, as shown in Fig. 4.36(b). Wire-wound resistors are designed to run hot and have a power rating up to 20W. Care should be taken when mounting wire-wound resistors to prevent the high operating temperature affecting any surrounding components.

A variable resistor is one which can be varied continuously from a very low value to the full rated resistance. This characteristic is required in tuning circuits to adjust the signal or voltage level for brightness, volume or tone. The most common type used in electronic work has a circular carbon track contacted by a metal wiper arm. The wiper arm can be adjusted by means of an adjusting shaft (rotary type) or by placing a screwdriver in a slot (preset type), as shown in Fig. 4.37. Variable resistors are also known as potentiometers because they can be used to adjust the potential difference (voltage) in a circuit. The variation in resistance can be either a logarithmic or a linear scale.

The value of the resistor and the tolerance may be marked on the body of the component either by direct numerical indication or by using a standard colour code. The method used will depend upon the type, physical size and manufacturer's preference, but in general the larger components have values marked directly on the body and the smaller components use the standard resistor colour code.

ABBREVIATIONS USED IN ELECTRONICS

Where the numerical value of a component includes a decimal point, it is standard practice to include the prefix for the multiplication factor in place of the decimal point, to avoid accidental marks being mistaken for decimal points. Multiplication factors and prefixes are dealt with in Chapter 8.

The abbreviation	R means $\times$ 1
	k means $\times$ 1000
	M means $\times$ 1,000,000

Therefore, a 4.7 kΩ resistor would be abbreviated to 4k7, a 5.6 Ω resistor to 5R6 and a 6.8 MΩ resistor to 6 M8.

Tolerances may be indicated by adding a letter at the end of the printed code.

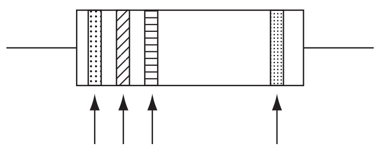
The abbreviation F means ±1%, G means ±2%, J means ±5%, K means ±10% and M means ±20%. Therefore a 4.7 kΩ resistor with a tolerance of 2% would be abbreviated to 4k7G. A 5.6 Ω resistor with a tolerance of 5% would be abbreviated to 5R6J. A 6.8 MΩ resistor with a 10% tolerance would be abbreviated to 6 M8 K.

This is the British Standard BS 1852 code which is recommended for indicating the values of resistors on circuit diagrams and components when their physical size permits.

THE STANDARD COLOUR CODE

Small resistors are marked with a series of coloured bands, as shown in Table 4.3. These are read according to the standard colour code to determine the resistance. The bands are located on the component towards one end. If the resistor is turned so that this end is towards the left, the bands are then read from left to right. Band (a) gives the first number of the component value, band (b) the second number, band (c) the number of zeros to be added after the first two numbers and band (d) the resistor tolerance. If the bands are not clearly oriented towards one end, first identify the tolerance band and turn the resistor so that this is towards the right before commencing to read the colour code as described.

Table 4.3 The Resistor Colour Code



Colour	Band (a) first number	Band (b) second number	Band (c) number of zeros	Band (d) tolerance band (%)
Black	0	0	None	–
Brown	1	1	1	1
Red	2	2	2	2
Orange	3	3	3	–
Yellow	4	4	4	–
Green	5	5	5	–
Blue	6	6	6	–
Violet	7	7	7	–
Grey	8	8	–	–
White	9	9	–	–
Gold	–	–	÷10	5
Silver	–	–	÷100	10
None	–	–	–	20

The tolerance band indicates the maximum tolerance variation in the declared value of resistance. Thus a 100 Ω resistor with a 5% tolerance will have a value somewhere between 95 and 105 Ω, since 5% of 100 Ω is 5 Ω.

Example 1

A resistor is colour coded yellow, violet, red, gold. Determine the value of the resistor.

Band (a) – yellow has a value of 4.
Band (b) – violet has a value of 7.
Band (c) – red has a value of 2.
Band (d) – gold indicates a tolerance of 5%.
The value is therefore 4700 ± 5%.
This could be written as 4.7 kΩ ± 5% or 4 k7J.

Example 2

A resistor is colour coded green, blue, brown, silver. Determine the value of the resistor.

Band (a) – green has a value of 5.
Band (b) – blue has a value of 6.
Band (c) – brown has a value of 1.
Band (d) – silver indicates a tolerance of 10%.

The value is therefore 560 ± 10% and could be written as 560 Ω± 10% or 560 RK.

Example 3

A resistor is colour coded blue, grey, green, gold. Determine the value of the resistor.

Band (a) – blue has a value of 6.
Band (b) – grey has a value of 8.
Band (c) – green has a value of 5.
Band (d) – gold indicates a tolerance of 5%.

The value is therefore 6,800,000 ± 5% and could be written as 6.8 MΩ ± 5% or 6 M8J.

Example 4

A resistor is colour coded orange, white, silver, silver. Determine the value of the resistor.

Band (a) – orange has a value of 3.
Band (b) – white has a value of 9.
Band (c) – silver indicates divide by 100 in this band.
Band (d) – silver indicates a tolerance of 10%.

The value is therefore 0.39 ± 10% and could be written as 0.39 Ω ± 10% or R39 K.

Try This

Electronics

Electricians are increasingly coming across electronic components and equipment. Make a list in the margin of some of the electronic components that you have come across at work.

