NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: CHM 304

COURSE TITLE: COLOUR CHEMISTRY AND TECHNOLOGY

COURSE GUIDE

CHM304
COLOUR CHEMISTRY AND TECHNOLOGY

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Published By:
National Open University of Nigeria

First Printed 2011

ISBN: 978-058-333-5

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Introduction

Colour Chemistry and Technology is a second semester course and a three - credit degree course available to students offering Bachelor of Science (B.Sc) Chemistry.

Colour Chemistry and Technology is an emerging field of Industrial Chemistry. The first synthetic dye, Mauveine, was discovered by Perkin in 1856. Colour, pigment and polymer industry can rightly be described as a new idea. However, it remains a vibrant, challenging industry requiring a continuous stream of new products because of the quickly changing world in which we live. Polymer science is, driven by the desire to produce new materials for new applications. The success of materials such as polyethylene, polypropylene, and polystyrene is so enormous that these materials are now manufactured on a huge scale and are indeed ubiquitous. There is still a massive drive to understand these materials and improve their properties in order to meet the material requirements. However, increasingly, polymers are being applied to a wide range of problems and in developing new materials.

The oil crisis in the early 1970s, which resulted in a steep increase in the prices of raw materials for colour, dyes, fibres and polymers, led to the search for more cost-effective materials, both by improving the efficiency of the manufacturing processes and by replacing tinctorially weak chromogens such as anthraquinone with tinctorially stronger chromogens such as (heterocyclic) azo and benzodifuranone. These themes are still important and ongoing, as they are the current themes of product safety, quality, and protection of the environment. There is also considerable activity in colour and dyes for high-tech applications, especially in the electronics and non-impact printing Industries.

This course guide is primarily a simple description of what the course is made up of, the materials to be used and how you can work with these materials. In addition, it advocates some general guidelines on the time you are likely to spend on each unit of the course in order to complete it successfully.

What you will Learn in this Course

In this course, you will learn about important chemical materials such as colour, dyes, pigment, etc. You will also learn how fibres and related polymers are produced from natural sources and in synthetic forms. In addition, the applications of colours, dyes, pigments, fibres and polymers in the environment will be examined. New challenges and economic importance of chemical material in an emerging economy will also be discussed.

Course Aims

The aim of the course is to provide a basic understanding of the nature of chemical materials and the emerging trend. In addition, it seeks to address the massive drive to understand these materials and improve their properties in order to meet material requirements

Course Objectives

To achieve the set aims, the course has a set of objectives. Each of the unit contained in a specific module has stated objectives which are included at the beginning of the unit. A clearer understanding of each of the objectives is a prerequisite for also understanding the contents of the unit. It is highly essential to reflect, as you work through each unit, on the objectives.

The main objectives of the course are listed below. By meeting these objectives, you should have achieved the aims for which the course has been designed. At the end of this course, you should be able to:

i. explain the concept of colour, pigments, dyes and related materials
ii. identify each of the colours, dyes and pigments; their properties and uses. In addition, you should be able to produce colours that best suited your desired need
iii. explain the relationship and difference between colours, pigment and dyes
iv. illustrate how fibers and related polymers are produced
v. define the concept of dyeing and pigment technology in relation to specific materials
vi. describe new challenges in the emerging world of chemical and material technology
vii. demonstrate the basic mechanism and processes involved in dyeing and pigment.

Working through this Course

In order to successfully complete this course, you are required to carefully study each unit along with other recommended textbooks and materials that may be provided by the National Open University. You may also need to exploit e-reading such as the internet for further useful information on the course.

Each unit contains self assessment exercise and at some point in the course you would be required to submit assignments for grading and recording purposes. You are also to participate in the final examination at the end of the course. It is recommended that you devote sufficient time for reading and comprehension. It is highly necessary that you avail yourself the opportunity of attending the tutorial sessions where you will be able to compare your understanding of the course contents with your colleagues.

The Course Materials

The main components of this course are:

1. The Course Guide
2. Study Units
3. Self Assessment Exercise
4. Tutor-Marked Assignments
5. References/Further Reading

Study Units

There are 17 study units in this course as follows:

Module 1 Colour, Pigments and Dyes

Unit 1 Colour and its Features
Unit 2 Types of Colour
Unit 3 Pigments
Unit 4 Organic, Inorganic and Metallic Pigments
Unit 5 The Linkages between Pigments and Dyes
Unit 6 Application of Dyes and Pigments

Module 2 Classification of Dyes and Fibres

Unit 1 Classification of Dyes
Unit 2 Classification of Fibres
Unit 3 Natural Dyes and Dyeing Processes

Module 3 Synthetic Dyes and Fibres

Unit 1 Synthetic Fibres
Unit 2 Polymer Fibres
Unit 3 Polyesters and Polyamide Fibres
Unit 4 Polyurethanes, Cellulose and Polyacrylonitrile
Unit 5 Aramids, Poly (methyl methacrylate) and Polycarbonate

Module 4 Dyeing Mechanisms

The first unit addresses the nature and concept of colour and related materials. It focuses on why objects are in colour we see. The second unit describes in details the different types of colour and their application in the environment. The third unit is primarily concerned with the nature and properties of pigments as a class of coloured materials. The fourth unit addresses the classes of pigments and their chemical characteristics. The fifth unit deals with the linkages between pigments and dyes. The sixth unit explains the applications of dyes and pigments. The seventh unit enumerates the various classes of dyes while the eighth unit addresses the classification of fibres. The ninth unit is concerned with the dyeing processes.

Unit10 focuses on the meaning and different types of synthetic fibres. Unit 11 also addresses the nature and chemical constituents of synthetic polymers with emphasis on the polyethylene group. Unit 12 discusses the chemical formation and importance of polyesters and polyamide fibres, while the 13th unit explains the nature, formation and uses of Polyurethanes, Cellulose and Polyacrylonitrile. Units 14, 15 and 16 focus on the advances in the instruments and machines employed in the dyeing processes. The 14th unit explains the textile dyeing process with emphasis on the continuous, semi-continuous and pad batch dyeing processes. Unit 15 primarily deals with the workings of beam dyeing machine, hank dyeing machine and jig dyeing machine. Lastly, the 17th unit addresses the jet dyeing machine.

Each of the units is made up of one or two weeks' work consisting of introduction, objectives, reading materials, self assessment exercise, conclusion, summary, tutor- marked assignment (TMA), suggestions for further reading and source materials. The unit directs you to work on exercises related to the required reading. Together with the TMAs, they are meant to test your basic understanding and comprehension of the course materials, which is a prerequisite for achieving the stated aims and objectives of the course.

Presentation Schedule

The course materials have important dates for the timely completion and submission of your TMAs and tutorial lessons. You are vividly reminded of the need to promptly submit answers to tutorials and assignments as at when due.

Assessment

The course assessment consists of three aspects namely the self assessment exercise, the tutor- marked assignment and the end of course examination.

It is essential that you attempt all exercises and assignments and submit appropriately to the course facilitator for grading. Let your answers be concise and as accurate as possible. You are expected to consult other materials in addition to your course material to answer the questions. Kindly note that the tutor- marked assignment constitute only 30 per cent of the total marks for the course.

Tutor-Marked Assignment (TMA)

The TMA is a continuous assessment component of your course. It accounts for 30 per cent of the total score. You will be given five TMAs to answer. Three of these must be answered before you are allowed to sit for the end of the course examination. The TMAs will be given to you by your facilitator and returned after you have done the assignment. Note that these assignments are already contained in the assignment file to be given to you. You may do yourself good by reading and researching well before you attempt to answer the questions.

You are warned to submit these assignments to the facilitator at the stipulated time as indicated in the assignment file. However, if for any reason you are unable to meet the deadline, you are required to intimate the facilitator of your problem before the due date and seek for an extension which may be granted or not.

Final Examination and Grading

The end of the course examination for Colour Chemistry and Technology will be for about three hours with maximum score value of 70 per cent of the total course work. The examination will be made up of questions which will reflect what you have learnt in the course materials/further reading. In addition, they may be similar to the self assessment exercises and the TMAs. The end of the course examination is intended to cover information from all parts of the course.

Avail yourself the opportunity of the period between the completion of the course and the beginning of the examination to revise as much as possible the whole course material, the exercises and assignments.

Course Marking Scheme

Assignment	Marks
Assignments 1-5	Five assignments, best three of the five count at 10% each i.e. 30% of the course marks
End of course Examination	70% of overall course marks
Total	100% of the course materials

Facilitation/Tutorials

There are 17 hours of tutorials provided in support of this course. You will be informed appropriately of the name, telephone number and e-mail address of your facilitator. In addition, the time, dates and location of the tutorial lessons will be communicated beforehand. You are required to mail or submit your tutor- marked assignment to your facilitator, at least two working days, before the scheduled date.

Note that all the submitted assignments will be duly marked by the facilitator with further comments that can improve on your performance. The facilitator will from time to time take track record of your comprehension, progress and difficulty in the course.

Endeavour to attend tutorial lessons at the fixed appointment. It is probably the only avenue to meet face- to- face and discuss with your facilitator. This will also afford you the opportunity to ask questions or seek clarification on seemingly grey areas in the course material. It is advisable that you have questions and comments for your facilitator before the due date. An active participation during the tutorial lessons will be an added advantage to boost your confidence level.

In case any of the situations listed below arises, do not hesitate to intimate your facilitator using his or her telephone number or e-mail address:

- You do not understand any part of the study or the assigned readings
- You are not skilled enough to attempt the self assessment exercise
- The questions in the TMAs are not clearly understood

Summary

Colour Chemistry and Technology is a course which is intended to provide students with the nature and concept of chemical materials that are indispensable and highly valuable in our environment. Upon completion of this course therefore, it is expected that you would apply the knowledge to cause a positive change in our environment.

Accept my best wishes in the course and I do hope that you will benefit considerably from its application.

Course Code CHM327
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Published By:
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First Printed 2011

ISBN: 978-058-333-5

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MODULE 1 COLOUR, PIGMENTS AND DYES

UNIT 1 COLOUR AND ITS FEATURES

CONTENTS

1.0 INTRODUCTION

Electromagnetic radiation is characterised by its wavelength (or frequency) and its intensity. When the wavelength is within the visible spectrum (the range of wavelengths humans can perceive, approximately from 380 nm to 740 nm), it is known as "visible light". Most light sources emit light at many different wavelengths; a source's *spectrum* is a distribution giving to its intensity at each wavelength. Although the spectrum of light received by the eye from a given direction determines the colour sensation in that direction, there are many more possible spectral combinations than colour sensations. Therefore, one may formally define a colour as a class of spectra that gives rise to the same colour sensation, although such classes would vary widely among different species, and to a lesser extent among individuals within the same species. In each such class, the members are called *metamers* of the colour in question.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- explain the history of colour
- define colour
- identify the different kinds of colour
- explain why objects appear the colour they are.

3.0 MAIN CONTENT

3.1 Definition of Colour

Colour is simply defined as the light of different wavelengths and frequencies. Light, however, is just one form of energy that we can actually see that is made up of photons.

3.2 History of Colour

Some of the early studies and theories about light were done by Aristotle. He discovered that by mixing two colours, the third is produced. He did this with a yellow and blue piece of glass, which when brought together produced green. He also discovered that light travels in waves. Plato and Pythagoras also studied light. In the 10th century, Al-Haytham researched into colour and his findings inspired Newton. During the Middle Ages, Paracelsus reintroduced the knowledge and philosophy of colour using the power of the colour rays for healing along with music and herbs. Unfortunately, he was hounded throughout Europe and ridiculed for his work. Most of his manuscripts were burnt, but now he is thought of, by many, to be one of the greatest doctors and healers of his time. A man, it would seem, very much ahead of his time. Not only do we now use Colour Therapy once again, but, his other ideas, using herbs and music in healing, can also be seen reflected in many of the complementary therapies now quite in commonplace.

A pioneer in the field of colour, Isaac Newton, in 1672 published his first, controversial paper on colour, and forty years later, his work 'Opticks'. Newton passed a beam of sunlight through a prism, when the light came out of the prism it was not white but was of seven different colours: Red, Orange, Yellow, Green, Blue, Indigo and Violet. The spreading into rays of these colours was called ‘dispersion’ by Newton and he called the different coloured rays the 'spectrum'. He discovered that when the light rays were passed again through a prism, the rays turned back into white light. If one ray was passed through the prism it would come out the same colour as it went in. Newton concluded that white light was made up of seven different coloured rays.

3.3 Where Does Colour Come from?

Colour comes from light. We can see seven main colours of the Visible Spectrum. The retinas in our eyes though have three types of colour receptors in the form of cones, we can actually only detect three of these visible colours – red, blue and green. These colours are called additive primaries. It is these three colours that are mixed in our brain to create all of the other colours we see. The wavelength and frequency of light also influences the colour we see. The seven colours of the spectrum all have varying wavelengths and frequencies. Red is at the lower end of the spectrum and has a higher wavelength but lower frequency than that of violet at the top end of the spectrum which has a lower wavelength and higher frequency.

To physically see this, we need a prism. When light from the sun passes through a prism, the light is split into the seven visible colours by refraction. Refraction is caused by the change in speed experienced by a wave of light when it changes medium.

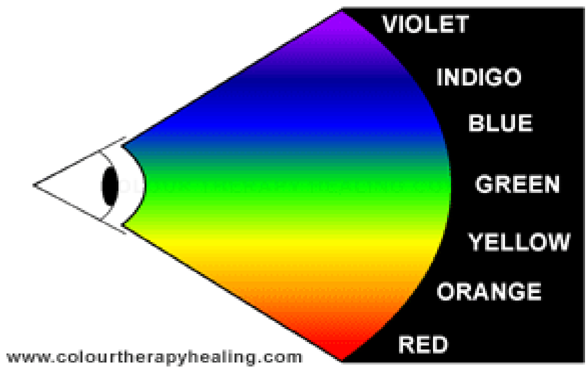


Fig. 1.1: Colours of Visible Spectrum
Source: www.colourtherapyhealing.com

3.4 Electromagnetic Waves and Visible Spectrum

The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. The electromagnetic spectrum of an object is the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object. The electromagnetic spectrum extends from below frequencies used for modern radio through to gamma radiation at the short wavelength end, covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. The long wavelength limit is the size of the universe itself, while it is thought that the short wavelength limit is in the vicinity of the Planck length, although in principle the spectrum is infinite and continuous.

Generally, electromagnetic radiation (EM) is classified by wavelength into radio wave, microwave, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays. The behaviour of EM radiation depends on its wavelength. When EM radiation interacts with single atoms and molecules, its behavior also depends on the amount of energy per quantum (photon) it carries.

The diagram below shows what small part of the whole electromagnetic visible spectrum light actually forms.

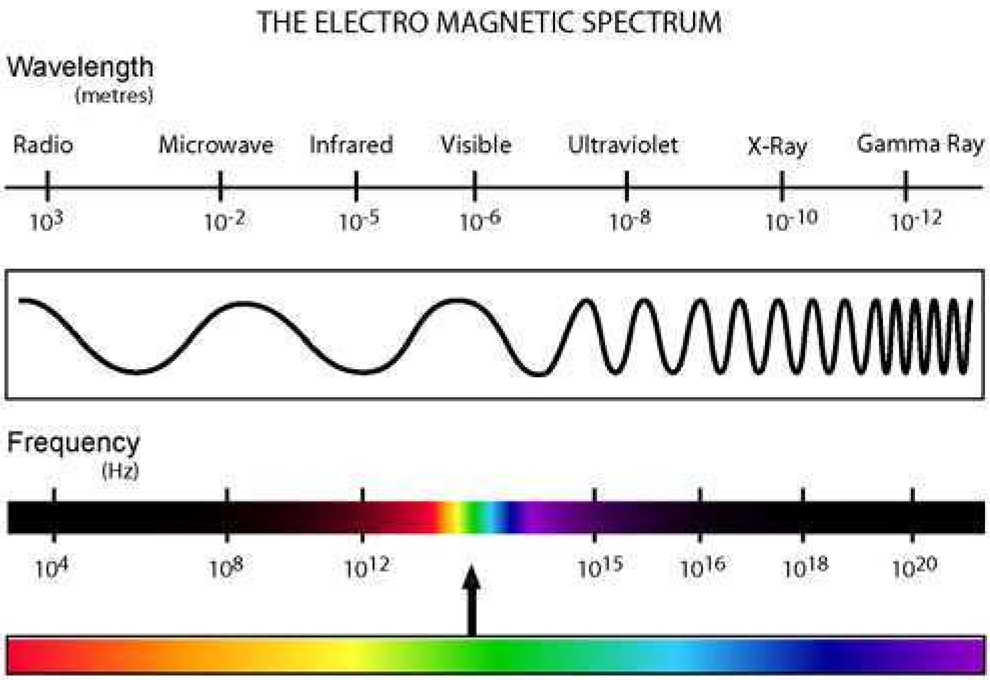


Fig. 1.2: **Nature of Electromagnetic Radiation**
Source: www.colourtherapyhealing.com

The amount of energy in a given light wave is proportionally related to its frequency, thus a high frequency light wave has a higher energy than that of a low frequency light wave.

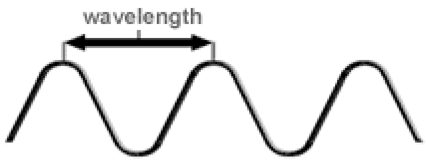
$E = h\nu$ where E= Energy; h=Planck' constant; v= velocity of light

SELF ASSESSMENT EXERCISE 1

1. Explain briefly the origin of colour.
2. Highlight the content of visible spectrum.

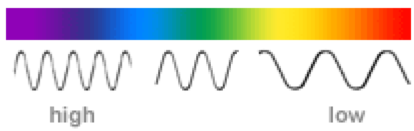
3.5 Wavelengths and Frequencies of Colour

Each colour has its own particular wavelength and frequency. Each colour can be measured in units of cycles or waves per second. If we can imagine light traveling in waves like that in an ocean, it is these waves that have the properties of wavelength and frequency. A wavelength is the distance between the same locations on adjacent waves.



Each of these waves has a different wavelength and speed of vibration. Together they form the electromagnetic spectrum. Light travels in waves.