PREFERRED VALUES

It is difficult to manufacture small electronic resistors to exact values by mass production methods. This is not a disadvantage as in most electronic circuits the value of the resistors is not critical. Manufacturers produce a limited range of *preferred* resistance values rather than an overwhelming number of individual resistance values. Therefore, in electronics, we use the preferred value closest to the actual value required.

A resistor with a preferred value of 100 Ω and a 10% tolerance could have any value between 90 and 110 Ω. The next larger preferred value which would give the maximum possible range of resistance values without too much overlap would be 120 Ω. This could have any value between 108 and 132 Ω. Therefore, these two preferred value resistors cover all possible resistance values between 90 and 132 Ω. The next preferred value would be 150 Ω, then 180, 220 Ω and so on.

There is a series of preferred values for each tolerance level, as shown in Table 4.4, so that every possible numerical value is covered. Table 4.4 indicates the values between 10 and 100, but larger values can be obtained by multiplying these preferred values by some multiplication factor. Resistance values of 47 Ω, 470 Ω, 4.7 kΩ, 470 kΩ, 4.7 MΩ, etc., are available in this way.

Table 4.4 Preferred Values

E6 series 20% tolerance	E12 series 10% tolerance	E24 series 5% tolerance
10	10	10
		11
	12	12
		13
15	15	15
		16
	18	18
		20
22	22	22
		24
	27	27
		30
33	33	33
		36
	39	39
		43
47	47	47
		51
	56	56
		62
68	68	68
		75
	82	82
		91

TESTING RESISTORS

The resistor being tested should have a value close to the preferred value and within the tolerance stated by the manufacturer. To measure the resistance of a resistor which is not connected into a circuit, the leads of a suitable ohmmeter should be connected to each resistor connection lead and a reading obtained.

If the resistor to be tested is connected into an electronic circuit it is *always necessary* to disconnect one lead from the circuit before the test leads are connected, otherwise the components in the circuit will provide parallel paths, and an incorrect reading will result.

Capacitors

The fundamental principles of capacitors were discussed earlier in this chapter under the subheading 'Electrostatics'. In this section we shall consider the practical aspects associated with capacitors in electronic circuits.

A capacitor stores a small amount of electric charge; it can be thought of as a small rechargeable battery which can be quickly recharged. In electronics we are not only concerned with the amount of charge stored by the capacitor but in the way the value of the capacitor determines the performance of timers and oscillators by varying the time constant of a simple capacitor–resistor circuit.

CAPACITORS IN ACTION

If a test circuit is assembled as shown in Fig. 4.38 and the changeover switch connected to d.c. the signal lamp will only illuminate for a very short pulse as the capacitor charges. The charged capacitor then blocks any further d.c. current flow. If the changeover switch is then connected to a.c. the lamp will illuminate at full brilliance because the capacitor will charge and discharge continuously at the supply frequency. Current is *apparently* flowing through the capacitor because electrons are moving to and fro in the wires joining the capacitor plates to the a.c. supply.

COUPLING AND DECOUPLING CAPACITORS

Capacitors can be used to separate a.c. and d.c. in an electronic circuit. If the output from circuit A, shown in Fig. 4.39(a), contains both a.c. and d.c.

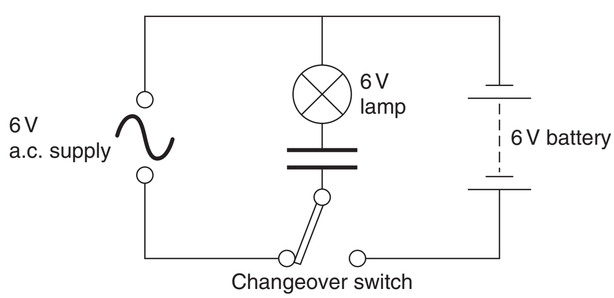


FIGURE 4.38
Test circuit showing capacitors in action.

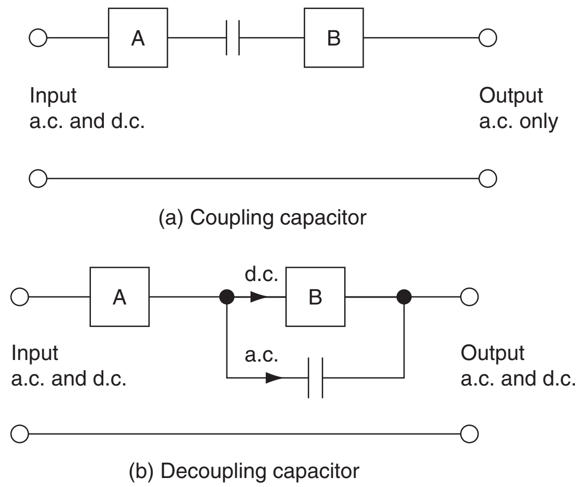


FIGURE 4.39
(a) Coupling and (b) decoupling capacitors.

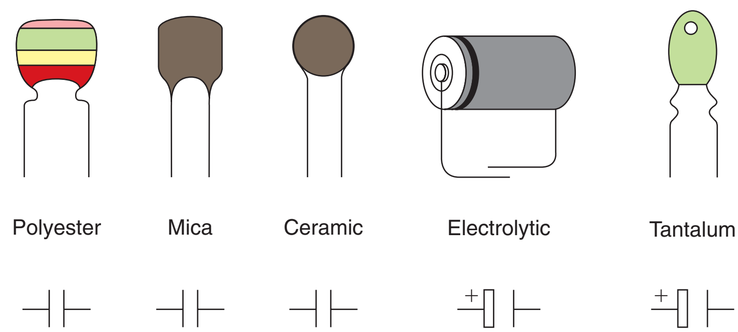


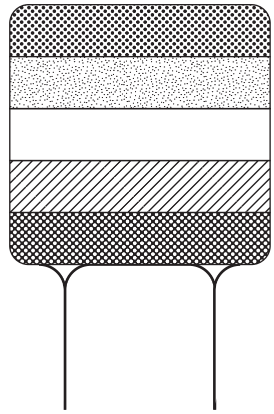
FIGURE 4.40
Capacitors and their symbols used in electronic circuits.

but only an a.c. input is required for circuit B then a *coupling* capacitor is connected between them. This blocks the d.c. while offering a low reactance to the a.c. component. Alternatively, if it is required that only d.c. be connected to circuit B, shown in Fig. 4.39(b), a *decoupling* capacitor can be connected in parallel with circuit B. This will provide a low reactance path for the a.c. component of the supply and only d.c. will be presented to the input of B. This technique is used to *filter out* unwanted a.c. in, for example, d.c. power supplies.

TYPES OF CAPACITOR

There are two broad categories of capacitor, the non-polarized and polarized type. The non-polarized type can be connected either way round, but polarized capacitors *must* be connected to the polarity indicated otherwise a short circuit and consequent destruction of the capacitor will result. There are many different types of capacitor, each one being distinguished by the type of dielectric used in its construction. Fig. 4.40 shows some of the capacitors used in electronics.

Table 4.5 Colour Code for Plastic Film Capacitors (Values in Picofarads)



Colour	Band (a) first number	Band (b) second number	Band (c) number of zeros to be added	Band (d) tolerance (%)	Band (e) maximum voltage (V)
Black	–	0	None	20	–
Brown	1	1	1	–	1000
Red	2	2	2	–	250
Orange	3	3	3	–	–
Yellow	4	4	4	–	400
Green	5	5	5	5	–
Blue	6	6	6	–	–
Violet	7	7	7	–	–
Grey	8	8	8	–	–
White	9	9	9	10	–

Polyester capacitors

Polyester capacitors are an example of the plastic film capacitor. Polypropylene, polycarbonate and polystyrene capacitors are other types of plastic film capacitor. The capacitor value may be marked on the plastic film, or the capacitor colour code given in Table 4.5 may be used. This dielectric material gives a compact capacitor with good electrical and temperature characteristics. They are used in many electronic circuits, but are not suitable for high-frequency use.

Mica capacitors

Mica capacitors have excellent stability and are accurate to ±1% of the marked value. Since costs usually increase with increased accuracy, they tend to be more expensive than plastic film capacitors. They are used where high stability is required, for example in tuned circuits and filters.

Ceramic capacitors

Ceramic capacitors are mainly used in high-frequency circuits subjected to wide temperature variations. They have high stability and low loss.

Electrolytic capacitors

Electrolytic capacitors are used where a large value of capacitance coupled with a small physical size is required. They are constructed on the ‘Swiss roll' principle as are the paper dielectric capacitors used for power-factor correction in electrical installation circuits. The electrolytic capacitors' high capacitance for very small volume is derived from the extreme thinness of the dielectric coupled with a high dielectric strength. Electrolytic capacitors have a size gain of approximately 100 times over the equivalent non-electrolytic type. Their main disadvantage is that they are polarized and must be connected to the correct polarity in a circuit. Their large capacity makes them ideal as smoothing capacitors in power supplies.

Tantalum capacitors

Tantalum capacitors are a new type of electrolytic capacitor using tantalum and tantalum oxide to give a further capacitance/size advantage. They look like a 'raindrop' or 'blob' with two leads protruding from the bottom. The polarity and values may be marked on the capacitor, or a colour code may be used. The voltage ratings available tend to be low, as with all electrolytic capacitors. They are also extremely vulnerable to reverse voltages in excess of 0.3 V. This means that even when testing with an ohmmeter, extreme care must be taken to ensure correct polarity.

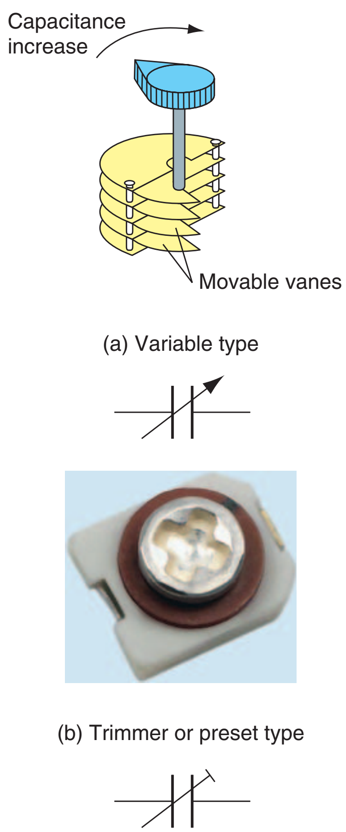


FIGURE 4.41
Variable capacitors and their symbols: (a) variable type; (b) trimmer or preset type.

Variable capacitors

Variable capacitors are constructed so that one set of metal plates moves relative to another set of fixed metal plates as shown in Fig. 4.41. The plates are separated by air or sheet mica, which acts as a dielectric. Air dielectric variable capacitors are used to tune radio receivers to a chosen station, and small variable capacitors called *trimmers* or *presets* are used to make fine, infrequent adjustments to the capacitance of a circuit.