The frequency of a wave is determined by the number of complete waves or wavelengths that pass a given point each second. All light travels at the same speed but each colour has a different wavelength and frequency. It is these different wavelengths and frequencies that cause different colours of light to be separate and visible when passing through a prism. This can be compared to the radio waves which have different frequencies and wavelengths in which certain stations can only be listened to at a particular frequency or wavelength. So, colour blue, for instance, - can only be visible at a particular frequency and wavelength range. The higher the frequency of a colour, the closer the waves of its energy.



Higher frequency colours are violet, indigo, and blue while the lower frequency colours are yellow, orange and red. A high frequency light wave has a higher energy than that of a low frequency light wave.

3.6 Properties of Colour

Each colour has its own properties with its own wavelength and frequency. Although white could be said to be a colour, it is generally not included in the scientific spectrum as it is in fact made up of all the colours of the spectrum, but it is often being referred to as a colour.

Table 1.1: Colour and Relative Property

Colour	Wavelength Range (nm)	Frequency Range (THz)
Red	700-635	430-480
Orange	635-590	480-510
Yellow	590-560	510-540
Green	560-490	540-610
Blue	490-450	610-670
Violet	450-400	670-750

(Frequency = Terahertz (one trillion cycles per second); **Wavelength** = Nanometers

One meter equals 1,000,000,000 nanometers. One nanometer is about the length of ten atoms in a row)

3.7 Colour Perception

We see colour with the sensors in the retina of the eye called rods and cones. The rods are sensitive to low light and the cones, which require a greater intensity of light, are sensitive to colour. The message is passed to the optic nerve and then on to the brain.

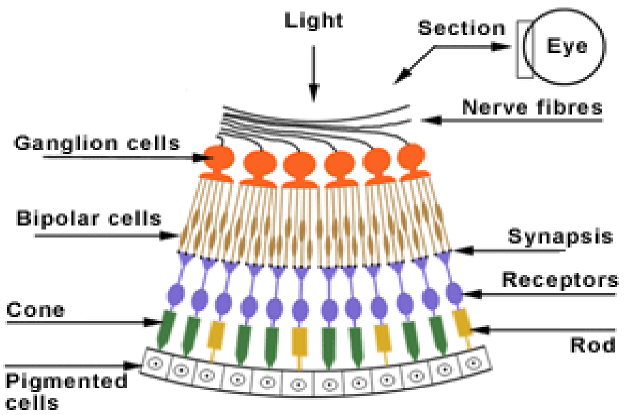


Fig. 1.3: Colours and Eyes
Source: www.colourtherapyhealing.com

The eye picks up colour and light by the rods and cones. It is the *Cones* that detect colour. Each cone contains one of three pigments sensitive to either red green or blue. There are about 120 million rods and about 6 to 7 million cones in the human eye. Rods are more sensitive than the cones but they are not sensitive to colour, they perceive images as black, white and different shades of grey. More than one thousand times as sensitive, the rods respond better to blue but very little to red light.

Each pigment absorbs a particular wavelength of colour. There are short wavelength cones that absorb blue light, middle wavelength cones that absorb green light, and long wavelength cones that absorb red light. When we observe a colour that has a wavelength between that of the primary colours red, green and blue, combinations of the cones are stimulated. An example could be that yellow light stimulates cones that are sensitive to red and green light. The result is that we can detect light of all colours in the visible spectrum.

People who suffer from colour blindness have less numbers of particular cones than normal, so they get confused with colours. If we lose our eye sight, the body adapts and receives colour rays through the skin. It takes time for the body to adapt, but it has been shown that people, who are blind, can differentiate between different colours.

3.8 Why are Objects the Colour they are?

Everything we can see has a colour. Around us, in our homes, at work, in nature, in space - it is universal; everywhere has a colour, of some sort. The colour of anything we observe depends upon a few factors. Firstly **-** *Everything* is made up of electrons and atoms. Different materials, objects and items have a different make up of atoms and electrons. Any object, by its nature, will, when exposed to light, do one of the following: reflect or scatter light (reflection and scattering), absorb light (absorption), do nothing (transmission) and refract light (refraction).

3.8.1 Reflection and Scattering

A lot of objects reflect light to some degree, but something that is particularly reflective, has more free electrons that are able to pass from one atom to another with ease. The light energy that is absorbed by these electrons is not passed onto any other atoms, instead, the electrons vibrate and the light energy is sent out of the material at the same frequency as the original light coming in. Smooth surface reflect light while rough surface scatter it and the angle of incidence is always equal to angle of reflection.

3.8.2 Absorption

When something appears to have no reflection or is opaque, then the incoming light source frequency is the same as, or very close to the vibration frequency of the electrons in the given material. The electrons of the material absorb the energy of the light source, and because the light is absorbed, the material or object appears opaque - it has very little or no reflection.

3.8.3 Transmission

This occurs when the energy of the incoming light is either much lower or much higher than the energy or frequency required to making the electrons in the particular material vibrate. As a result of this, the electrons in an object that appears to be transparent, instead of capturing the light energy, allows the light wave pass through the object/material unchanged, thus the object/material is transparent to that frequency of light.

3.8.4 Refraction

If you have ever put a straw in a drink, then you may have noticed that the straw appears to be bent under the water. The reason for this is ***Refraction***. If the energy of the incoming light is the same as the vibration frequency of the electrons in the material, the light is able to go deep into the material and causes small vibrations in the electrons. These vibrations are passed on to the atoms by the electrons, and in turn they send out light waves at the same frequency as the incoming light. Although this happens extremely quickly, some of the light that is inside of the material slows down, but the frequency of the light outside the material remains the same. The result of this is that the light inside the material is bent. The angle of the distortion (refraction) depends upon how much the material is able to slow down the light, in this case as in the image above water.

A good example as to why objects possess a particular colour is shown in the picture below (of ripe tomatoes). Tomatoes appear to be red because when ripe, tomatoes contain a carotenoid known as "Lycopene". Lycopene is a bright red carotenoid pigment, a phytochemical found not only in tomatoes but also other red fruits. Lycopene absorbs most of the visible light spectrum, and being red in colour, Lycopene reflects mainly red back to the viewer, and thus, a ripe tomato appears to be red.

Fig. 1.4: Tomato and its Colour
Source: www.colourtherapyhealing.com

Another example is the green leaf or green grass which uses Chlorophyll to change light into energy. Because of its nature and chemical makeup, Chlorophyll absorbs the blue and red colours of the spectrum and reflects the green. The green is reflected back out to the viewer making the grass and leaves appear green.

SELF ASSESSMENT EXERCISE 2

1. Explain in detail why objects possess a particular colour.
2. Mention the relationship between colours and the eyes.
3. What is colour perception?

4.0 CONCLUSION

Colour comes from light which resides mainly in the visible region of the electromagnetic radiation. This should not be interpreted as a definitive list – the pure spectral colours form a continuous spectrum, and how it is divided into distinct colours linguistically is a matter of culture and historical contingency. (Although people everywhere have been shown to *perceive* colours the same way). A common list identifies six main bands: red, orange, yellow, green, blue, and violet. Newton's conception included a seventh colour, indigo, between blue and violet – but most people do not distinguish it, and most colour scientists do not recognise it as a separate colour; it is sometimes designated as wavelengths of 420–440 nm. The *intensity* of a spectral colour may alter its perception considerably; for example, a low-intensity orange-yellow is brown, and a low-intensity yellow-green is olive-green.

5.0 SUMMARY

In this unit, you have learnt that:

- colour comes from light which is the visible portion of the electromagnetic radiation
- there are seven different kinds of colours namely: red, orange, yellow, green, blue, indigo and violet
- the *intensity* of a spectral colour may alter its perception considerably; for example, a low-intensity orange-yellow is brown, and a low-intensity yellow-green is olive-green
- the colour of anything we observe depends on what happened on exposure to light source
- any object, by its nature, will, when exposed to light, do one of the following: reflect or scatter light (reflection and scattering), absorb light (absorption), do nothing (transmission) and refract light (refraction).

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the concept of colour.
2. What are factors that determine what the colour of objects are?
3. Examine the concept of colour perception.

7.0 REFERENCES/FURTHER READING

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UNIT 2 TYPES OF COLOURS

CONTENTS

1.0 INTRODUCTION

The science of colour is sometimes called *chromatics*. It includes the perception of colour by the human eye and brain, the origin of colour in materials, colour theory in art, and the physics of electromagnetic radiation in the visible range (that is, what we commonly refer to simply as *light*). The familiar colours of the rainbow in the spectrum – named using the Latin word for *appearance* or *apparition* by Isaac Newton in 1671 – include all those colours that can be produced by visible light of a single wavelength only, the *pure spectral* or *monochromatic* colours.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- identify the different types of colour
- describe the constitution of each type of colour
- produce colour combination
- determine the kind of colour that best suits a particular environment
- enumerate the use to which colours are subjected.

3.0 MAIN CONTENT

3.1 Types of Colours

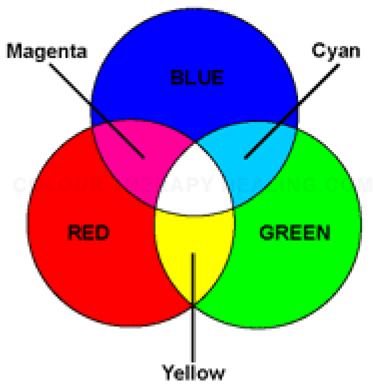
There are basically three types, namely primary, secondary and tertiary colours

3.2 Primary Colour

Contrary to popular belief, there are actually two methods of producing colours. They are the **Additive and Subtractive Colour.** To create all the colours of the rainbow, both processes use primary colours, which are colours that cannot be created by mixing other colours.

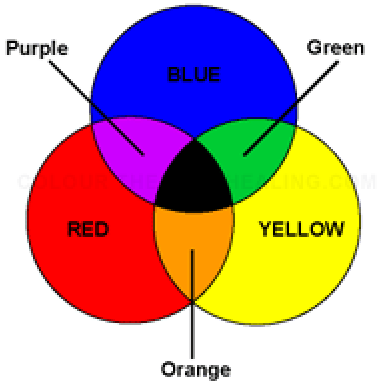
3.2.1 Additive Primary Colours

Additive colours are colours that are associated with emitted light directly from a source before an object reflects the light. These colours are red, green and blue. These are the colours we are probably most familiar with that are associated with television, and computer displays. If all three of the additive colours were combined together in the form of light, they would produce white. Some examples where additive primary colours are used include television, theatrical lighting and computer monitors. The additive colour theory was first described by James Clark Maxwell in the mid 1800s. When equal amounts of red, green and blue light are combined, they produce white light. By adding the colours together to produce white, we call these additive colours. Red, green and blue are the "primary" colours of white light. This is called colour by addition and is a direct way to prove that all of these three colours do indeed come from white light.



3.2.2 Subtractive Primary Colours

Subtractive colours are colours that are associated with reflected light. In this case the subtractive colours are blue, red and yellow. These are the colours we are probably most familiar with as primary colours in school. These colours are associated with the subtraction of light and used in pigments for making paints, inks, coloured fabrics, and general coloured coatings that we see and use every day. If all three of the subtractive primary colours are combined together, they will produce black. By adding the colours together to produce black, we call these subtractive colours.



The subtractive primary colours used in the printing process are cyan, magenta and yellow. Black is also used. All printing processes use subtractive colours in the form of cyan (blue), magenta (red), yellow, and sometimes black. This is known as CMYK for short (cyan, magenta, yellow, black) the K stands for black in the printing process. These colours: cyan, magenta and yellow are a set of subtractive primaries and are commonly used by printers. They are commonly referred to as the 'printing primaries'. It is difficult to achieve a good black from just these colour pigments so printers sometimes also use black. The reason that printers use this set of primaries as opposed to the painting primaries of blue, red and yellow, is that they yield far better results. If you are using these colours for painting however, you will find that mixing them is far less intuitive than when mixing the painting primaries.

Some examples where subtractive primary colours are used: textiles, clothes, furnishings, printing, paints and coloured coatings.

SELF ASSESSMENT EXERCISE 1

1. What is colour?
2. Differentiate between additive and subtractive primary colours.

3.3 Secondary Colours

If two of the primary colours are mixed together, a **secondary colour** is created. As more colours are mixed, the selection of colours grows. **The following colours can be created:**

Violet/Purple – mixing of Blue and Red
Orange - mixing of Red and Yellow
Green - mixing of Blue and yellow
Black - mixing of Blue, Red and Yellow

These colours that are created from mixing the primary colours are called secondary colours.

3.3.1 Additive Secondary Colours

Secondary additive colours are produced by mixing two additive primary colours together. The additive primary colours are red, green and blue. When these additive colours are mixed, they produce three secondary colours. These are: cyan, magenta and yellow.

3.3.2 Subtractive Secondary Colours

Secondary subtractive colours are produced by mixing two subtractive primary colours together. The additive primary colours are red, green and blue. When these subtractive colours are mixed, they produce three secondary colours. These are: Violet/purple, Orange and green.

3.4 Tertiary Colours

Tertiary colours are combinations of primary and secondary colours. There are six tertiary colours; red-orange, yellow-orange, yellow-green, blue-green, blue-violet, and red-violet. An easy way to remember these names is to place the primary name before the other colour. For instance, the tertiary colour produced when mixing the primary colour blue with the secondary colour green, is called 'blue-green"

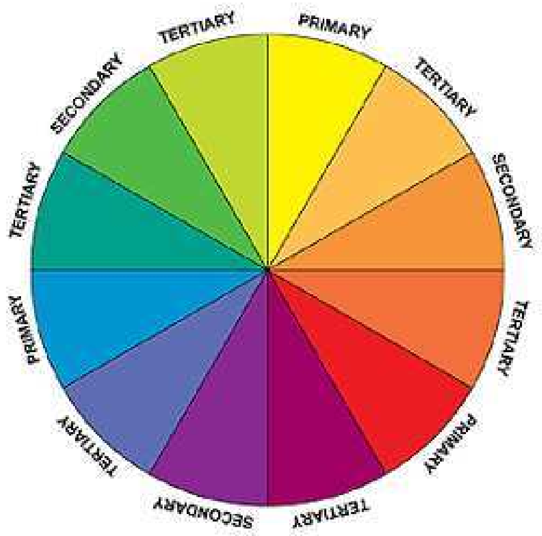


Fig. 2.1: Formation of Colours
Source: www.colourtherapyhealing.com

3.5 Colours in the Home

There are many variations of the basic colours. The paler versions, which are sometimes more appropriate for covering the walls within our homes, give us the same qualities as the bold colour but in a gentler way. When decorating an area - the complementary colours, and their variations, should be remembered and combined with our main choice of colour by way of soft furnishings, pictures etc.

It is also helpful to take in to account the aspect of a room. For example, should you require a calming atmosphere in a north facing room, which may well be one of the colder rooms in your house, remember to use some warm colours (i.e. variations of the warm colours of yellow, orange and red) to avoid the room feeling colder.

3.5.1 Using Colours in the Home

When using colour in the home environment, we all have our own personal choices. A Particular colour choice can help towards providing a specific 'feeling' for a space. Below are some suggested uses of colour in the home, workplace and various environments, and the effects these colours can produce.

Table 2.1: Colours, Features and Uses

Colour	Effect	Suggested Area of Use
Violet	Calming for body and mind. Good for meditation and prayer. Enhances purpose and dignity. Heightens our awareness and helps us to give our very best. Purifying.	Places of worship Entry areas to clinics and hospitals Festival areas Pale violet in bedrooms.
Indigo	Sedative Helps to open up our intuition The colour of divine knowledge and the higher mind.	Not suitable for areas for entertainment but for more 'quiet' places Bedrooms Treatment rooms Some people find indigo is helpful for studying so this colour could be used as part of the decor of a library or study.
Blue	Calming, relaxing and healing Not as sedating as indigo. Also the colour of communication.	Any rooms except those used for physical activity or play.
Green	Balancing, harmonising and encourages tolerance and understanding.	Depending upon the shade, can be used for most areas Useful for any rooms except those used for physical activity or play. It can be used with other colours/colour as well to avoid the balanceand harmony becoming more like total inactivity and indecision.
Yellow	Stimulates mental activity Promotes feeling of confidence Helpful for study as it helps us to stay alert.	Activity rooms Entrance halls Not for bedrooms as yellow can interfere with sleep since it tends to keep our minds "switched on"

		Not ideal for areas of possible stress.
Orange	Warming and energizing Can stimulate creativity Orange is the colour of fun and sociability.	Any activity area and creative areas Not ideal for bedrooms or areas of possible stress.
Red	Energizing, exciting the emotions Stimulates appetite.	Any activity area but red needs careful choice of tone and depth and the space in which it is to be used as it can make a space look smaller and can be claustrophobic or oppressive. However, used well, red and its variations can make a space feel warm and cosy. Often used in restaurants.
Magenta	Magenta is the eighth colour in the colour spectrum and is a combination of red and violet, it combines our earthly self and spiritual self, thus balancing spirit and matter. It is uplifting and helps us to gain a feeling of completeness and fulfillment.	Lecture spaces Chapels halls etc Not ideal for play rooms or activity rooms
White	White contains all the colours. It emphasises purity and illuminates our thoughts, giving us clarity.	Any room, but it can be a little intimidating to some. Needs to be broken up with another colour or with plants/ornaments/pictures etc.
Black	Black used with another colour enhances the energy of that second colour Black gives us the space for reflection and inner searching.	Not ideal as a single colour, but when used with care,can enhance and complement other colours in almost any situation.
Pink	This colour soothes and	Ideal for a baby's or child's

	nurtures It helps to dissolve anger and encourages unconditional love.	bedroom.
Turquoise	Cool and calming and good for the nervous system and immune system.	Any room except it is not ideal for activity areas.

SELF ASSESSMENT EXERCISE 2

Distinguish between secondary and tertiary colours

4.0 CONCLUSION

There are basically three types of colours: namely primary, secondary and tertiary colours. In addition, both the secondary and the tertiary colours arise through combinations of some primary colours.

5.0 SUMMARY

In this unit, we have learnt that:

additive colours are colours that are associated with emitted light directly from a source before an object reflects the light. These colours are red, green and blue.

subtractive colours are colours that are associated with reflected light. By adding the colours together to produce black, we call these subtractive colours.

the colours that are created from mixing the primary colours are called Secondary Colours

if the secondary colours are mixed, they produce what are called Tertiary Colours

use of colour in the home, workplace and various environments to produce aesthetic, psychological or healing.