SELECTING A CAPACITOR

When choosing a capacitor for a particular application, three factors must be considered: value, working voltage and leakage current.

The unit of capacitance is the *farad* (symbol F), to commemorate the name of the English scientist Michael Faraday. However, for practical purposes the farad is much too large and in electrical installation work and electronics we use fractions of a farad as follows:

$$1 \text{ microfarad} = 1\mu\text{F} = 1 \times 10^{-6} \text{ F}$$
$$1 \text{ nanofarad} = 1\text{nF} = 1 \times 10^{-9} \text{ F}$$
$$1 \text{ picofarad} = 1\text{pF} = 1 \times 10^{-12} \text{ F}$$

The power-factor correction capacitor used in a domestic fluorescent luminaire would typically have a value of 8 μF at a working voltage of 400 V. In an electronic filter circuit a typical capacitor value might be 100 pF at 63 V.

One microfarad is one million times greater than one picofarad. It may be useful to remember that:

$$1000 \text{ pF} = 1\text{nF}$$
$$1000 \text{ nF} = 1\mu\text{F}$$

The working voltage of a capacitor is the *maximum* voltage that can be applied between the plates of the capacitor without breaking down the dielectric insulating material. This is a d.c. rating and, therefore, a capacitor with a 200 V rating must only be connected across a maximum of 200V d.c. Since a.c. voltages are usually given as rms values, a 200 V a.c. supply would have a maximum value of about 283 V, which would damage the 200 V capacitor. When connecting a capacitor to the 230 V mains supply we must choose a working voltage of about 400 V because 230 V rms is approximately 325 V maximum. The 'factor of safety' is small and, therefore, the working voltage of the capacitor must not be exceeded.

An ideal capacitor which is isolated will remain charged forever, but in practice no dielectric insulating material is perfect, and the charge will slowly *leak* between the plates, gradually discharging the capacitor. The loss of charge by leakage through it should be very small for a practical capacitor.

Capacitor colour code

The actual value of a capacitor can be identified by using the colour codes given in Table 4.5 in the same way that the resistor colour code was applied to resistors.

Example 1

A plastic film capacitor is colour coded, from top to bottom, brown, black, yellow, black, red. Determine the value of the capacitor, its tolerance and working voltage.

From Table 4.5 we obtain the following:

Band (a) – brown has a value 1.
Band (b) – black has a value 0.
Band (c) – yellow indicates multiply by 10,000.
Band (d) – black indicates 20%.
Band (e) – red indicates 250 V.

The capacitor has a value of 1,00,000 pF or 0.1 μF with a tolerance of 20% and a maximum working voltage of 250 V.

Example 2

Determine the value, tolerance and working voltage of a polyester capacitor colour-coded, from top to bottom, yellow, violet, yellow, white, yellow.

From Table 4.5 we obtain the following:

Band (a) – yellow has a value 4.
Band (b) – violet has a value 7.
Band (c) – yellow indicates multiply by 10,000.
Band (d) – white indicates 10%.
Band (e) – yellow indicates 400 V.

The capacitor has a value of 4,70,000 pF or 0.47 μF with a tolerance of 10% and a maximum working voltage of 400V.

Example 3

A plastic film capacitor has the following coloured bands from its top down to the connecting leads: blue, grey, orange, black, brown. Determine the value, tolerance and voltage of this capacitor.

From Table 4.5 we obtain the following:

Band (a) – blue has a value 6.
Band (b) – grey has a value 8.
Band (c) – orange indicates multiply by 1000.
Band (d) – black indicates 20%.
Band (e) – brown indicates 100 V.

The capacitor has a value of 68,000 pF or 68 nF with a tolerance of 20% and a maximum working voltage of 100 V.

CAPACITANCE VALUE CODES

Where the numerical value of the capacitor includes a decimal point, it is standard practice to use the prefix for the multiplication factor in place of the decimal point. This is the same practice as we used earlier for resistors.

The abbreviation μ means microfarad, n means nanofarad and p means picofarad. Therefore, a 1.8 pF capacitor would be abbreviated to 1p8, a 10 pF capacitor to 10 p, a 150 pF capacitor to 150 p or n15, a 2200 pF capacitor to 2n2 and a 10,000 pF capacitor to 10 n.

$$1000\ \text{pF} = 1\text{nF} = 0.001\mu\text{F}$$

Packaging electronic components

When we talk about packaging electronic components we are not referring to the parcel or box which contains the components for storage and delivery, but to the type of encapsulation in which the tiny semiconductor material is contained. Figure 4.42 shows three different package outlines for just one type of discrete component, the transistor. Identification of the pin connections for different packages is given within the text as each separate or discrete component is considered, particularly later in this chapter when we discuss semiconductor devices. However, the Appendices aim

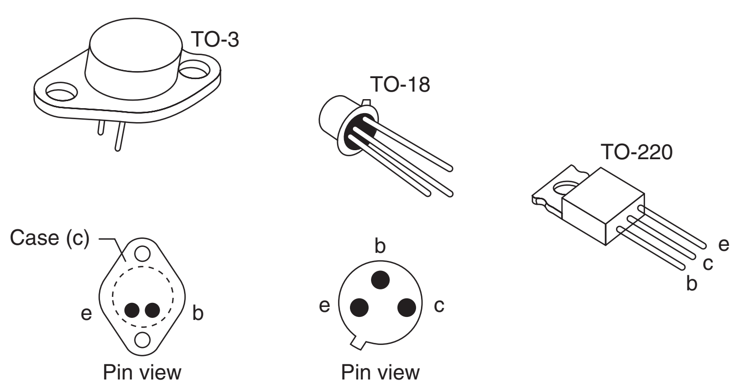


FIGURE 4.42
Three different package outlines for transistors.

to draw together all the information on pin connections and packages for easy reference.

Obtaining information and components

Electricians use electrical wholesalers and suppliers to purchase electrical cable, equipment and accessories. Similar facilities are available in most towns and cities for the purchase of electronic components and equipment. There are also a number of national suppliers who employ representatives who will call at your workshop to offer technical advice and take your order. Some of these national companies also offer a 24-hour telephone order and mail order service. Their full-colour, fully illustrated catalogues also contain an enormous amount of technical information. The names and addresses of these national companies are given in the Appendix A. For local suppliers you must consult your local phone book and *Yellow Pages*. The Appendices of this book also contain some technical reference information.

SEMICONDUCTOR MATERIALS

Modern electronic devices use the semiconductor properties of materials such as silicon or germanium. The atoms of pure silicon or germanium are arranged in a lattice structure, as shown in Fig. 4.43. The outer electron orbits contain four electrons known as *valence* electrons. These electrons are all linked to other valence electrons from adjacent atoms, forming a covalent bond. There are no free electrons in pure silicon or germanium and, therefore, no conduction can take place unless the bonds are broken and the lattice framework is destroyed.

To make conduction possible without destroying the crystal it is necessary to replace a four-valent atom with a three- or five-valent atom. This process is known as *doping*.

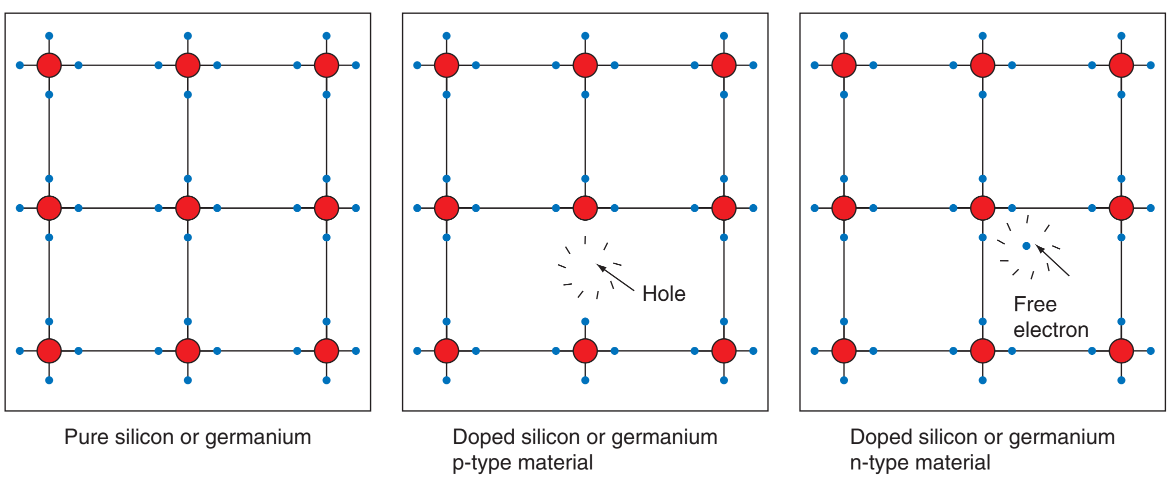


FIGURE 4.43
Semiconductor material.

If a three-valent atom is added to silicon or germanium a hole is left in the lattice framework. Since the material has lost a negative charge, the material becomes positive and is known as a p-type material (p for positive).

If a five-valent atom is added to silicon or germanium, only four of the valence electrons can form a bond and one electron becomes mobile or free to carry charge. Since the material has gained a negative charge it is known as an n-type material (n for negative).

Bringing together a p-type and n-type material allows current to flow in one direction only through the p–n junction. Such a junction is called a diode, since it is the semiconductor equivalent of the vacuum diode valve used by Fleming to rectify radio signals in 1904.

SEMICONDUCTOR DIODE

A semiconductor or junction diode consists of a p-type and n-type material formed in the same piece of silicon or germanium. The p-type material forms the anode and the n-type the cathode, as shown in Fig. 4.44. If the anode is made positive with respect to the cathode, the junction will have very little resistance and current will flow. This is referred to as forward bias. However, if reverse bias is applied, that is, the anode is made negative with respect to the cathode, the junction resistance is high and no current can flow, as shown in Fig. 4.45. The characteristics for a forward and reverse bias p–n junction are given in Fig. 4.46.

It can be seen that a small voltage is required to forward bias the junction before a current can flow. This is approximately 0.6V for silicon and 0.2V for germanium. The reverse bias potential of silicon is about 1200V and for germanium about 300V. If the reverse bias voltage is exceeded the diode

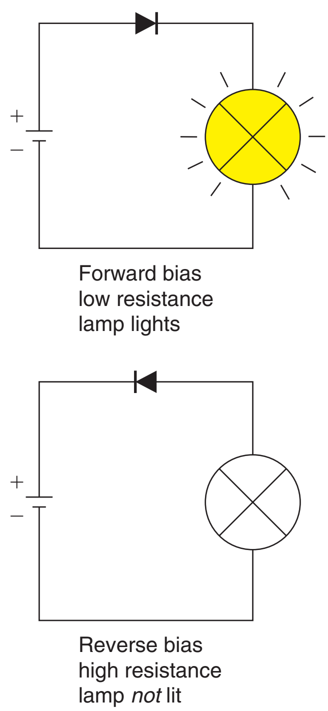


FIGURE 4.45
Forward and reverse bias of a diode.