6.0 TUTOR-MARKED ASSIGNMENT

1. Write short notes on the followings:

(a) Primary colours
(b) Secondary colours

2. In a tabular form, compare and contrast the nature and the uses of violet, magenta and blue colours

7.0 REFERENCES/FURTHER READING

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UNIT 3 PIGMENTS

CONTENTS

1.0 INTRODUCTION

Both dyes and pigments appear to be coloured because they absorb some wavelengths of light preferentially. In contrast with a dye, a pigment generally is insoluble, and has no affinity for the substrate. Some dyes can be precipitated with an inert salt to produce a lake pigment, and based on the salt used they could be aluminum lake, calcium lake or barium lake pigments.

2.0 OBJECTIVES

By the end of this, you should be able to:

define what a pigment is
identify types of pigments and their structure
differentiate between the known pigments.

3.0 MAIN CONTENT

3.1 Definition of Pigments

Pigments are generally coloured, organic or inorganic solid powder, and usually are insoluble. They are not affected physically or chemically in the substrate in which they are incorporated. Pigments can give a full range of colours.

3.2 Features of Pigments

The pigments are versatile colouring agents that come with all round features to give credence to their suitability in a variety of mediums. Some of the striking features are: -*----------------
Excellent light and weather fastness:

A good baking stability that makes them suitable for automotive and other industrial paints
High tinting strength--
Good over spray fastness when applied in paints
Gives heat stability of around 300° C in the case of Polyolefins Plastics
Excellent solvent resistance properties
Easily dispersible
Consistency and uniqueness of shades.

3.3 Types of Pigments

a. **Inorganic Pigments:** Those pigments that are made up of mineral compounds are known to be Inorganic Pigments. These minerals are mainly oxides, sulphides of one or more metals. To impart colours in different compounds, inorganic pigments are applied.

b. **Organic Pigments:** In organic pigments, the molecules are made of carbon atoms along with hydrogen, nitrogen or oxygen atoms. Organic pigments can be subdivided into two viz. Natural organic pigments and Synthetic organic pigments.

c. **Metallic Pigments:** Obtained from the ores of metal

3.3.1 Natural and Synthetic Organic Pigments

i. **Natural Organic Pigments -** Pigments of this category are derived from animal and plant products. The use of these pigments is rare due to their poor light fastness property.

ii. **Synthetic Organic Pigments -** Pigments of this category are carbon based and are often made from petroleum products. Under intense pressure or heat, carbon base molecules are manufactured from petroleum, acids, and other chemicals and synthetic organic pigments have been formulated from these molecule. Most of the synthetic organic pigments except carbon black are not stable and they will wear away at the time of use as a pigment.

Table 3.1: Comparison between Natural and Synthetic Organic Pigments

Natural Organic Pigments	Synthetic Organic Pigments						
Miscellaneous: e.g. Rose-Madder, Bone Black, Carbon Black	Quinacrid-ones	Phthaloc-yanines	Peryle-nes	Pyrroles	Ary-lamides	Metal Complexes: e.g. Transparent Yellow, New Gamboge	Miscellaneous: e.g. Dioxazsine-in Danthrone.

3.4 Differences among Types of Pigments

Table 3.2: Property of various Kinds of Pigments

Property Behaviour	Inorganic Pigments	Classical Organic Pigments	Specialty Organic Pigments	Organic Dyestuffs
Opacity	Usually high	Translucent to Transport		Very Transparent
Colour Strength	Low to moderate	Considerably stronger than Inorganic Pigments		Strongest
Dispersability	Usually Good: Often Abrasive	Adequate	Poor to good	Not required; Soluble
Heat Resistant	Usually 500^0 F; Some 200^0 C	150^0 C-300^0 C	200^0 C-300^0 C	250^0 C-350^0 C
Migration resistance	Excellent	Moderate - Good	Good - Outstanding	Very Poor - good
Light Fastness (on a Blue scale	6 to 8	2 to 6	6 to 8	2 to 7
Weather resistance	Outstanding for selection	Insufficient	Excellent for Selection	Good for selection

Source: www.dyespigments.com.

SELF ASSESSMENT EXERCISE 1

1. What do you understand by the word pigment?
2. List the kinds of pigments you know

3.5 Natural Pigments

Different types of natural pigments are found in different kinds of natural sources. Some of these pigments are obtained from insects/animals and others are obtained from plants. Other pigments belong to cosmetics and have affinity to all such foods and drugs which require colour additives. Natural pigments are good for use in the shower gel, bath bombs, bath salts, shampoo, soap, lotion and in many more other products. These pigments have good quality of bleed protectiveness in soap and these are also water dispersible. But, these pigments do not have high intensity in light.

3.5.1 Kinds of Natural Pigments

3.5.2 Annatto Natural Pigments

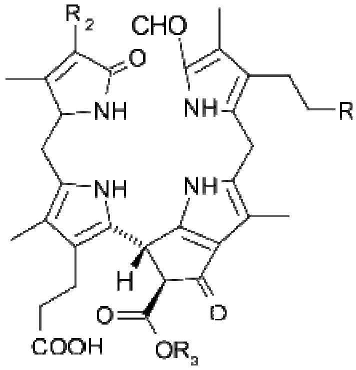
Annatto natural pigments have reddish-orange colourant. This colourant is derived from seeds of Achiote trees. Annatto pigments are given 'annatto' as a name because these pigments are derived from Annato shrubs. The concentration of annatto pigments in the annatto shrubs, vary from place to place. When the foodstuffs require hues of yellow to orange, annatto based pigments are used. The main food items in which annatto dyes are used are: in making cheese (around 50%), fish processing (around 20%), confectionery (around 10%), dairy products except cheese (around 20%). Bixin is the major carotenoid of annatto

Bixin

3.5.3 Plant Pigments

Chlorophyll is responsible for the green colour of flowering plants. Acetone is required for the extraction of plant pigments. Calcium carbonate must be present for stimulating the extraction process. Any other mild alkali can also be used for the extraction of plant pigments.

The alkali is used during the extraction process to neutralize the acid which liberates from the plant tissues.



Chlorophyll

3.5.4 Carotenoid Pigments

Carotenoid pigments e.g. β-carotene, have colour range from yellow to red. Mixture of acetone and hexane in the 1:3 ratios is used for the extraction of carotenoid pigments. The acetone fraction containing the extracted carotenoid pigments is removed with water. To remove the hexane residue, the mixture is treated with activated MgO_2 in diatomaceous earth column.

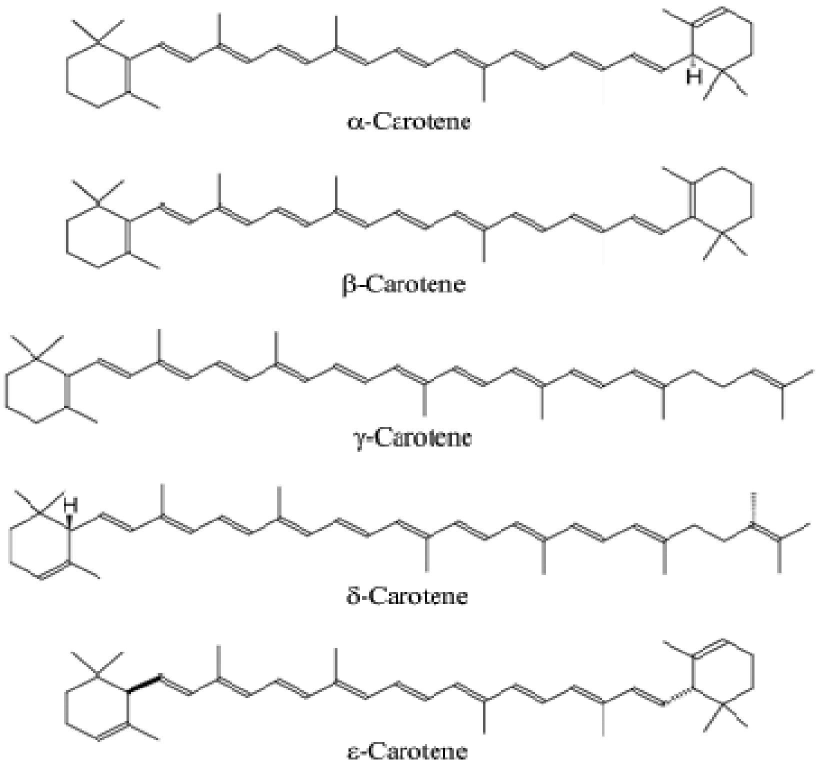
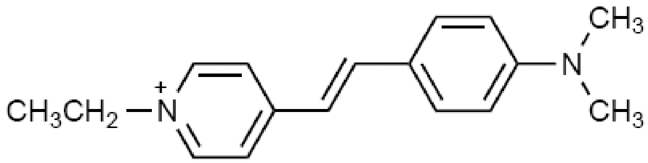


Figure 1. Chemical structure of carotene series.

3.5.5 Betalain Pigments

Betalains are another type of colour pigments which are also derived from plants. These pigments are present in two forms. The first is -cyanin having purple-red colour and are present in high concentration. The second is -xanthine which is yellow in colours which are obtained in low concentration. These pigments can easily be extracted from plant tissues with water as they are highly soluble in water. The extracted water is then mixed smoothly with ethyl alcohol in 1:1 ratio. The use of ethanol in the mixture is to reduce the enzymatic action; otherwise the pigments will be degraded.

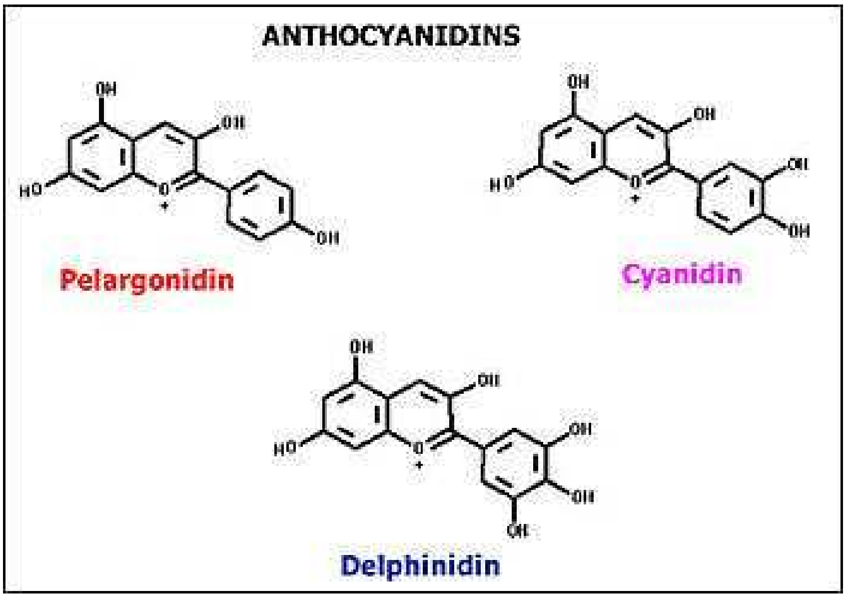


Cyanin

Xanthine

3.5.6 Anthocyanin Pigments

Anthocyanin pigments are coloured pigments and these are found in abundance in plant kingdom. The colours imparted by these pigments are blue, red and purple. The colour of fruits and flowers are also due to the colour impartation of these pigments. Anthocyanins are soluble in water and their extraction from the plant parts is also easy. Slightly acid mixed water is required for the extraction of these pigments.



3.6 Limitations of Natural Pigments

1. Natural pigments are produced by traditional methods.
2. These pigments have lower intensity in comparison to synthetic pigments.
3. To obtain the same depth like synthetic pigments, natural pigments require large quantities of raw materials.
4. These pigments are not efficient for colouring of the synthetic clothes.
5. To ensure adequate wash and light fastness, these pigments require application with different metallic mordants.
6. Application with few mordants like alumina and iron has adverse effects on the environment.
7. The liquid waste of natural pigments contains heavy metals which is much more than the desired limit.

3.7 Factors affecting the selection of Pigments

Factors affecting the choice of a pigment depend on application. The following broad factors can be taken as a guide:

Hiding efficiency
Colour pH value
Bulking value
Density
Refractive index
Hardness
Oil absorption

SELF ASSESSMENT EXERCISE 2

1. Mention four limitations of natural pigments.
2. Give the names and structures of three common pigments.

4.0 CONCLUSION

Pigments have been known since ages to impact positively as coloured substances made of both natural and synthetic materials. There are several factors to be taken into consideration when working with a pigment.

5.0 SUMMARY

In this unit, we have learnt that:

- pigments are generally described as insoluble colour materials
- there are different kinds of pigments, both natural and synthetic forms
- these natural pigments are made of diverse chemical structures which affects their colouring properties.

6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between natural and synthetic pigments.
2. Mention four limitations of natural pigments.
3. With structural examples, explain.

a. Betalain pigments
b. Anthocyanin pigments
c. Carotenoid pigments

7.0 REFERENCES/FURTHER READING

Brunello, F. (1973). *The Art of Dyeing in the History of Mankind*. Neri Press: Vincenza.

www.dyepigments.com

UNIT 4 ORGANIC, INORGANIC, AND METALLIC PIGMENTS

CONTENTS

1.0 INTRODUCTION

There are a number of pigments available today. In fact, after the advent of synthetic pigments there has evolved various types of pigments that are suited to particular needs and types of industries.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- State the different types of pigments
- discuss the features of each type of pigments
- identify the differences and similarities between types of pigments.

3.0 MAIN CONTENT

3.1 Definition of types of Pigments

Inorganic Pigments: Pigments that are made up of mineral compounds are known as Inorganic Pigments.

Organic Pigments: Organic Pigments are not usually found in nature. That is the reason why a majority of these pigments are chemically synthesized. They contain carbon and come with relatively low levels of toxicity, not providing any major environmental challenge.

Industrial Pigments: These are based on their industrial application.

3.2 Organic Pigments

Raw materials include coal tar and petroleum distillates that are transformed into insoluble precipitates. Traditionally organic pigments are used as mass colourants. They are popular in plastics, synthetic fibres and as surface coatings-paints and inks. In recent years the organic pigments are used for hi-tech applications that include photo-reprographics, opto-electronic displays and optical data storage.

3.2.1 Categories of Organic Pigments

a. Monoazo Pigments
b. Diazo Pigments
c. Acid and base dye Pigments
d. Phthalocyanine Pigments: Some of the striking features which makes it a very useful for a variety of applications are the following: Light fastness, tinting strength, covering power, resistance to the effects of alkalies and acids and good stability
e. Quinacridone Pigments: The following are important features of these pigments; outstanding light fastness, excellent bleed and heat resistance, bright and vibrant tones, very good tinting value along with working properties and high transparencies
f. Other polycyclic Pigments

3.2.2 Key Features of Organic Pigments

a. Very good stability to solvents, light, heat, and weathering
b. Good tinctorial strength
c. Cost effectiveness
d. Consistency and unique shades
e. Completely non-toxic
f. Very bright, pure, rich colors
g. Organic pigments shows good color strength

SELF ASSESSMENT EXERCISE 1

1. Mention the source of organic and inorganic pigments.
2. Mention three of the characteristics of organic pigments.

3.3 Inorganic Pigments

Inorganic pigments may be obtained from vivid naturally occurring mineral sources or minerals which have been obtained synthetically. They are of the type mineral-earth but generally are metallic oxides or synthetics. Pigments that are of the type Mineral-earth are very simple and naturally occurring coloured substances. The preparation process is also simple and consists of the steps of washing, drying, pulverizing and mixing into a formulation. Inorganic pigments are available in the market in different forms. These different forms are powder, pastes, slurries and suspensions. The Inorganic Pigments are again divided into two sub types.

3.3.1 Natural Inorganic Pigments

Natural inorganic pigments are the earth colours in natural form like ochers, umbers etc. These colour pigments are extracted from the earth bed, Iron oxide and hydroxide which are present in the soil. These two compounds are responsible for the colouration of these colour pigments. Clay, chalk and silica are also present in these pigments in varying quantity.

The types of Natural Inorganic Pigments are:

(i) **Azurite-** Actually these kind of natural inorganic pigments are copper carbonates having greenish blue shading. Over a very long period, azurite has been used as a pigment. But, often these pigments have been replaced by synthetic pigments or used to paint the expensive ultramarine as under paintings.

(ii) **Red earths-** These pigments are the most diverse kind of natural inorganic pigments. These are made from clay and they have a large amount of iron oxide. The colour varies from dull yellow to dull deep yellow or from dull orange to dull red or from dull dark brown to dark brown.

(iii) **Yellow earths-** These are natural earth containing silica and clay. These pigments are present in hydrous form of iron oxide. These pigments also contain gypsum or manganese carbonate. All over the world, these pigments are available and have been used from the prehistoric period.

3.3.2 Synthetic Inorganic Pigments

Synthetic inorganic pigments are manufactured in the laboratory. These pigments consist of metallic compounds like manganese violet; cobalt blue e.t.c. Synthetic inorganic pigments can also be produced by the replication of the natural earth colours like mars, red or yellow. As these pigments are manufactured in the laboratory, so they are found in pure form having fine particles.

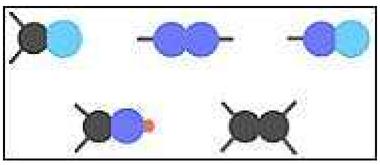
Table 4.1: Refractive Index of some of the very Popular Class of Inorganic Pigments

Pigment	Refractive Index
TiO_2 (rutile)	2.71
TiO_2 (Anatase)	2.55
Antimony Oxide	2.20
Zinc Oxide	2.01
Calcium Carbonate	1.65
Fumed Silica	1.45

Source: www.dyespigments.com

Synthetic organic pigments are mainly derived from some selective elements atoms. These are as follows:

Chromophore is a pair or group of atoms which creates a complex and dynamic clouding of the electrons within the respective electron shells in single atom or more than one atom. These chromophores are responsible for the colour creation phenomena of the pigment's molecules.



3.3.3 Shortcomings of Inorganic Pigments

Colour that comes from inorganic pigments is comparatively less bright. These pigments also seemed to be less rich and pure than the organic pigments. As these pigments have low tinting strength so a large number of pigments are required to produce the desired effects.

3.4 Differences between Organic and Inorganic Pigments

The differences between organic and inorganic pigments are based upon three principal factors.

i. Molecular structure of the pigments

Carbon chains or carbon rings are always present in the molecules of the *Organic Pigments*. As carbon element is associated with nitrogen and sulphur elements of the same class of the atomic table, so, sometimes in the molecules of the organic pigments, the atoms of nitrogen and sulphur are also found along with the carbon atoms.