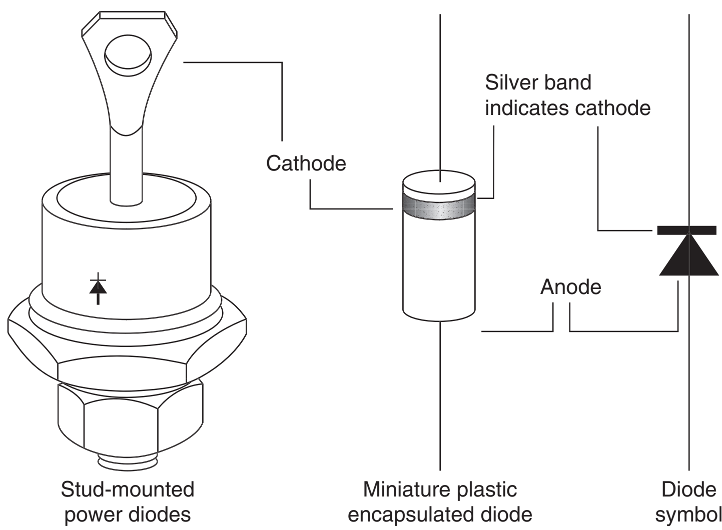


FIGURE 4.44
Symbol for and appearance of semiconductor diodes.

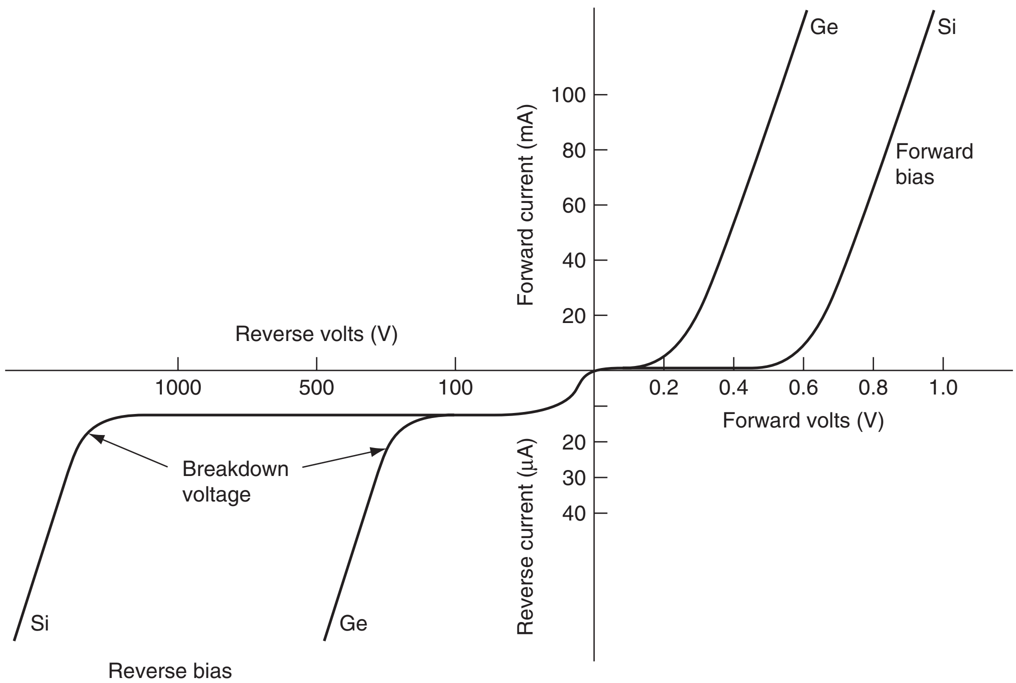


FIGURE 4.46
Forward and reverse bias characteristic of silicon and germanium.

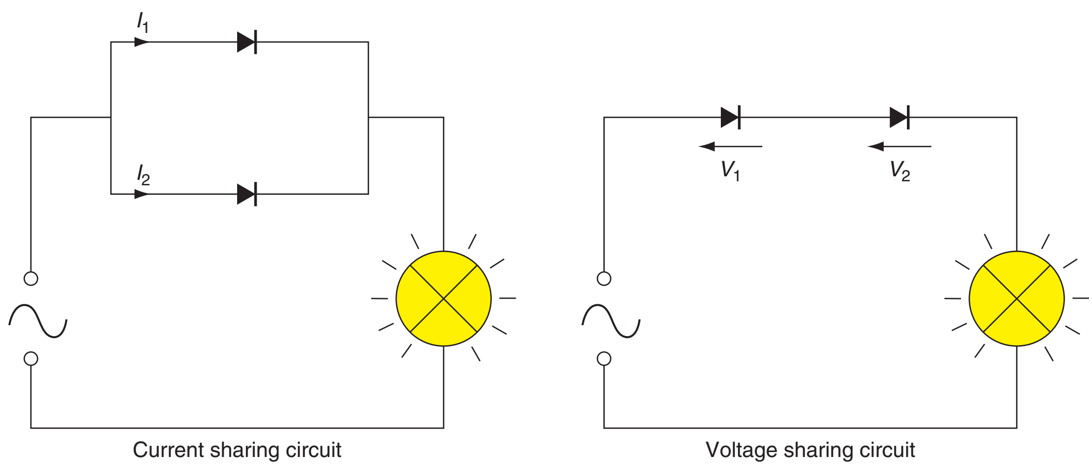


FIGURE 4.47
Using two diodes to reduce the current or voltage applied to a diode.