Examples: Azo, Phthalocyanine, Diazo and Anthraquinone pigments.

However, in the molecules of the *Inorganic Pigments*, the cations of metal are found in an array form with the non-metallic anions. This arrangement does not allow these pigments to dissolve in the solvent and plastic. Examples: Iron oxide, yellow, black, red and tan pigments.

ii. Sources

The main sources of organic pigments are plants and plant products.

iii. Exposure

Inorganic pigments are considered better over their organic counterparts. These inorganic pigments can withstand the impact of sunlight and chemical much better. .They have also good opacity and thus can protect other objects by preventing light. These pigments also increase rash inhibition, abrasion resistance and rigidity to the molecules. These pigments are available at low cost in respect to the organic pigments. They are also durable.

Table 4.2: The Differences between Organic and Inorganic Pigments

Particulars	Inorganic Pigments	Organic Pigments
Source	Minerals	Chemically refined oil
Color	Often dull	Bright
Dyeing/Coloring Strength	Low	High
Opacity	Opaque	Transparent
Light fastness	Very good	Vary from poor to good
Solubility	Insoluble in solvents	Have little degree of solubility
Degree of safety	May be unsafe	Usually safe
Chemical Stability	Often sensitive	Usually good
Cost	Moderate	Mostly too expensive

Source: www.dyespigments.com

3.5 Metallic Pigments

Nowadays, metallic pigments are a very popular category of pigments, as a further classification. Metallic pigments can be of two types:

(i) Aluminium Pigments: Aluminium pigments are further divided into two categories namely leafing grade and non-leafing grade. The aluminum pigments are produced from aluminium that has purity in the range of 99.3-99.97%. The particle has lamellar shape with 0.1-2 µm in thickness and diameter of 0.5-200 µm. These pigments found use in automotive topocoats. Some of the preferred applications of Aluminium pigments are the following:

i. Corrosion protection coats
ii. Reflective paints
iii. In Marine paints (covering coats)
iv. Roof coatings
v. In Heat-proof and highly heat-resistance paints
vi. Chrome effect paints
vii. Aerosols

(ii) Zinc Pigments: Zinc Pigments come in two forms of powder and dust. Usually the zinc dust is finer as compared to powder and is spherical in shape. The dust also has a light coating of zinc oxide.

Table 4.3: Zinc Pigments along with their Applications

Zinc Pigments	Application
Zinc dust	Chemical applications Metallurgical applications
Zinc phosphate	Active ingredient in domestic cleaning products
Zinc oxide	Agricultural applications Rubber industry Brick kilns Ceramics

Source: www.dyespigments.com

4.0 CONCLUSION

There a number of pigments in the world today that have serve mankind in various applications. The use to which pigments are put depends on a number of factors. The presence of chromophores that absorbs light of certain wavelength is the most striking feature of individual pigments.

5.0 SUMMARY

In this unit, you have learnt that:

natural organic pigments are abundant in nature and consist of carbon and some other elements
inorganic pigments are obtained from naturally occurring mineral sources or minerals which have been obtained synthetically. They are of the type mineral-earth but generally are metallic oxides
synthetic inorganic pigments are manufactured in the laboratory. These pigments consist of metallic compounds like manganese violet, cobalt blue
metallic pigments are primarily composed of aluminium and zinc

6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between organic and inorganic pigments.
2. Write short notes on the following:

a. kinds of natural inorganic pigments
b. Application of aluminium pigments
c. Categories of organic pigments

7.0 REFERENCES/FURTHER READING

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UNIT 5 THE LINKAGE BETWEEN PIGMENTS AND DYES

CONTENTS

1.0 INTRODUCTION

Both dyes and pigments appear to be coloured because they absorb some wavelengths of light preferentially. In contrast with a dye, a pigment generally is insoluble, and has no affinity for the substrate. However, there has been an interchange of usage between the two. Pigment dyeing is a comparatively recent addition.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- state what makes a dye
- identify the types of dyes
- differentiate between a dye and pigments
- explain how dyes work.

3.0 MAIN CONTENT

3.1 Definition of Dyes

A dye can generally be described as a coloured substance that has an affinity for the substrate to which it is being applied. The dye is generally applied in an aqueous solution, and may require a mordant to improve the fastness of the dye on the fiber.

3.2 Features of Dyes

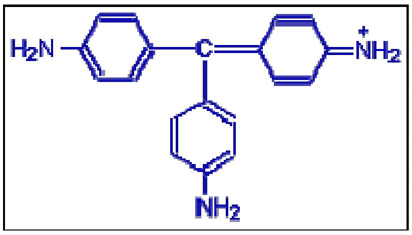
At the very basic level, the use of colour in identifying individual components of tissue sections can be accomplished primarily with dyes. Although there are other means, Dyes are however, the largest group that can easily be manipulated to our liking. Dyes are applied to numerous substrates for example to textiles, leather, plastic and paper in liquid form. One characteristic of dye is that the dyes must get completely or at least partially soluble in what it is being put to. The rule that we apply to other chemicals is similarly applicable to dyes also. For example, certain dyes can be toxic, carcinogenic or mutagenic and can be hazardous to health.

3.3 How Can the Colour of the Dyes be Altered?

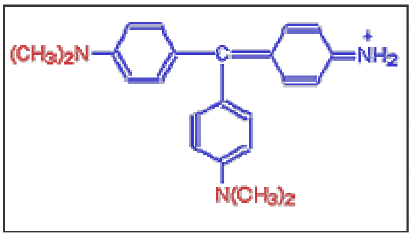
The answer lies in the modifiers. Colour modifiers like methyl or ethyl groups can actually alter the colour of dyes. They do so by altering the energy in the delocalised electrons. It has been found that by addition of a particular modifier there is a progressive alteration of colour. An example can be given for methyl violet series.

The following step explains what happens to the colour of the dyes when modifiers are added

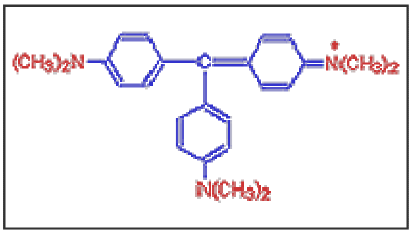
Step A: When no methyl group is added, the original dye *Pararosanil* as it is called is red in colour.



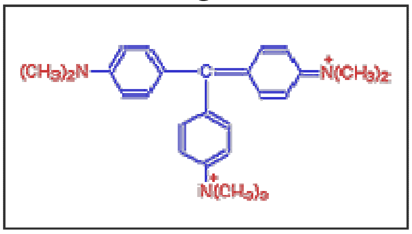
Step B: As four methyl groups are added a reddish purple dye *Methyl Violet* is got.



Step C: With the addition of more methyl groups a purple blue dye *Crystal Violet* is obtained. It has in it six such groups.



Step D: Further addition of a seventh methyl group the dye that is got is called *Methyl green.*



3.3.1 What Gives Dyes Solubility and Cohesiveness?

The answer to this riddle lies in substance called Auxochrome. Auxochromes have the abilty to intensify colours. It is a group of atoms which attaches to non-ionising compounds yet has to ionise. Auxochromes are of two types, positively charged or negatively charged.

—OH —NHR —Cl —Br

$—CH_3$ $—NO_2$ $—NR_2$ —COOH

$—NH_2$ $—SO_3H$

SELF ASSESSMENT EXERCISE 1

1. What is a dye?
2. What are the basic features of a dye

3.4 Dyeing and Fabric

This is an application of dyes with respect to the fabrics.

Table 5 .1: Types of Dyes and Fabric

Group	Application
Direct	Cotton, cellulosic and blended fibres
Vat dyes	Cotton, cellulosic and blended fibres
Sulphur	Cotton, cellulosic fibre
Organic pigments	Cotton, cellulosic, blended fabric, paper
Reactive	Cellulosic fibre and fabric
Disperse dyes	Synthetic fibres
Acid Dyes	Wool, silk, paper, synthetic fibres, leather
Azoic	Printing Inks and Pigments
Basic	Silk, wool, cotton

Source: www.dyespigments.com

3.5 Conventional Pigment Dyeing System

There is a challenge in pigment dyeing. In the process of pigment dyeing no actual chemical reaction takes place between the dye and the fabric. Instead, what happens is that the pigments get seated on the fabric with the help of binders.

Pigments are not soluble in water and show no affinity for fibre. So, conventional dyestuff-based dyeing conditions are not feasible for pigment dyeing. To come to terms with such limitations, a new kind of pigments have been formulated for use in fibres. These are maintained in a stable dispersion in the medium of water by anionic surfactants. This type of pigment is known as pigment resin color (PRC), primarily used in printing. Some of the popular pigments used in fabrics are given here.

a. Yellow colour: Acetoacetic acid anilide pigments
b. Red: Azoic pigments
c. Blue or green: Phthalocyanine pigments

A typical process of pigment dyeing for cellulosic textile materials consists of padding the textile materials with a dye bath. The dye bath contains anionic or neutral colour dispersions of pigments. Along with the pigments it also contains anionic binders, acid-liberating catalyst, anti-migrating agents, and other types of additives. Then, the textile materials are dried at high temperatures, this cures the film-forming binders and pigment colours firmly on the textiles.

3.6 Differences between Dyes and Pigments

The major differences between the Dyes and Pigments are highlighted below

Table 5.2: Differences between Dyes and Pigments

Points of Difference	Dyes	Pigments
Solubility	They are soluble	Pigments are colourants that are insoluble in water and most solvents
Number	Available in large number	Comparatively lesser in number
Product resistance	Lower as compared to pigments	Very high
Light fastness	Lower Dyes are very much vulnerable. Lights destroy coloured objects by breaking open electronic bonding within the molecule	Traditionally pigments have been found to be more lightfast than dyes
Size	Dye molecules are comparatively smaller it's like comparing a football (pigment) to say a head of a pin (dye)	Pigment particles are about 1-2 microns in size. (1 micron =1/1000 meter). It means that the particles can be seen under a magnifying glass
Bonding	Taking the example of dyeing a wood surface, the dye and the substrate (wood) that is dyed are chemicals that have certain features called functional groups. At the level of molecules these groups serve as open pockets of electrostatic charges (+ or -). The functional group in dyes, serve as a point for attaching the dye to the	Taking the example of a wood surface pigment requires the help of a binder for gluing. As it is an inert substance which is merely suspended in a carrier/binder

	wood	
Structure during the application process	During application process there is a temporary alteration in the structure of the dyes	During application, pigments have the capacity to retain its particulate or crystalline structure
Imparting of Colours	Dyes can only impart colour by selective absorption	Pigments impart colours by either scattering of light or by selective absorption
Combustible properties	Taking the example of a candle making process, if the candles are dyed it is easily combustible and can be applied throughout the candle	In the example of a candle making as pigments are coloured particles, they tend to clog a wick when burned. This makes them undesirable for a candle if it is coloured throughout and used for burning
Chemical Composition	Usually the dyes are organic (i.e. carbon-based) compounds	While pigments are normally inorganic compounds, often involving heavy toxic metals
Longevity factor	The dye based printing inks do not last as long as the pigment inks	In case of ink based printing prints made with pigments last longer
Printing on substrates	Compatible with almost all the substrates that needs to be dyed	Owing to the physical makeup of the pigment inks the range for suitable substrates are limited
Colour gamut	Taking the case of printing inks, dye based inks offers a wide variety	As compared to dye-based inks, pigment inksets somewhat lags behind, on the same paper stock

Source: www.dyespigments.com

4.0 CONCLUSION

It could be seen that dyes and pigments are not the same, though they may be similar in some cases. Interestingly, pigment can be dyed too. Certain chemical modification explains the reason behind the dyeing processes.

5.0 SUMMARY

In this unit, you have learnt that:

- a dye can generally be described as a coloured substance that has an affinity to the substrate to which it is being applied
- dye is generally applied in an aqueous solution, and may require a mordant to improve the fastness of the dye on the fiber
- the functional group in dyes, serve as a point for attaching the dye to the wood
- in the process of pigment dyeing no actual chemical reaction takes place between the dye and the fabric.

6.0 TUTOR-MARKED ASSIGNMENT

1. What are auxochromes? Mention four kinds of auxochrome.
2. In a tabular form, mention five differences between dye and pigment.

7.0 REFERENCES/FURTHER READING

Industrial Dyes, Chemistry, Properties, Applications; Edited by Klaus Hunger (2003). Wiley-VCH.

Herbst, W. & Hunger, K. (1997). *Industrial Organic Pigments*. Weinheim: VCH.

UNIT 6 APPLICATION OF DYES AND PIGMENTS

CONTENTS

1.0 INTRODUCTION

Modern dyes serve more than just being pretty. They have become indispensable tools for a variety of industries. Today various dyes are manufactured to meet the requirements of various industries. Dyes are available in various forms. Examples are dry powders, granules, pastes, liquids, pellets, and chips. Today the role and application of pigments have increased.. There would hardly be any industry left where dyes and pigments do not play any substantial role. The challenge is now to discover pigments that are capable of not only long-lasting applications but also are environmentally safe.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- identify the various applications of dyes and pigments
- describe the economic importance of dyes and pigments.

3.0 MAIN CONTENT

3.1 Application of Dyes and Pigments

From acting as colourants for plastics, textile dyeing industries and the highly sophisticated biotechnology industry, dyes are touching lives everywhere. Dyes and pigments are also used by industries for inks and tinting. Other industries, where dyes are used in a variety of products include paper and pulp, adhesives, art supplies, beverages, ceramics, construction, cosmetics, food, glass, paints, polymers, soap, wax, biomedicine etc.

3.2 Overview of the Important Applications of Pigments

- Paints- A diversified application in the whole gamut of paints that include decorative and protective coatings, in paints that are oil and resin based, automotive finishes, emulsion paints, distempers etc.
- Printing inks- Pigments are used in all kinds of printing inks that includes inks for printing metal foils, lacquers etc.
- Pigment finishes for leather and textiles: Colouration application for popular textiles such as polyesters, nylon etc
- Colouration of Plastics- Pigments are used in host of plastic applications that includes poly vinyl chloride (PVC), rubber and synthetic polymers, urea-formaldehyde (U-F) and melamine-formaldehyde moulding powders polystyrene, nylons, polyfins, phenol-formaldehyde (P-F), acrylonitrile-butadiene-styrene resins (ABS).

SELF ASSESSMENT EXERCISE 1

Give a brief account of the industrial application of dyes and pigments.

3.3 Industrial Application of Dyes and Pigments

3.3.1 Colourants for Plastic Industry

Colour selection is one of the vital things to be considered in the plastics industry. Colour is an integral part of the plastic material and it should not be considered as an afterthought. The whole system of colouring has to deal with using what is called a total systems approach. No doubt the colour enhances the part's functionality, but it has also the potential to degrade certain material properties like impact strength, if not properly applied. The colourants that are used in the plastic industries are the dyes and pigments. Both dyes and pigments exhibit colour through the process of visible light absorption and scattering. Typically colour formulations generally have four colourants. Black and white are used basically to control the value and Chroma, while two coloured pigments or dyes are applied to establish the Hue. The resulting colour that is achieved is governed by the laws of subtractive mixing, the same law that is used in printing and painting.

3.3.2 Cement Industry

Over the years, people have generated interesting effects by mixing cement and pigments in different ways and in different proportions. Concrete is derived from cement. For about last one century, pigments have been used with concrete to give them different colours. When pigments are mixed with concrete, then actually, these pigments tint the colour of the paste portion of the concrete.

To ensure a long lasting cement colour shade, the pigment that is being used in the cement, must have a good quality. These pigments (colour) are made from both natural and synthetic iron oxide, cobalt, titanium dioxide and chromium oxide. From iron oxide pigments, red, black and yellow colour can be obtained. From cobalt pigments, blue colour can be obtained. White colour and green colour can be obtained from titanium dioxide and chromium oxide respectively. Other colours like buffs, brown, tans, coppers, oranges, chocolates and many other colours can be obtained from the blends of the red, black and yellow coloured iron oxide pigments. These coloured pigments are: water-wetable, lightfast, alkali resistant and will not negatively affect the firmness and strength of the cement. But, one thing we should remember about the concentration of these pigments in the cement. This concentration should be within the range of 10% of the weight of the cementation ingredients.

3.3.3 Ceramic Industry

The applications of different pigments on ceramics are brought in different forms. These applications are as follows:

- **In Coating Ceramic Materials; Ceramic Glaze; Frits-** By formulating these coating applications of pigments on ceramics, the end users get attractive looking products with more durability and utility.
- **In Glaze development-** One of the applications of pigments on ceramics is to develop leading glazes for various whiteware ceramics. These include sanitary ware, tile, dinner ware etc.
- **In preventing Ceramics Corrosion and colour fading-** In this process, by applying pigment coating and protective layer with other kind of chemicals, the corrosion of the metals can be prevented. The lasting effect of colours also increases.

For enforcing the different applications on ceramics, various kind of special pigments are available. How much of which pigment will be used depends upon the desired colour intensity. But, the quantity of pigments that is used for these applications can vary from 1% to 10%. This variation does not make any noticeable impacts on the substances. Enamel (colourful) can be produced by colouring the melt during manufacturing. Enamel can also be generated by mixing colouring stains during the milling process.

3.3.4 Colourants for Security Printing

In view of the ever increasing threats of the cases involving forgery and fraud being committed in the financial institutions involving currency, both dyes and pigments play a vital role in giving cutting edge solutions to detect and prevent such fraud. Here we will discuss about the fluorescent dyes as well as about the luminescent pigments as applied in security applications.

Considerable research over the last decade or more on the study of fluorescence has borne fruits in the form of development of new fluorescent dyes. These security dyes are now applied increasingly in the very sensitive area of security printing. The fluorescent dyes are providing ways to create and apply effectively controlled"signatures". The United States Pharmacopeia (USP) of these dyes is that they are customized and are printed as patches on different kinds of surfaces. Each of them has a signature element that is able to identify the patch as authentic. As the different dye formulas are able to vary their fluorescence characteristics in various repeatable ways, as a result unique signatures can be achieved. A very popular Example of a dye that is used in security printing is that of Coumarin.

Coming now to *Luminescent pigments*, these days a new range of luminescence has been developed that are either excited by ultraviolet (UV) or infrared (IR) or applied in security printing applications. Here a few specific uses of the luminescent pigments in the security printing are discussed.

- Security Printing and prevention of counterfeiting- Security marks and features that are not visible under normal light are made with *Luminescent pigments*. They cannot be duplicated even by the ultra sophisticated photocopiers. They can be easily verified using a very simple Ultra violet light or a luminescence sensor. That is the reason why security printing of stamps, checks, credit cards, licenses etc are done with *Luminescent pigments.*

- Brand Protection and Security of Products- In applications that involve product security, luminescent pigments are used in making tamper evident seals for pharmaceuticals and other products. When it comes to brand protection, luminescent pigments and fluorescent dyes are used for proprietary invisible security marks and features which get printed on products, packaging and labels.

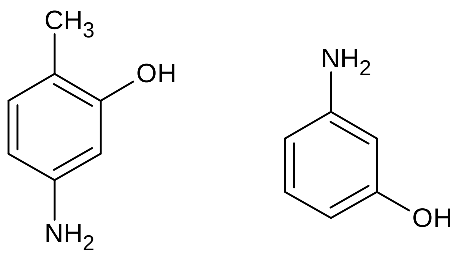
- Property Identification and Prevention of loss- As the invisible security marks created by luminescent dyes are not visible under normal conditions, do not deface the property and cannot be removed they are an ideal forensic tool.

SELF ASSESSMENT EXERCISE 2

Describe in detail, the application of dye or pigment in a security and printing industrial.

3.3.5 Colourants for Cosmetics Industry

Dyes have found a wide variety of uses in the cosmetics industry. Be it the hair dyes or lipsticks or nail polish shampoo everywhere there is wide use of dyes. Most of the commercial hair dye formulas available now are complex that use bountiful of ingredients and the formulas also differ considerably with manufacturers. The dye chemicals that are used in making hair dyes usually consist of amino compounds, like 4-amino-2-hydroxytoluene and m-Aminophenol. Pigments of metal oxides, like titanium dioxide and iron oxide, are also used.



4_amino_2_hydroxyltoluene m_amino phenol

In the category of decorative cosmetics, the majority of colours used are pigments. It is the inorganic pigments that are popular with cosmetics but are subject to purity levels of heavy metals. The range of inorganic pigments used in cosmetics is generally made up of various chemical types. A few of the popular ones are provided in the table.

Table 6.1: Applications of Pigments

Pigments	Features and applications
Iron Oxides	Three basic shades: black, yellow and red, finds use in liquid foundations, face powders, and blushers.
Chromium Dioxides	Shades range from dull olive green, to a blue green, or bright green, finds use in most categories of cosmetic preparations but prohibited for use in lip products in the USA.
Ultramarines	Shade range from bright blue to violet, pink and green also, not allowed for lip products in the USA.
Manganese Violet	Shade is purple.
Iron Blue	Colour is dark blue, used in a wide range of applications.
White Pigments Titanium Dioxide Zinc Oxide	White pigments have a wide use in all cosmetics, they show extremely good covering power, are almost totally inert also extremely stable to heat and light.
Mica	Mica gives a natural translucence when used as face powders and powder blushers.

Source: www.dyespigments.com

In addition to this some types of organic pigments are also used along with water soluble and oil soluble dyes in the cosmetics application.

Some examples of water soluble dyes are given here.

Dye	Colours
Carotene PS 300	
Annato Hydrosouble	
Carmin of Cochineal	

Table 6.2: Colour of some Dyes

Dye	Colours
Carotene PS 300	Medium yellow
Annato Hydrosouble	Sand
Carmin of Cochineal	Orchid

3.3.6 Dyes in Medicine

Dyes are now an important ingredient in medical tests. Many of the tests that are carried out on patients use dye to get accurate results. One such example is that of Fluorescein angiography. Fluorescein angiography derives its name from fluorescein, the dye that is used very successfully for carrying out tests. Angiogram is a very valuable test that gives information about the circulatory system.

3.3.7 Colourants for Agriculture Industry

Primarily there are three main types of agricultural industries that use the dye. They are the crop protection industry, fertilizer industry and the seed dressing industry. The purpose of the dye used here is for colouring of agricultural chemicals or in the identification process of agricultural chemicals. The basic selection criteria depend upon the following:

Colour strength of the particular dye
Dye colour
Colour stability
Compatibility of the dye with the particular agent

(i) Fertilizer Industry: Fertilizers are often added with colouring to differentiate between qualities and to avoid any type of errors in application. Fertilizers are also coloured for purely marketing purposes. Usually water based pigment is often used in the diluted form and is sprayed onto the fertilizer or sometimes incorporated into a melt.

(ii) Crop Protection Industry: Use of colourants in crop protection agents of the type insecticide and fungicides helps to clearly demarcate treated areas from the untreated ones. In addition, the dye stuffs also help in promoting safety in the handling techniques. Colouring of pesticides or herbicides is generally done by mixing chromatic pigments with dry powder formulations of the agents. Milori blue is a very popular pigment, which goes well with viticultural fungicides. Other categories of pigments include lithol rubine, heliogen blue etc., Dyes used in the crop protection industry are Solvent dyes, Acid dyes or Basic dyes.

(iii) Seed Dressing Industry: The main objective of colouring the seed dressings is used for marking and a warning reference. To avoid any sort of confusion and making sure that it does not end up being used as fodder. The most important colourant used here is red with typical concentrations of 600 ppm.

3.3.8 Paper Industry

Over the years Paper makers have used dyes. Seeing the growth in the paper industry it can be safely assumed that Dyes for paper industry has a very promising future. Given below is a comprehensive list of the various grades of paper that are open to dyeing.

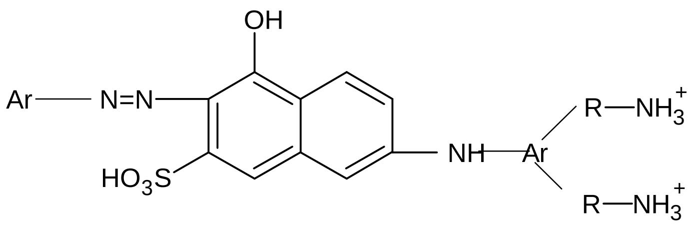
Writing and printing paper
Tissue - Facial, toilet, towel, napkin
Copier papers
Boards/Cover papers
Decorative laminated paper
Packaging grades - corrugated case stuff
Envelope grades
Specialty papers like, label, laundry tag, posters

The dyes that are used include sulphur dyes and cationic direct dyes. Other than these two popular options, acid dyes and basic dyes are also used. Sulphur dyes are reduced alkaline solutions.

Coming to the Cationic Direct Dye, some features which make them suitable towards use in paper are:

An extended conjugation
A planar molecular structure
An excess of positive charge over the negatively charged surface groups

A typical structure of a cationic direct dye is given here.



Ar = Aromatic
R = Aliphatic

3.3.9 Pigments in Paints Industry

Pigments are the colouring elements present in the paints. They have a very special place in the paints industry. The paints industry uses them from a broad array, which includes specialty pigments to manufacture paints for a variety of applications. Ranging from automobiles to buildings to hardware the list is virtually endless.

The paints that employ the wide variety of pigments can be broadly classified according to application into two types. They are colourants for the industrial applications and architectural/decorative applications respectively. The pigment types are:

(i) **Earth colour Pigment-** Earth colours are derived from natural sources and are inorganic in nature (i.e. metal oxides). Examples that can be given of earth colours are: ocher, umber, terra di siena, bolus, swedish red etc.

(ii) **Mineral Pigments-** Mineral pigments comprise synthetic inorganic pigments. They include among others chrome oxide green, titanium dioxide, iron oxide yellow, red, brown and black, ultramarine blue, nickel-titanium yellow etc. One of the disadvantages of mineral pigments is the toxicity and ecological imbalance.

(iii) **Plant Colour** Pigments- Plant colours are sourced from natural organic pigment found in plants. Examples of plant colours can be given of indigo, alizarin red, woad, reseda, alkanna violet and saffron.

(iv) **Synthetic Pigments-** Synthetic Pigments are the most widely used artificial organic pigments and dyes. They give the advantage of synthesisation of almost any shade, especially of pure colour tones and gives dazzling visual effects. Examples are: azo, dioxazine and phthalocyanin.

3.3.10 Wire and Cable Industry

In the Wire and cable industry, various types of pigments are used to colour polyolefins. Mainly they are employed for Wire Identification Methods. As in cables, it can be seen that the colouring done on the outer layer is governed by a different set of requirements as from the inner layers. Pigments that are used in the wire and cable industries are of two types inorganic and organic. Newer alternatives that are coming in to the market are known as the "mixed-phase metal oxide" pigments. Examples can be given of, yellow nickel titanates and blue and green cobalt aluminates. A relatively new entrant is the brilliant yellow bismuth vanadate. Organic pigments are also used but are not as popular because they are more difficult to disperse than inorganic ones leading to possible loss in mechanical strength.

Table 6.3: Common Pigments and Applications

Pigment	Colour	Application
Titanium dioxide	White	Used in variety of resins
Zinc sulphide	White	Wide use
Iron oxides	Red, yellow, brown, and black	Wide use
Lead chromates and lead chromate molybdates	Colours can include bright yellow and orange	Good use
Cadmium	Comes in reds, yellows, oranges and maroons	Excellent for engineering resins
Chromium oxides	Green	Shows good heat and light fastness, variety of uses
Ultramarines	Comes in blue, pink and violet shades	Works in a wide gamut of resins

Source: www.dyespigments.com

4.0 CONCLUSION

It could be seen that the use to which dyes and pigments are employed is endless. These vary from cosmetic industry to paper making. They have added value to our day to day living.

5.0 SUMMARY

In this unit, we have learnt that:

- from acting as colourants for plastics, textile dyeing industries and the highly sophisticated biotechnology industry dyes are touching lives everywhere
- pigments have diversified application in paints, textile, printing
- wide variety of options applicable for the usage of dye and pigment.

6.0 TUTOR- MARKED ASSIGNMENT

Describe in detail, the application of dye or pigment in the following industries:

i. Paper making
ii. Cosmetic
iii. Security printing
iv. Wire and cable

7.0 REFERENCES/FURTHER READING

Buxbaum,G. (1998). *Industrial Inorganic Pigments*. VCH, Weinheim.

Klaus Hunger, Peter Mischke, Wolfgang Rieper, Roderich Raue, Klaus Kunde, Aloys Engel "Azo Dyes” in Ullmann’s Encyclopedia of Industrial Chemistry (2005). Wiley-VCH, Weinheim.

MODULE 2 CLASSIFICATION OF DYES AND FIBRES

UNIT 1 CLASSIFICATION OF DYES

CONTENTS

1.0 INTRODUCTION

A dye can generally be described as a coloured substance that has an affinity to the substrate to which it is being applied. At the very basic level the use of colour in identifying individual components of tissue sections can be accomplished primarily with dyes. Although there are other means, dyes are however, the largest groups that can easily be manipulated to our liking. Dyes are applied to numerous substrates for example to textiles, leather, plastic, paper in liquid form.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define what a dye is
- describe the several ways for classification of dyes
- identify each class of dye with the very unique chemistry, structure and particular way of bonding.

3.0 MAIN CONTENT

3.1 Definition of Dyes

By definition dyes can be said to be coloured, ionising and aromatic organic compounds which show an affinity towards the substrate to which it is being applied. It is generally applied in a solution that is aqueous. Dyes may also require a mordant to improve the fastness of the dye on the material on which it is applied. A mordant is an element which aids the chemical reaction that takes place between the dye and the fiber so that the dye is absorbed.

3.2 Different Classification of Dyes

There are several ways for classification of dyes. It should be noted that each class of dye has a very unique chemistry, structure and particular way of bonding. While some dyes can react chemically with the substrates forming strong bonds in the process, others can be held by physical forces. Some of the prominent ways of classification is given hereunder.

a. Organic/Inorganic
b. Natural/Synthetic
c. By area and method of application
d. Chemical classification- Based on the nature of their respective chromophores.
e. By nature of the Electronic Excitation (i.e. energy transfer colourants, absorption colourants and fluorescent colourants).
f. According to the dyeing methods

    Anionic (for Protein fibre)
    Direct (Cellulose)
    Disperse (Polyamide fibres)

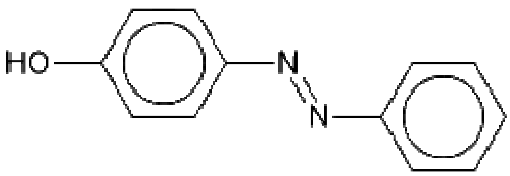
3.2.1 Chemical Classification of Dyes

Table 1.1: Chemical Classification of Dyes

Group	Uses
Acridine dyes, derivatives of acridine >C=N- and>C=C	Textiles, leather
Anthraquinone dyes, derivatives of anthraquinone >C=O and >C=C	Textiles
Arylmethane dyes	

Diarylmethane dyes, based on diphenyl methane Triarylmethane dyes, based on triphenyl methane	
Azo dyes, based on a -N=N- azo structure	
Cyanine dyes, derivatives of phthalocyanine	
Diazonium dyes, based on diazonium salts	
Nitro dyes, based on the $-NO_2$ nitro functional group	
Nitroso dyes, are based on a -N=O nitroso functional	
Phthalocyanine dyes, derivatives of phthalocyanine >C=N	Paper
Quinone-imine dyes, derivatives of quinone	Wool and paper
Azin dyes Eurhodin dyes Safranin dyes, derivatives of safranin -C-N=C- -C-N-C	Leather and textile
Xanthene dyes, derived from xanthene $-O-C_6H_4-0$	Cotton, Silk and Wool
Indophenol dyes, derivatives of indophenol >C=N- and >C=O	Colour photography
Oxazin dyes, derivatives of oxazin -C-N=C =C-O-C=	Calico printing
Oxazone dyes, derivatives of oxazone	
Thiazin dyes, derivatives of thiazin	
Thiazole dyes, derivatives of thiazole >C=N-and -S-0=	Intermediate
Fluorene dyes, derivatives of fluorene	
Rhodamine dyes, derivatives of rhodamine	
Pyronin dyes	

Source: www.dyespigments.com



Yellow azo dye

SELF ASSESSMENT EXERCISE 1

1. List carefully the different means of classification of dyes.
2. Mention the functional groups present in the azo, thiazole, and the phthalocyanine types of dyes.

3.2.2 Industrial Classification of Dyes

Majority of the dyestuff is primarily consumed by the textile industry, so at this level a classification can be done according to their performances in the dyeing processes. Worldwide around 60% of the dyestuffs are based on azo dyes that are used in the textile finishing process. Major classes of dyes in textile finishing are as listed below;

(a) **Acid dyes**: They are water-soluble anionic dyes that are applied to fibers such as silk, wool, nylon and modified acrylic fibers using neutral to acid dye baths. Attachment to the fiber is attributed, at least partly, to salt formation between anionic groups in the dyes and cationic groups in the fiber. Acid dyes are not substantive to cellulosic fibers. Most synthetic food colors fall in this category.

(b) **Basic dyes**: These are water-soluble cationic dyes that are mainly applied to acrylic fibers, but find some use for wool and silk. Usually acetic acid is added to the dye bath to help the uptake of the dye onto the fiber. Basic dyes are also used in the colouration of paper.

(c) **Direct or substantive dyeing**: This is normally carried out in a neutral or slightly alkaline dyebath, at or near boiling point, with the addition of either sodium chloride (NaCl) or sodium sulfate (Na_2SO_4). Direct dyes are used on cotton, paper, leather, wool, silk and nylon. They are also used as pH indicators and as biological stains.

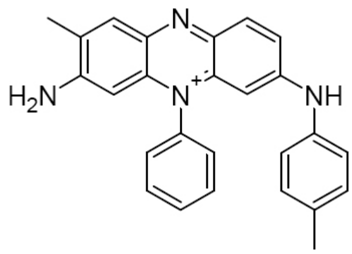
(d) **Mordant dyes**: This class of dye requires a mordant, which improves the fastness of the dye against water, light and perspiration. The choice of mordant is very important as different mordants can change the final color significantly. Most natural dyes are mordant dyes and there is therefore a large literature base describing dyeing techniques. The most important mordant dyes are the synthetic mordant dyes, or chrome dyes, used for wool; these comprise some 30% of dyes used for wool, and are especially useful for black and navy shades. The mordant, potassium dichromate, is applied as an after-treatment. It is important to note that many mordants, particularly those in the heavy metal category, can be hazardous to health and extreme care must be taken in using them.

(e) **Vat dyes**: They are essentially insoluble in water and incapable of dyeing fibres directly. However, reduction in alkaline liquor produces the water soluble alkali metal salt of the dye, which, in this leuco form, has an affinity for the textile fibre. Subsequent oxidation reforms the original insoluble dye. The colour of denim is due to indigo, the original vat dye.

(f) **Reactive dyes**: They utilise a chromophore attached to a substituent that is capable of directly reacting with the fibre substrate. The covalent bonds that attach reactive dye to natural fibers make them among the most permanent of dyes. "Cold" reactive dyes, such as Procion MX, Cibacron F, and Drimarene K, are very easy to use because they can be applied at room temperature. Reactive dyes are by far the best choice for dyeing cotton and other cellulose fibers at home or in the art studio.

3.2.3 Classification Based on the Source of Materials

(a) **Natural Dyes**: These are dyes obtained from natural sources – plant, animal or mineral. Roots, nuts and flowers that grow in the backyard are all sources of colouring pigments known as Natural Dyes. Many natural dyes had been earlier created and used at home long before the chemist created dyes in laboratories, there were dyers who extracted colours from flowers, leaves, roots, the outer and inner bark of trees as well as their heartwood. A common example is Indigo.



Indigo

(b) **Synthetic Dyes**: The first human-made (synthetic) organic dye, mauveine, was discovered by William Henry Perkin in 1856. Thousands of synthetic dyes have since been prepared. Synthetic dyes quickly replaced the traditional natural dyes. They cost less, they offered a vast range of new colours, and they imparted better properties upon the dyed materials.

3.2.4 Classification Based on Application

A number of other classes have also been established, based on application that includes the following:

(a) **Leather Dyes** – Used for leather.
(b) **Oxidation Dyes** – Used mainly for hair
(c) **Optical Brighteners** – Used primarily for textile fibres and paper.