will break down and current will flow in both directions. Similarly, the diode will break down if the current rating is exceeded, because excessive heat will be generated. Manufacturer's information therefore gives maximum voltage and current ratings for individual diodes which must not be exceeded. However, it is possible to connect a number of standard diodes in series or parallel, thereby sharing current or voltage, as shown in Fig. 4.47, so that the manufacturers' maximum values are not exceeded by the circuit.

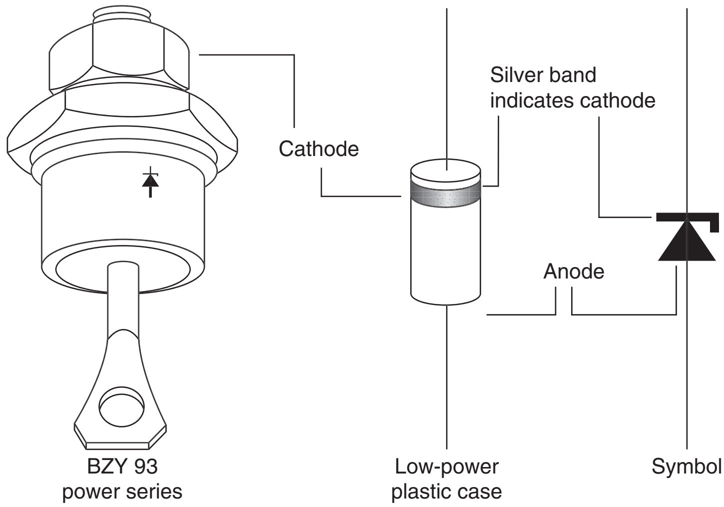


FIGURE 4.48
Symbol for and appearance of Zener diodes.

DIODE TESTING

The p–n junction of the diode has a low resistance in one direction and a very high resistance in the reverse direction.

Connecting an ohmmeter, with the red positive lead to the anode of the junction diode and the black negative lead to the cathode, would give a very low reading. Reversing the lead connections would give a high resistance reading in a 'good' component.

ZENER DIODE

A Zener diode is a silicon junction diode but with a different characteristic than the semiconductor diode considered previously. It is a special diode with a predetermined reverse breakdown voltage, the mechanism for which was discovered by Carl Zener in 1934. Its symbol and general appearance are shown in Fig. 4.48. In its forward bias mode, that is, when the anode is positive and the cathode negative, the Zener diode will conduct at about 0.6 V, just like an ordinary diode, but it is in the reverse mode that the Zener diode is normally used. When connected with the anode made negative and the cathode positive, the reverse current is zero until the reverse voltage reaches a predetermined value, when the diode switches on, as shown by the characteristics given in Fig. 4.49. This is called the Zener voltage or reference voltage. Zener diodes are manufactured in a range of preferred values, for example, 2.7, 4.7, 5.1, 6.2, 6.8, 9.1, 10, 11, 12V, etc., up to 200V at various ratings. The diode may be damaged by overheating if the current is not limited by a series resistor, but when this is connected, the voltage across the diode remains constant. It is this property of the Zener diode which makes it useful for stabilizing power supplies and these circuits are considered at the end of this chapter.

If a test circuit is constructed as shown in Fig. 4.50, the Zener action can be observed. When the supply is less than the Zener voltage (5.1V in this case) no current will flow and the output voltage will be equal to the input