(d) **Solvent Dyes** – For application in wood staining and production of coloured lacquers, solvent inks, waxes and colouring oils etc.
(e) **Fluorescent Dyes** – A very innovative dye. Used for application in sports good etc.
(f) **Fuel Dyes** – As the name suggests it is used in fuels
(g) **Smoke Dyes** – Used in military activities.
(h) **Sublimation Dyes** – For application in textile printing.
(i) **Inkjet Dyes** – Writing industry including the inkjet printers
(j) **Leuco Dyes** – Has a wide variety of applications including electronic industries and papers.

3.3 Classification based on International Trade Commission

However the most popular classification is the one that is advocated by the US International Trade Commission. This system classifies dyes into 12 types:

Type 1: Acridine dyes, derivatives of acridine
Type 2: Anthraquinone dyes, derivatives of anthraquinone
Type 3: Arylmethane dyes

- **Category 1**: Diarylmethane dyes, based on diphenyl methane
- **Category 2**: Triarylmethane dyes, derivatives of triphenyl methane

Type 4: Azo dyes, based on -N=N- azo structure
Type 5: Cyanine dyes, derivatives of phthalocyanine
Type 6: Diazonium dyes, based on diazonium salts
Type 7: Nitro dyes, based on a -NO_2 nitro functional group
Type 8: Nitroso dyes, based on a -N=O nitroso functional group
Type 9: Phthalocyanine dyes, derivatives of phthalocyanine
Type 10: Quinone-imine dyes, derivatives of quinone

- **Category 1**: Azin dyes

Class (a): Eurhodin dyes
Class (b): Safranin dyes, derivatives of safranin

- **Category 2**: Indamins
- **Category 3**: Indophenol dyes, derivatives of indophenols
- **Category 4**: Oxazin dyes, derivatives of oxazin
- **Category 5**: Oxazone dyes, derivatives of oxazone
- **Category 6**: Thiazin dyes, derivatives of thiazin

Type 11: Thiazole dyes, derivatives of thiazole
Type 12: Xanthene dyes, derived from xanthene

- **Category 1**: Fluorene dyes, derivatives of fluorene

  Pyronin dyes

- **Category 2**: Fluorone dyes, based on fluorone
  Rhodamine dyes, derivatives of rhodamine

SELF ASSESSMENT EXERCISE 2

1. Mention four types of dyes and their applications.
2. Enumerate the specific role of a mordant in the dyeing process.

4.0 CONCLUSION

Dyes are applied to numerous substrates for example to textiles, leather, plastic and paper in liquid form. One characteristic of dye is that the dyes must get completely or at least partially soluble in the medium which it is being put to. The rules that apply to other chemicals are similarly applicable to dyes. For example, certain kind of dyes can be toxic, carcinogenic or mutagenic and can pose as a hazard to health.

5.0 SUMMARY

In this unit, you have learnt that:

- dyes generally can be described as coloured substances that have an affinity to the substrate to which they are being applied
- dyes may also require a mordant to improve the fastness of the dye on the material on which it is applied
- there are different means of classification of dyes, but the most generally acceptable one is based on the International Trade Commission, which differentiated dyes into twelve categories.

6.0 TUTOR-MARKED ASSIGNMENT

1. Dyes are made up of vast arrays of chemical bonding. Discuss
2. Write short notes on dyes obtained from natural source.
3. Mention four types of dyes and their uses.

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UNIT 2 CLASSIFICATION OF FIBRES

CONTENTS

1.0 INTRODUCTION

Plants which yield fibres have been companion to human kind since time immemorial. Materials for rope and weaving were collected from the wild by the earliest peoples; later societies began to care for particular strands of these plants. Fibres have long been of natural origin. Human uses for fibres are diverse. They can be spun into filaments, thread, string or rope. They can be used as a component of composite materials. They can also be matted into sheets to make products such as paper or felt. Fibres are often used in the manufacture of other materials.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- identify the sources of fibres
- describe the several ways for classification of fibres
- identify some of the plants and trees that gives good natural fibres.

3.0 MAIN CONTENT

3.1 Definition of Fibres

Fibre or **fibre** is a class of materials that are continuous filaments or are in discrete elongated pieces, similar to lengths of thread. Fibres are of great importance in the biology of both plants and animals, for holding tissues togther.

3.2 Classification of Fibres

Fibres used by man come from a wide variety of sources. They are classified into two broad types namely natural and synthetic fibres.

3.3 Natural Fibres

Natural fibres include those produced by plants, animals, and geological processes. They are biodegradable over time. They can be classified according to their origin:

(a) **Vegetable Fibres:** Vegetable fibres are generally based on arrangements of cellulose, often with lignin: examples include cotton, linen, hemp jute, flax, ramie, and sisal. Plant fibres serve in the manufacture of paper and cloth.

(b) **Wood Fibres:** Wood fibre, distinguished from vegetable fibre, is from tree sources. Forms include groundwood, thermomechanical pulp (TMP) and bleached or unbleached kraft or sulfite pulps. Kraft and sulfite, also called sulphite, refer to the type of pulping process used to remove the lignin bonding the original wood structure, thus freeing the fibres.

(c) **Animal Fibres:** They consist largely of particular proteins. Instances are spider silk, sinew, catgut and hair (including wool). Polar bear fibres are noted for being hollow.

(d) **Mineral Fibres:** This comprises of asbestos. Asbestos is the only naturally occurring long mineral fibre. Short, fibre-like minerals include wollastinite, attapulgite and halloysite.

In general, natural fibres can be grouped into two categories: soft fibres and hard fibres.

3.3.1 Soft Fibres

Most soft fibres come from the bast portion of the plant. Also called the phloem, the bast lies directly under the outer bark or skin. Here the transport of the products of photosynthesis and the development of stabilizing structures take place. Through the process of retting, the bast is removed from the stems. Hemp, Flax, Jute and Ramie are soft fibres.

3.3.2 Hard Fibres

Hard fibres are comprised not only of the phloem but also partly of the hardened wood core of the plant, the Xylem. The hardness in the plant's fibres is caused by the deposit of lignin in the cell walls. Hard fibres generally come from the leaves of monocot (single seed-leaf) species, for example Sisal agave, fibre banana and diverse palms.

SELF ASSESSMENT EXERCISE

1. List carefully the different types of natural fibres you have studied.
2. Distinguish a soft fibre from a hard one.

3.4 Human -Made Fibres

These may come from natural raw materials or from synthetic chemicals. They are of two types:

(a) Many types of fibre are manufactured from natural cellulose, including rayon, modal, and the more recently developed Lyocell. Cellulose-based fibres are of two types, regenerated or pure cellulose such as from the cupro-ammonium process and modified or derivitized cellulose such as the cellulose acetates. Fibreglass made from specific glass formulas and optical fibre, made from purified natural quartz, are also man-made fibres that come from natural raw materials. Metallic fibres can be drawn from ductile metals such as copper, gold or silver and extruded or deposited from more brittle ones such as nickel, aluminum or iron.

(b) Synthetic fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process. Such fibres are made from polyamide, nylon, polyethylene (PET) or PBT polyester, phenol-formaldehyde (PF), polyvinyl alcohol fibre (PVOH), polyvinyl chloride fibre (PVC), polyolefins (PP and PE), or acrylic polymers, although pure polyacrylonitrile (PAN) fibres are used to make carbon fibre by roasting them in a low oxygen environment. Traditional acrylic fibre is used more often as a synthetic replacement for wool. Carbon fibres and PF fibres are noted as two resin-based fibres that are not thermoplastic, most others can be melted. Aromatic nylons such as Kevlar and Nomex thermally degrade at high temperatures and do not melt. More exotic fibres have strong bonding between polymer chains (e.g. aramids), or extremely long chains (e.g. Dyneema or Spectra). Elastomers can even be used, e.g. spandex although urethane fibres are starting to replace spandex technology.

3.5 Extraction of Fibres

The extraction of bast fibres from the stems of linen, hemp, ramie, nettle and many other fibre plants is accomplished through retting. The strings of fibres in each are glued together and to the outer bark and the inner wood by pectin. During the retting process, the activity of various fungi, bacteria and weathering dissolve the pectin and the fibres can be separated by chemical and/or mechanical means.

3.5.1 Dew Retting

Dew retting takes place directly on the field. The stems of plants are harvested, gathered in bundles, stacked and left to the elements. Depending on temperature and weather, retting can take some weeks.

3.5.2 Water Retting

Water retting is done in large basins filled with water. Soaking in water, the pectin is more quickly dissolved. Earlier in Europe and still today in developing countries, plant fibres are retted in rivers and streams which often is the cause for severe water pollution.

3.6 Natural Sources of Fibres

3.6.1 Cotton

Cotton is King, the most produced and most consumed of all natural fibres. Cotton's soft, flexible qualities and its unique ability to regulate moisture and warmth make it first choice material for many industries. Few can deny the fundamental comfort of cotton in its most recognizable form, 'jeans and T-shirt', simple fashion and skin-friendly uniform of the American West. Cotton is derived from the plant *Gossypium arboreum* L., *G. herbaceum* L. (Old World Cotton) and *Gossypium barbadense* L and *G. hirsutum* L (New World Cotton). New world cotton give much higher yields than those from the Old World, their fibres are finer and generally longer.

3.6.2 Flax or Linen

In Western Civilisation linen was the most important material made from plant fibres, from ancient times until the end of the 18th Century. Finds of archaic linen seeds in Iraq and in southeastern Turkey show that wild linen *Linum bienne* was cultivated as early as 9000 years ago. The living and the dead of Egypt were, for thousands of years, wrapped in linen.

Linen from the plant *Linum usitatissimum* L., grows to 120cm. Its short fibres are found in the stem. Bound together end to end and into bundles by pectin, linen fibres form strands 60 to 90cm long. Linen is extremely rip-resistant but not particularly flexible. For the finest of fibres, the green plant is harvested following its flowering period. When left until golden, middle-ripe, linen gives stronger fibres and rougher textiles. Completely ripe and dried when harvested, linen fibre is only useful for ropes and sackcloth. The extreme parallel order of flax fibres in their bundles gives linen fabric a characteristic wrinkle.

4.0 CONCLUSION

Fibres are all inclusive natural products. Synthetic fibres can be produced very cheaply and in large amounts compared to natural fibres, but natural fibres enjoy some benefits, such as comfort, over their man-made counterparts.

5.0 SUMMARY

In this unit, we have learnt that:

- fibres are of great importance in the biology of both plants and animals, for holding tissues together
- fibres are divided into tow types namely natural and synthetic or man- made
- fibres are extracted from plants by retting
- cotton and Linen or Flax are the two sources of natural fibre
- fibres are divided into two major groups- natural and synthetic.

6.0 TUTOR-MARKED ASSIGNMENT

1. Mention four types of synthetic fibres.
2. Mention the major differences between vegetable and wood fibre.
3. Discuss briefly the method of extraction of fibres.

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UNIT 3 NATURAL DYES AND DYEING PROCESS

CONTENTS

1.0 INTRODUCTION

Historically, natural dyes were used to colour clothing or other textiles, and by the mid-1800, chemists began producing synthetic substitutes for them. By the early part of this century only a small percentage of textile dyes were extracted from plants. Lately, there has been increasing interest in natural dyes, as the public became aware of ecological and environmental problems related to the use of synthetic dyes. The use of natural dyes cuts down significantly on the amount of toxic effluent resulting from the synthetic dye process. Natural dyes generally require a mordant, which are metallic salts of aluminum, iron, chromium, copper and others, for ensuring the reasonable fastness of the colour to sunlight and washing.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define natural dye
- identify categories of natural dye
- produce dye from natural plant
- identify different sources of natural dye
- explain the simple dyeing procedure.

3.0 MAIN CONTENT

3.1 Definition of Natural Dyes and Mordant

Natural dyes are a class of colourants extracted from vegetative matter and animal residues.

A mordant is an element which aids the chemical reaction that takes place between the dye and the fiber so that the dye is absorbed.

3.2 Types of Natural Dyes

Natural dyes can be sorted into three categories: natural dyes obtained from plants (e.g. indigo), those obtained from animals (e.g. cochineal), and those obtained from minerals (e.g. ocher).

3.2.1 Natural Dyes Obtained from Plants

(a) One example of a natural dye obtained from plants is madder, which is obtained from the roots of the madder plant. The plants are dug up, the roots washed and dried and ground into powder. During the 19th century, the most widely available fabrics were those which had been dyed with madder. Analyses of red fabrics found in King Tutankhamen's tomb show that they were dyed with madder, a plant-based dye. This red was considered brilliant and exotic. The madder plant continued to be used for dyeing until the mid-1800s when a synthetic substitute was developed.

(b) Another example of a natural dye obtained from plants is woad. Until the Middle Ages, Europeans used woad to create a blue fabric dye. The woad was a shrub that grew abundantly in parts of Europe. The colouring was in the leaves, which were dried and ground, mixed with water and made into a paste. This dye was supplanted by indigo, an ancient shrub well known to the Egyptians and Indians. Like woad, its colour lay in its leaflets and branches. The leaves were fermented, the sediment purified, and the remaining substance was pressed into cakes.

(c) Indigo prevailed as the preferred blue dye for a number of reasons. It is a substantive dye, needing no mordant, yet the colour achieved is extremely fast to washing and to light. The manufacture of natural indigo lasted well into the early 1900s. In 1905 Adolf von Bayer (the scientist who also formulated aspirin) was awarded the Nobel Prize for discovering the molecular structure of indigo, and developing a process to produce it synthetically.

3.2.2 Natural Dyes Obtained from Animals

A good example is cochineal, which is a brilliant red dye produced from insects living on cactus plants. The properties of the cochineal bug were discovered by pre-Columbian Indians who would dry the females in the sun, and then ground the dried bodies to produce a rich red powder. When mixed with water, the powder produced a deep, vibrant red colouring. Cochineal is still harvested today on the Canary Islands. In fact, most cherries today are given their bright red appearance through the artificial colour "carmine", which comes from the cochineal insect.

3.2.3 Natural Dyes Obtained from Minerals

Dyes made with minerals, coloured clays and earth oxides. For example, Ochre, made from iron ore, is one of the oldest pigments and has been in use since pre-historic times.
Categories of Natural Dyes

Table 3.1: Categories of Natural Dyes

Colours	Chemical Classifications	Common Names
Yellow and Brown	Flavone Dyes	Weld, Quercitron, Fustic, Osage, Chamomile, Tesu, Dolu, Marigold, Cutch
Yellow	Iso-quinoline Dyes	Barberry
Orange-Yellow	Chromene Dyes	Kamala
Brown and Purple-Grey	Naphthoquinone Dyes	Henna, Walnut, Alkanet, Pitti
Red	Anthraquinone Dyes	Lac, Cochineal, Madder (Majithro)
Purple and Black	Benzophyrone Dyes	Logwood
Blue	Indigoid Dyes	Indigo
Neutrals	Vegetable Tannins:	Wattle, Myrobalan,

	gallotannins, ellagitannins and catechol tannins	Pomegranate, Sumach, Chestnut, Eucalyptus

Source: Colour Trend, U.S. Agency for International Development.

3.4 Natural Dyeing

Beautiful bright colours can be obtained by dyeing with natural dyes. Dyes can be gathered from nature or you can use dyestuff which will give you any colour under the rainbow.

3.4.1 Some Natural Dyeing Materials

a. **Alkanet Root** (*Alkania tinctoria)*: This will give colours from bluish grey to soft burgundy. This plant grows like a weed when planted.

b. **Annato Seed** (*Bixa Orellana*): Will give an orange shade, it is a good dye for cotton.

c. **Brazilwood Dust** (*Caesalpania echinata*): This dye will give reds. Before using the dust, it is first exposed to the air and sprinkle with water and alcohol.

d. **Cochineal** (*Dactylopius coccus*): The little cochineal bug will give the most colour when ground into a fine powder. Obtainable colours are dark burgundy to bright red, soft lilac and pink.

e. **Indigo Solution Natural** (Saxony blue): Produces a bright blue and is very easy to use, similar to a chemical dye. All of the dye will be absorbed in the fiber. It is not very good to dye cotton or other vegetable fibers.

f. **Red Sandalwood** (*Pterocarpus*): This dye is beautiful for blending. It produces lovely browns and act as good shade combinations for doll hair.

g. **Madderroot** (*Rubia tinctorum*): Is available in two forms: root or dust. Colour ranges from red to red-brown and oranges. It dyes cotton well.

h. **Loqwood Concentrate** (*Hematoxylon campechianum*): Expected colours anywhere from magenta's and brown to purples and pink. A mordant is absolutely needed. The concentrated powder will give more bluish colours. It dyes cotton well.

i. **Osage Orange Dust** (*Maclura pomifer*): Two different colours can be obtained; bright yellow and gold.

SELF ASSESSMENT EXERCISE 1

1. What is a natural dye?
2. Describe four categories of natural dyes with respect to source and colour they produced.

3.4.2 Mordants for Natural Dyeing

Mordants are needed to set the colour when using natural dyes. Different mordants will give different results:

(a) **Alum:** (AlK_2SO_4; Aluminum Potassium Sulfate): This is the most widely used mordant. Be careful not to use too much with wool, otherwise you will get a sticky feeling that does not come out.

(b) **Copper:** ($CuSO_4$; Copper Sulfate): This mordant is used to bring out the greens in dyes. It will also darken the dye colours, similar to using tin, but is less harsh.

(c) **Chrome:** ($K_2Cr_2O_7$; Potassium Dichromate): Chrome brightens dye colours and is more commonly used with wool and mohair than with any other fiber. Chrome should not be inhaled and gloves should be worn while working with chrome. Left over mordant water should be disposed of at a chemical waste disposal site and treated as hazardous waste.

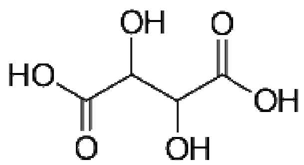
(d) **Iron:** (Fe_2SO_4; Ferrous Sulfate): Dulls and darkens dye colours. Using too much will make the fiber brittle.

(e) **Glaubersalt:** (Na_2SO_4; Sodium Sulfate): Used in natural dyes to level out the bath. Also use in chemical dye.

(f) **Spectralite**: (Thiourea Dioxide): This is a reducing agent for indigo dyeing.

(g) **Tara Powder:** (*Caesalpinia spinosa*): Tara Powder is a natural tannin product. It is needed for darker colours on cotton, linen and hemp.

(h) **Tartaric Acid:** A must for cochineal. This mordant will expand the cochineal colours.



(i) **Tin:** ($SnCl_2$; Stannous Chloride): Tin will give extra bright colours to reds, oranges and yellows on protein fibers. Using too much will make wool and silk brittle. To avoid this you can add a pin**ch** of tin at the end of the dying time with fiber that was premordanted with alum. Tin is not commonly used with cellulose fibers.

(j) **Calcium Carbonate ($CaCO_3$):** Is to be used with indigo powder for the saxon blue colour. It can also be used to lower the acidity of a dye bath.

3.5 Making Natural Dyes from Plant Source

There is a simple experiment requires to obtain dyes from plant materials.

(a) **Gathering plant material for dyeing:** Blossoms should be in full bloom, berries ripe and nuts mature. Never gather more than 2/3 of a stand of anything in the wild when gathering plant stuff for dying.

(b) **To make the dye solution:** Chop plant material into small pieces and place in a pot. It is most appropriate to double the amount of water being added to the plant materials. Bring to a boil, and then simmer for about an hour. For a stronger shade, allow material to soak in the dye overnight.

3.6 Natural Dyeing Process

(a) **Equipment**: The water you use for dyeing should be soft. Most tap water is too hard, and you should add a softener to it. Rain water may be an ideal option. The following items are useful for dyeing; stainless steel pot, strainer, stirrer, wooden spoon, measuring utensils, like cups and spoons, kitchen scale and rubber gloves.

(b) **Wool Preparation**: When working with raw wool fleece, you must first scour the wool to remove the oil from the fiber. For 1lb of wool: fill 3-4 gallons of water in a pot with detergent. Put the wool in and slowly simmer for 45 minutes. Cool, then rinse.

(c) **Mordant Directions**: Dissolve the mordant in a small amount of hot water. Add 4-5 more gallons of water, enough to cover 1lb of wool, and heat to luke warm. Add the wool and simmer 45 minutes to 1 1/2 hours. Cool and rinse.

3.6.1 Dyeing Process

(i) Place wet wool in luke warm dye bath and slowly raise to a simmer.

(ii) Dyes from flowers, fruits, and tender leaves: simmer 30 minutes - 1 hour

(iii) Dyes from tough leaves, roots, nut hulls, and bark: simmer 1 minute - 2 hours
(iv) Cool and rinse until the rinse water is clear.
(v) Never agitate the wool or it will felt. Lift and turn it gently in plenty of water.
(vi) Never shock with extreme changes in water temperature
(vii) Do not wring or twist - squeeze gently to remove excess water. It is not necessary to cover the pot when simmer in, unless you are using chrome which is light sensitive.
(ix) Dye entire amount of wool needed for project in one bath
(x) Add white vinegar (1/4 cup per gallon) to rinse water to help soften the wool.

3.7 Fibre Dyeing

Natural dyes can dye fibres in three main forms:

(a) Direct dyes can colour fibres without other fixing agents, often after simple extraction from plant material. These include very fast colours, such as walnut and bark browns, and also dye with very poor fastness, such as Saffron (*Crocus sativus*), Safflor (*Carthamus tinct*orum) and Pomegranite rinds.
(b) Adjective dyes colour fibres only in combination with a mordant. The most important mordants are metal salts (aluminum, iron, copper) and tannins. The ancient dyeing traditions of Egypt, India, China and Central America all incorporated the use of these minerals. The practices of mordant-dyeing worldwide are remarkably similar and such discoveries as the fixative properties of metal salts were made by many early peoples.
(c) Indigo dyes are a unique form of natural dye, which utilise particular processes. Complicated dye extraction using fermentation and even more complicated dyeing practices were developed in pre-historic cultures of Europe, Asia, Africa and the Americas, wherever indigo-bearing plants have been found in nature. Indigo blues can be quite permanent when properly applied.

3.8 Dyeing Process of Leather

Dyeing Leather substrate is an uphill task. As leather has myriad of structural differences, grooves, knurls, and folds along with other sorts of imperfections. Therefore for achieving the target of a level and uniform dyeing, the dyer needs to be experienced, and have a thorough knowledge of the dyeing processes, properties and the auxiliaries that need to be used. Leather dyeing is generally done by two processes. Drum dyeing and Rub dyeing, with Drum dyeing being predominant. In the process of drum dyeing, the application of dyestuffs to the leather is done by immersing the leather in drums. The drum is then tumbled. This tumbling allows the leather to be fully penetrated by the dyes. The ultimate aim of drum dyeing is getting the desired colour, which appears level and uniform throughout the skins. The leather colourants that are used is dominated by the acid dyes which accounts for nearly 90% of the market, followed by metal complex dyes and, cationic dyes to some extent. The dyes are applied either on the grain or suede side.

3.9 Some Dyeing Patterns

(i) **Raw fibres** are generally dyed by the dipping process. They are placed in a perforated metal cylinder that is dipped into a vat full of dye.
(ii) **Velour cloth and furs** are often hand-dyed. The dye is applied with a brush that has been dipped in a dye solution.
(iii) **Batik** is an ancient method of applying coloured dyes to fabrics, usually cotton and silk. It originates in Java and now widely used throughout the world.
(iv) **Tie- dyeing**, a hand-dyeing technique often practised as a craft, can be used to create multi-coloured patterns.

SELF ASSESSMENT EXERCISE 2

1. What is a mordant? Mention two types and their features.
2. How would you dye a fabric?

4.0 CONCLUSION

The dyes were obtained from animal, vegetable or mineral origin, with no or very little processing. By far the greatest source of dyes has been from the plant kingdom, notably roots, berries, bark, leaves and wood, but only a few have ever been used on a commercial scale. These dyes can dye different shades of materials such as plastic, fibres, cotton etc.

5.0 SUMMARY

In this unit, we have learnt about:

- the types and nature of natural dyes
- sources of natural dyes
- the nature and role of mordant in dyeing process
- natural dyeing process
- simple dyeing process for fibres.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe a simple experiment for the extraction of dye from plant materials.
2. What is a mordant? Mention two types and their features.
3. In a tabular form, describe four plants and the colour of the dye they produced.

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MODULE 3 SYNTHETIC DYES AND FIBRES

UNIT 1 SYNTHETIC FIBRES

CONTENTS

1.0 INTRODUCTION

Synthetic or man-made fibres generally come from synthetic materials such as petrochemicals. But some types of synthetic fibres are manufactured from natural cellulose, including rayon, modal, and the more recently developed Lyocell. Cellulose-based fibres are of two types, regenerated or pure cellulose such as from the cupro-ammonium process and modified cellulose- the cellulose acetates.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define synthetic dyes and fibres
- differentiate between synthetic dye and fibre
- identify each kind of synthetic dye and fibre
- identify the properties and applications of synthetic dye and fibre.

3.0 MAIN CONTENT

3.1 Definition of Synthetic Fibres

Synthetic fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process.

While, Synthetic dyes are man made dyes that impart better properties upon the dyed materials.

3.2 Kinds of Fibres

(a) **Cellulose fibres** are a subset of man-made fibres, regenerated from natural cellulose. The cellulose comes from various sources. Modal is made from beech trees, bamboo fiber is a cellulose fiber made from bamboo, soy silk is made from soybeans, seacell is made from seaweed, etc.

(b) Mineral fibres

Fiberglass made from specific glass, and optical fiber, made from purified natural quartz, are also man-made fibres that come from natural raw materials.

Metallic fibres can be drawn from ductile metals such as copper, gold or silver and extruded or deposited from more brittle ones, such as nickel, aluminum or iron.

Carbon fibres are often based on carbonised polymers, but the end product is pure carbon.

(c) Polymer fibres

Polymer fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process. These fibres are made from:

polyamide nylon,
PET or PBT polyester phenol-
formaldehyde (PF) polyvinyl
alcohol fiber (PVA) polyvinyl
chloride fiber (PVC)
polyolefins (PP and PE)
acrylic polyesters, pure polyester PAN fibres are used to make carbon fiber by roasting them in a low oxygen environment.

Traditional acrylic fiber is used more often as a synthetic replacement for wool. Carbon fibres and PF fibres are noted as two resin-based fibres that are not thermoplastic, most others can be melted.

aromatic polyamids (aramids) such as Twaron, Kevlar and Nomex thermally degrade at high temperatures and do not melt. These fibres have strong bonding between polymer chains
polyethylene (PE), eventually with extremely long chains / HMPE (e.g. Dyneema or Spectra).
elastomers can even be used, e.g. spandex although urethane fibres are starting to replace spandex technology.
polyurethane fiber

(d) **Microfibres**: Micro fibres in textiles refer to sub-denier fiber (such as polyester). Denier and Detex are two measurements of fiber yield based on weight and length. If the fiber density is known you also have a fiber diameter, otherwise it is simpler to measure diameters in micrometers. Microfibres in technical fibres refer to ultra fine fibres (glass or meltblown thermoplastics) often used in filtration. Newer fiber designs include extruding fiber that splits into multiple finer fibres. Most synthetic fibres are round in cross-section, but special designs can be hollow, oval, star-shaped or trilobal. The latter design provides more optically reflective properties. Synthetic textile fibres are often crimped to provide bulk in a woven, non woven or knitted structure. Fiber surfaces can also be dull or bright. Dull surfaces reflect more light while bright tends to transmit light and make the fiber more transparent.

SELF ASSESSMENT EXERCISE 1

Mention two kinds of synthetic fibres.

3.3 Properties and Applications of Synthetic Fibres

Table 1.1: Application of Synthetic Fibres

Polymer family and type	Common Names & Trade Names	Deniers (gm/9,000 m)	Tensile Strength (gm/denier)	Elongation at Break (%)	Initial Modulus (gm/denier)	Apparel and Home-Furnishing Applications	Industrial Applications
Polyamides							
Polycaprolactam (textile fibre)	nylon 6 (textile)	1.5-5	4.5-6.8	23-43	25-35	hosiery, lingerie, sports garments, soft-sided luggage, upholstery	no significant applications
Polyhexamethylene adipamide (textile fibre)	nylon 6,6 (textile)	1.5-5	4.5-6.8	23-43	25-35	hosiery, lingerie, sports garments, soft-sided luggage, upholstery	no significant applications
Polycaprolactam (industrial fibre	nylon 6 (industrial)	1.5-5	8.5-9.5	12-17	33-46	no significant applications	tyres, ropes, seat belts, parachutes, fishing lines and nets, hoses
Polyhexamethylene adipamide (industrial fibre)	nylon 6,6 (industrial)	1.5-5	8.5-9.5	12-17	33-46	no significant applications	tyres, ropes, seat belts, parachutes, fishing lines and nets, hoses
Aramids							
Poly-*p*-phenylene tereph-thalamide	Kevlar, Twaron, Technora	1.0-1.5	25-30	3-6	500-1,000	no significant applications	radial tyre belts, bulletproof vests, reinforcement for boat hulls and aircraft panels
Poly-*m*-phenylene isoph-	Nomex, Conex	2-5	3-6	2-30	130-150	no significant applications	filter bags for hot stack gases, flame-resistant

thalamide							clothing
Polyesters							
Polethylene terephtalate	Dacron, Terylene, Trevira	1.5-5	4.7-6.0	35-50	25-50	permanent-press clothing, fibre fill insulation, carpets	sewing thread, seat belts, tyre yarns, non-woven fabrics
Polyacrylonitrile							
Acylic (>85%) acrylonitrile	Acrilan, Creslan, Courtelle	2-8	2.5-4.5	27-48	25-63	substitute for wool--*e.g.*, in sweaters, hosiery, blankets	filters, battery separators, substitute for asbestos in cement
Modacrylic (35-85%) acrylonitrile	Verel, SEF	2-8	2.5-4.5	27-48	22-56	flame-resistant clothing--*e.g.*, artificial fur, children's sleepwear	flame-resistant awnings, tents, boat covers
Polyolefins							
Polypropylene	Herculon, Marvess	2-10	5-9	15-30	29-45	upholstery, carpets, carpet backing	ropes, nets, disposable non-woven fabrics
Polyethylene							
Regular		2-10	2-4	20-40	--	no significant applications	cordage, webbing
High-Modulus	Dyneema, Spectra	--	30-35	2.7-3.5	1,370-2,016	no significant applications	reinforcement for boat hulls, bulletproof vests
Polyurethane	spandex, Lycra	2.5-20	0.6-1.5	400-600	--	stretch fabrics--*e.g.*, for sportswear, swimsuits	no significant applications

3.4 Kinds of Synthetic Dyes

There are various kinds of synthetic dyes that impart colours on dyed materials. These are:

a. **Acid Dyes: They** come in a wide variety of colours, it is fairly fast to light and to washing. It is named acid dyes because they work best when applied in an acid bath. It is mainly used on nylon, silk and wool.

b. **Azoic (or Naphthol) Dyes:** This type of dyes is extremely fast to light, it is commonly used to dye a material red, orange or maroon. It is mainly used in cotton.

c. **Basic Dyes:** This type of dye is just fair when it comes to fastness to light and to washing, however this type can create a brilliant colour. It is mainly used on natural and acrylic fibres, it is also sometimes used for wool and silk. This dye is also used to colour paper. **Acetic acid** is usually added to the dyebath to help in the quick penetration of the dye onto the fiber.

d. **Chrome (or Mordant) Dyes:** This type of dye is fairly fast to light and to washing, it is especially useful for black and navy shades. The choice of mordant is very important as different mordants can alter the final colour significantly, it is important to know also that many mordants, particularly those in the hard metal category can be hazardous to health, that is why caution should be followed when using it. It is mainly used for wool and silk.

e. **Mordant** is a chemical that is mixed with the dye and the fiber, the modern mordants are dichromates and chromium complexes, that is why it is also called chrome dye.

f. **Developed (or Diazo) Dyes** are used to treat certain dyed fabrics to improve their fastness to light and to washing and also to change fabric's colour. The treatments are used primarily on cotton. Diazotizing is the treatment which involves the use of chemical called a developer. It is mainly used on cotton.

g. **Direct Dyes** this type is one of the easiest to use and has a wide range of colours, it is not fast to washing, but its fastness is often improved by more treatment. It is mainly used on cotton, rayon leather, wool, silk and nylon. It is also used as pH indicators and as biological stains.

h. **Disperse (or Acetate) Dyes** this dyes is finely ground in the presence of dispersing agent, its dyeing rate is greatly influenced by the dispersing agent used during the grinding. Disperse dyes were developed because other dyes would not work with acetate it is also used on different manmade fibres, including acrylic, acetate, and polyester fibres.

i. **Reactive (or Fiber-reactive) Dyes:** these types of dye have a good fastness to light and to washing. Reactive dyes create strong chemical bonds with the material being dyed which makes it the most permanent of dyes. This dye is by far the best choice for dyeing cotton, nylon, wool and other cellulose fibres at home or in the art studio.

j. **Sulphur Dyes:** these dyes are especially fast to washing and the best for material that is washed frequently. Sulphur dyes are colourless (upon application), but upon exposure to air they are oxidized and turn into their respective colours. They come mainly in dark, dull colours and used on cotton, linen and rayon.

k. **Vat Dyes:** This type is superior compared to the other dye when it comes to its fastness to light and to washing. Vat dyes like sulphur dyes must be oxidized before their real colour comes out. This dye is mainly used for cotton, linen, wool and silk. The indigo colour of blue jeans is vat dye.

3.5 Dyes for Man- Made Fibres

The first man-made fibre to achieve commercial significance was viscose rayon, in the early 1900s. This is chemically similar to cotton (in other words it is a cellulosic fibre) and so the dyes already available for cotton were used on viscose rayon. At the time these were mainly direct, vat, azoic and sulphur dyes, but since the 1960s fibre-reactive dyes have come to be widely used on all cellulosic fibres. In the 1930s, when acetate rayon appeared, the existing dyes were not very suitable, with the notable exception of the natural dye logwood black, which was already being used on silk and wool. A new class of dyes eventually to be called disperse dyes, was developed which allowed a full range of shades to be successfully applied to acetate rayon.

In the 1940s and 1950s the truly synthetic fibres, such as the polyamides (nylon), polyesters and acrylics, began to appear commercially. Disperse dyes proved to be particularly suitable for polyester and so the importance of this class of dye increased enormously. Because both fibres and dyes have been modified since then, polyamides are now dyed mainly with acid dyes, and acrylics mainly with modified basic dyes.

Over the last twenty to thirty years, developments in dye chemistry have enabled the man-made fibre to be dyed with better fastness to light and washing, and in an ever increasing range of colours.

4.0 CONCLUSION

It could be seen that synthetic or man-made fibres generally come from synthetic materials such as petrochemicals. Like fibres, synthetic dyes are also man made from various materials such as inorganic and metallic compounds. Synthetic fibres have wide application especially in clothing industry and other products being used in our day to day activities. Dyes also contribute to aesthetics by imparting various colours depending on convenience.

5.0 SUMMARY

In this unit, we have learnt that:

- polymer fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process
- microfibres in technical fibres refer to ultra fine fibres (glass or melt blown thermoplastics) often used in filtration
- reactive dye is by far the best choice for dyeing cotton, nylon, wool and other cellulose fibres at home or in the art studio
- disperse dyes proved to be particularly suitable for polyester, and
- the different kinds of synthetic dyes and fibres
- the application of synthetic dyes and fibres.

6.0 TUTOR-MARKED ASSIGNMENT

1. What are polymer fibres
2. In a tabular form, mention three of the polymer fibres and their application.
3. Write short notes on the following:

a. cellulose fibre
b. sulphur dye

7.0 REFERENCES/FURTHER READING

Synthetic Fibres: Nylon, Polyesters, Acrylic and Polyolefins. Edited by J.E McIntyre.

Woodhead Textiles Series No. 36, Woodhead Publishing Limited, 2009.

UNIT 2 POLYMER FIBRES

CONTENTS

1.0 INTRODUCTION

Polymer fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process. It is important to point out that fibres are always made of polymers which are arranged into crystals. They have to be able to pack into a regular arrangement in order to line up as fibres. (In fact, fibres are really a kind of crystal, a really long kind of crystal.). A polymeric fibre is a polymer whose chains are stretched out straight (or close to straight) and lined up next to each other, all along the same axis.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- define polymeric fibre
- identify the kind of polymeric synthetic fibres
- explain the production and applications of polymers made from olefins.

3.0 MAIN CONTENT

3.1 Definition of Polymer Fibres

Polymer fibres are a subset of man-made fibres, which are based on synthetic chemicals (often from petrochemical sources) rather than arising from natural materials by a purely physical process.