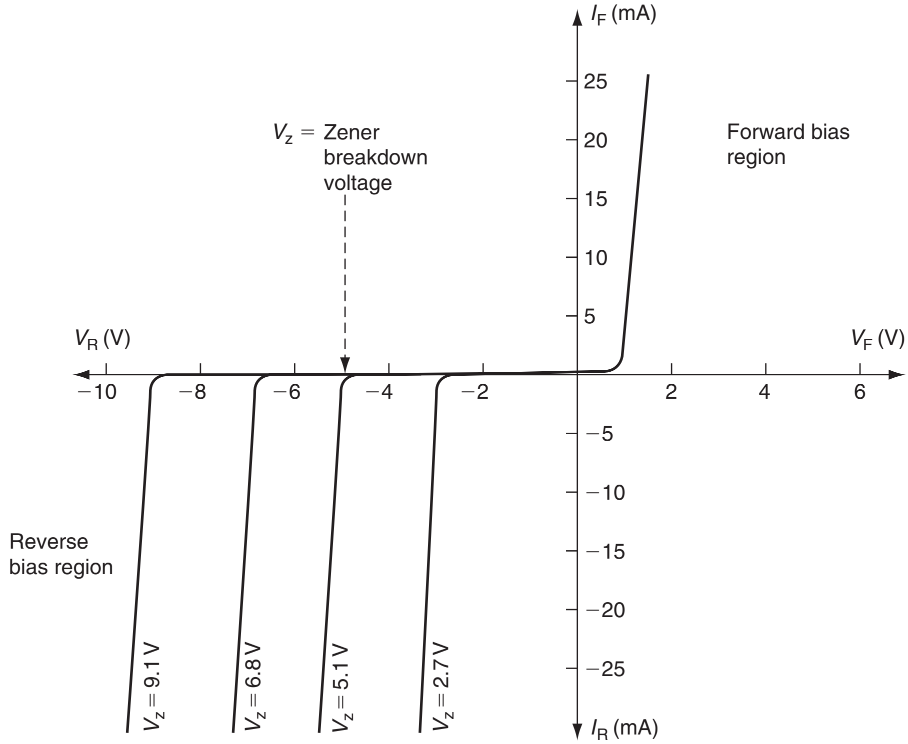
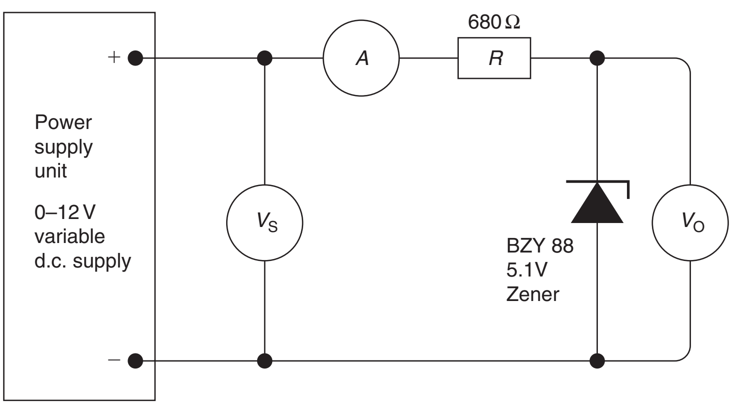


FIGURE 4.49
Zener diode characteristics.



P.S.U. Supply Volts (V_S)	Current (A)	Output Volts (V_O)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

FIGURE 4.50
Experiment to demonstrate the operation of a Zener diode.

voltage. When the supply is equal to or greater than the Zener voltage, the diode will conduct and any excess voltage will appear across the 680 Ω resistor, resulting in a very stable voltage at the output. When connecting this and other electronic circuits you must take care to connect the polarity of the Zener diode as shown in the diagram. Note that current must flow through the diode to enable it to stabilize.

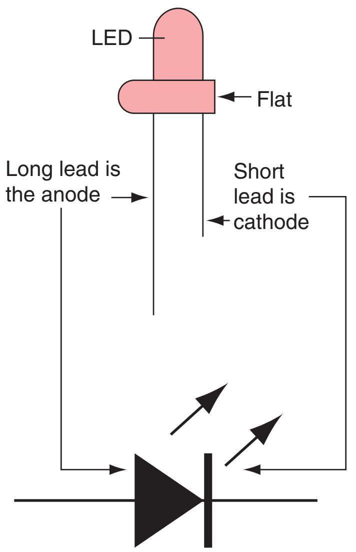


FIGURE 4.51
Symbol for and general appearance of an LED.

LIGHT-EMITTING DIODE

The light-emitting diode (LED) is a p–n junction especially manufactured from a semiconducting material which emits light when a current of about 10 mA flows through the junction.

No light is emitted when the junction is reverse biased and if this exceeds about 5V the LED may be damaged.

The general appearance and circuit symbol are shown in Fig. 4.51.

The LED will emit light if the voltage across it is about 2V. If a voltage greater than 2V is to be used then a resistor must be connected in series with the LED.

To calculate the value of the series resistor we must ask ourselves what we know about LEDs. We know that the diode requires a forward voltage of about 2V and a current of about 10 mA must flow through the junction to give sufficient light. The value of the series resistor *R* will, therefore, be given by:

$$R = \frac{\text{Supply voltage} - 2\text{ V}}{10\text{ mA}}\ \Omega$$

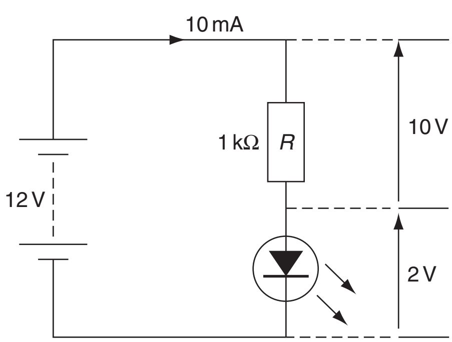


FIGURE 4.52
Circuit diagram for LED example.

Example

Calculate the value of the series resistor required when an LED is to be used to show the presence of a 12V supply.

$$R = \frac{12\text{ V} - 2\text{ V}}{10\text{ mA}}\ \Omega$$

$$R = \frac{10\text{ V}}{10\text{ mA}} = 1\text{ k}\Omega$$

The circuit is, therefore, as shown in Fig. 4.52.

LEDs are available in red, yellow and green and, when used with a series resistor, may replace a filament lamp. They use less current than a filament lamp, are smaller, do not become hot and last indefinitely. A filament lamp, however, is brighter and emits white light. LEDs are often used as indicator lamps, to indicate the presence of a voltage. They do not, however, indicate the *precise* amount of voltage present at that point.

Try This

LEDs

Make a list in the margin of examples where you have seen LEDs being used.

Another application of the LED is the seven-segment display used as a numerical indicator in calculators, digital watches and measuring instruments. Seven LEDs are arranged as a figure 8 so that when various segments are illuminated, the numbers 0–9 are displayed as shown in Fig. 4.53.