3.2 Kinds of Synthetic Polymers

(i) Olefins

Olefin includes the varieties of polyethylene, polystyrene and polypropylene. A very light fibre, Olefin particularly resembles wool; it is soil resistant and is a good heat insulator. Herculon and Vectra are trade names.

(ii) Acrylics

Acrylics are made from petroleum. They have wool like fibres. It is not as strong as polyester/nylon but it is soft and warm to handle. It washes and dry clean well. It is very resistant to UV light but sensitive to heat. It is moth proof. Modacrylics are also named because they have been chemically modified to offer good flame resistance. They do not wrinkle or crease easily. It can shrink with hot heat. Trade names include (unmodified) Acrilian, Orlon, Verel, Sef, Zefran, and Dynel (which also comes modified).

(iii) Polyesters

Polyester is a petroleum/oil byproduct. It is very strong and easy to wash. It dries quickly and has good shape retention. It is shrink and crease resistant. It is resistant to sunlight, perspiration and moths and has a low absorbency. A light fibre resembling wool or silk, polyester is often blended with natural fibres. It is an ideal fibre for sheeting when mixed with cotton. Dacron, Fortrel, and Kodel are trade names. Dacron is used as a substitute for the base in cushions and upholstery.

(iv) Polyamide (nylon)

Nylon is made from coal, tar and petroleum. It is a very strong resilient fibre with high strength and good elasticity. It drapes well and does not absorb moisture and does not shrink. It tends to attract dirt, but it is easy to wash and is crease resistant. It has a poor resistance to UV light. It is one of the first and most useful synthetics. Many types are now available. It is frequently used in blends. Ace, Antron and Cordura are familiar trade names. It is used widely in carpeting.

(v) Fibre Blends

Two or more fibres can be combined in one yarn to maximise the strengths and minimise the weaknesses of each. For example, natural and artificial fibres can be combined to retain the texture and appearance of the natural yarn while gaining the durability and dirt resistance of the synthetic. Many man-made and synthetic fibres are made to imitate natural fibres as their processing can provide similar properties usually at a reduced cost.

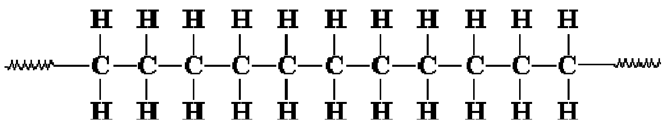
SELF ASSESSMENT EXERCISE 1

1. Define the word Polymer fibre.
2. Mention three kinds of synthetic polymers.

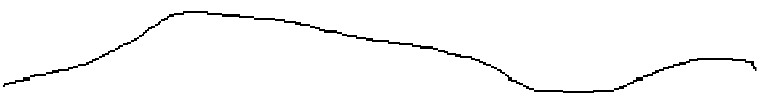
3.3 Polyethylene

$$[-CH_2-CH_2-]n$$

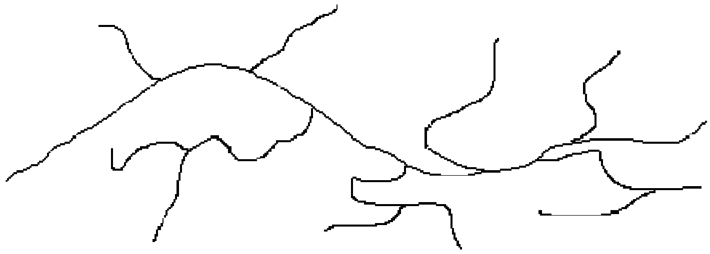
Polyethylene is probably the polymer you see most in daily life. Polyethylene is the most popular plastic in the world. This is the polymer from which grocery bags, shampoo bottles, children's toys, and even bullet proof vests are made. For such a versatile material, it has a very simple structure, the simplest of all commercial polymers. A molecule of polyethylene is nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom.



Sometimes some of the carbons, instead of having hydrogen attached to them, will have long chains of polyethylene attached to them. This is called branched, or low-density polyethylene, or LDPE. When there is no branching, it is called linear polyethylene, or HDPE. Linear polyethylene is much stronger than branched polyethylene, but branched polyethylene is cheaper and easier to make.



A molecule of linear polyethylene, or HDPE

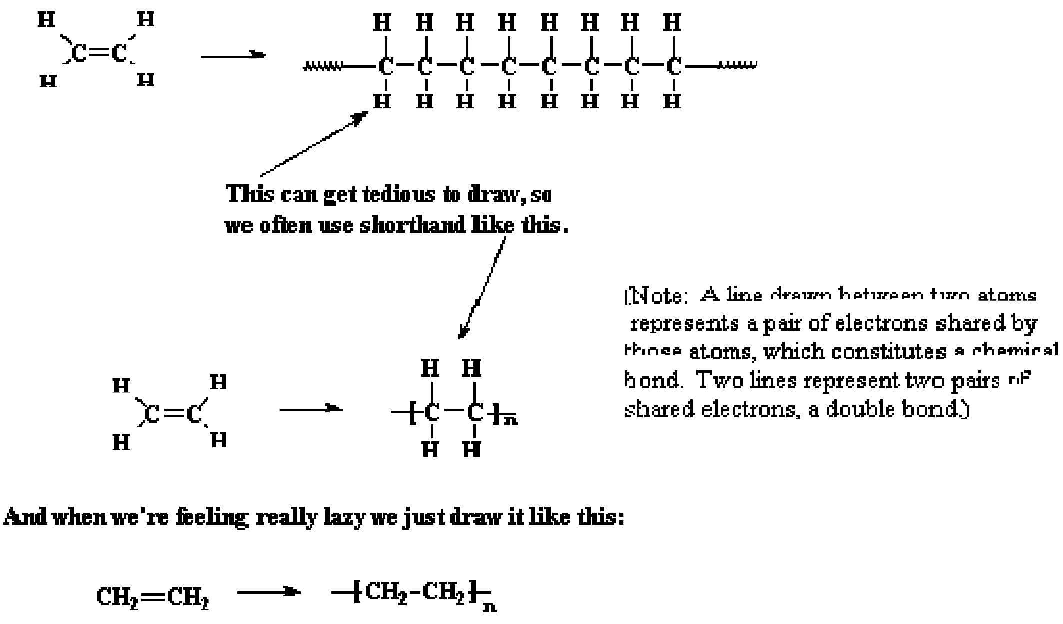


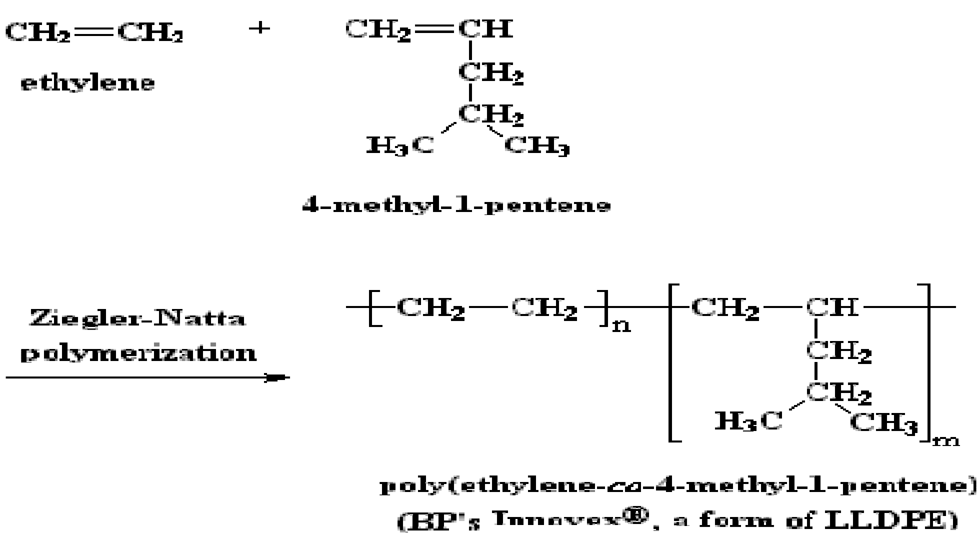
A molecule of branched polyethylene, or LDPE

Linear polyethylene is normally produced with molecular weights in the range of 200,000 to 500,000, but it can be made even higher. Polyethylene with molecular weights of three to six million is referred to as ultra-high molecular weight polyethylene, or UHMWPE. UHMWPE can be used to make fibres which are so strong and are used in bullet proof vests. Large sheets of it can be used instead of ice for skating rinks.

Polyethylene is vinyl polymer, made from the monomer ethylene. Branched polyethylene is often made by free radical vinyl polymerisation. Linear polyethylene is made by a more complicated procedure called Ziegler-Natta polymerisation. UHMWPE is made using metallocene catalysis polymerisation.

But Ziegler-Natta polymerisation can be used to make LDPE, too. By copolymerising ethylene monomer with a alkyl-branched comonomer such as one gets a copolymer which has short hydrocarbon branches. Copolymers like this are called *linear low-density polyethylene*, or LLDPE. BP produces LLDPE using a co-monomer with the catchy name 4-methyl-1-pentene, and sells it under the trade name Innovex®. LLDPE is often used to make things like plastic films.

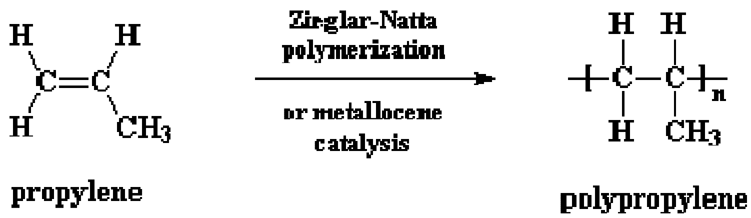




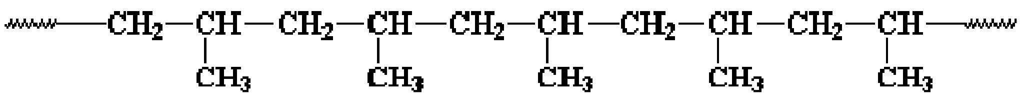
3.4 Polypropylene

Polypropylene is one of those rather versatile polymers. It serves double duty, both as plastic and fibre. As a plastic it is used to make things like dishwasher-safe food containers. It can do this because it is stable to heat below 160°C. Polyethylene, a more common plastic, will anneal at around 100°C, which means that polyethylene dishes will warp in the dishwasher. As a fibre, polypropylene is used to make indoor-outdoor carpeting, the kind that you always find around swimming pools and miniature golf courses. It works well for outdoor carpet because it is easy to make coloured polypropylene, and because polypropylene does not absorb water, like nylon.

Structurally, it's a vinyl polymer, and is similar to polyethylene, only that on every other carbon atom in the backbone chain has a methyl group attached to it. Polypropylene can be made from the monomer propylene by Ziegler-Natta polymerisation and by metallocene catalysis polymerisation.

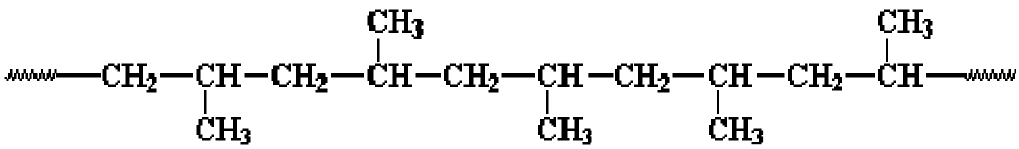


Research is being conducted on using metallocene catalysis polymerization to synthesise polypropylene. Metallocene catalysis polymerisation can do some pretty amazing things for polypropylene. Polypropylene can be made with different tacticities. Most polypropylene we use is *isotactic*. This means that all the methyl groups are on the same side of the chain, like this:



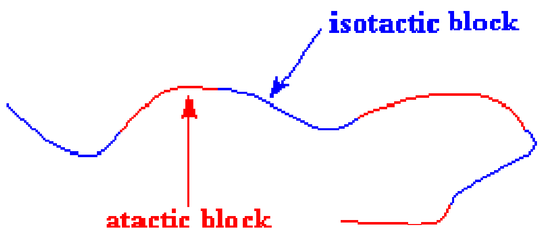
isotactic polypropylene

But sometimes we use *atactic* polypropylene. *Atactic* means that the methyl groups are placed randomly on both sides of the chain like this:



atactic polypropylene

However, by using special metallocene catalysts, it is believed that we can make polymers that contain blocks of isotactic polypropylene and blocks of atactic polypropylene in the same polymer chain, as is shown in the picture:



This polymer is rubbery, and makes a good elastomer. This is because the isotactic blocks will form crystals by themselves. But because the isotactic blocks are joined to the atactic blocks, the little hard clumps of crystalline isotactic polypropylene are tied together by soft rubbery tethers of atactic polypropylene. Indeed atactic polypropylene would be rubbery without help from the isotactic blocks, but it will not be very strong. The hard isotactic blocks hold the rubbery isotactic material together, to give the material more strength. Most kinds of rubber have to be crosslinked to give them strength, but not polypropylene elastomers.

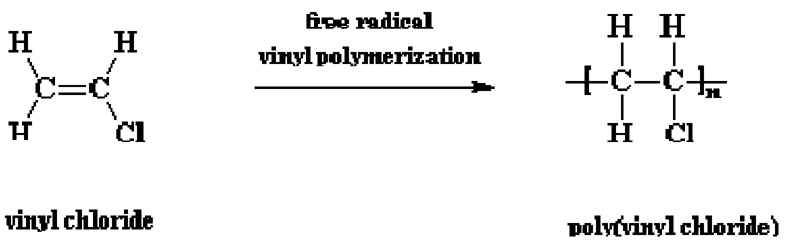
Elastomeric polypropylene, as this copolymer is called, is a kind of thermoplastic elastomer. However, until the research is completed, this type of polypropylene will not be commercially available.

3.5 Poly (vinyl chloride) PVC

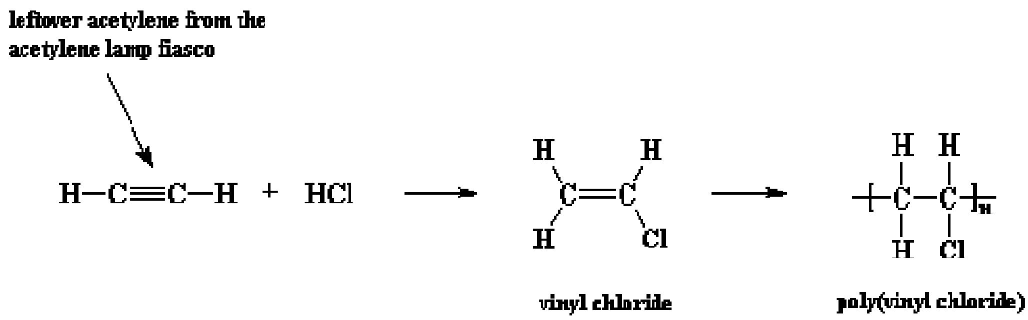
Poly (vinyl chloride) is the plastic known at the hardware store as PVC. This is the PVC from which pipes are made, and PVC pipe is everywhere. The plumbing in modern day structures is probably PVC pipe. PVC pipe is what rural high schools with small budgets use to make goal posts for their football fields. But there's more to PVC than just pipe. The "vinyl" siding used on houses is made of poly(vinyl chloride). Inside the house, PVC is used to make linoleum for the floor. In the seventies, PVC was often used to make vinyl car tops.

PVC is useful because it resists two things that are opposite of each other: fire and water. Because of its water resistance it is used to make raincoats and shower curtains, and of course, water pipes. It has flame resistance, too, because it contains chlorine. When you try to burn PVC, chlorine atoms are released, and chlorine atoms inhibit combustion.

Structurally, PVC is a vinyl polymer. It is similar to polyethylene, but on every other carbon in the backbone chain, one of the hydrogen atoms is replaced with a chlorine atom. It is produced by the free radical polymerization of vinyl chloride.



PVC was one of those odd discoveries that actually had to be made twice. It seems around a hundred years ago, a few German entrepreneurs decided they were going to make loads of cash lighting people's homes with lamps fueled by acetylene gas. Would you believe it?, right about the time they had produced tons of acetylene to sell to everyone who was going to buy their lamps, new efficient electric generators were developed which made the price of electric lighting drop so low that the acetylene lamp business was finished. That left a lot of acetylene lying around.



So in 1912 one German chemist, Fritz Klatte decided to do something with it, and reacted some acetylene with hydrochloric acid (HCl). Now, this reaction will produce vinyl chloride, but at that time no one knew what to do with it, so he put it on the shelf, where it polymerized over time. Not knowing what to do with the PVC he had just invented, he told his bosses at his company, Greisheim Electron, who had the material patented in Germany. They never figured out a use for PVC, and in 1925 their patent expired. However, in 1926 the very next year, an American chemist; Waldo Semon was working at B.F. Goodrich when he independently invented PVC. But unlike the earlier chemists, it dawned on him that this new material would make a perfect shower curtain. He and his bosses at B.F. Goodrich patented PVC in the United States. Tons of new uses for this wonderful waterproof material followed, and PVC was a smash hit the second time around.

SELF ASSESSMENT EXERCISE 2

1. Propose a simple equation for the production low density polyethylene
2. Differentiate between polyethylene and polypropylene.

4.0 CONCLUSION

Polymer fibres are a subset of man-made fibres, which are based on synthetic chemicals. Two or more fibres can be combined in one yarn to maximize the strength and minimize the weaknesses of each. For example, natural and artificial fibres can be combined to retain the texture and appearance of the natural yarn. Olefins, polyesters, polyamide etc are common examples of synthetic fibres of importance.

5.0 SUMMARY

In this unit, we have learnt that:

- it is well known that fibres are always made of polymers which are arranged into crystals
- polyethylene is probably the polymer you see most in daily life. Polyethylene is the most popular plastic in the world. This is the polymer from which grocery bags, shampoo bottles, children's toys, and even bullet proof vests are made
- polypropylene is one of those rather versatile polymers out there. It serves double duty, both as plastic and fibre
- poly (vinyl chloride) is the plastic known at the hardware store as PVC. It is used in the manufacture of pipes.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is Ziegler-Natta polymerisation?
2. With relevant examples explain the concept ‘Fibres are known to be polymers.’

7.0 REFERENCES/FURTHER READING

Burke, J. (1978). *Connections.* Boston: Little, Brown and Co.

Fenichell, S. (1996). *Plastic: The Making of a Synthetic Century*. New York: HarperCollins.

UNIT 3 POLYMERS AND POLYAMIDE FIBRES

CONTENTS

1.0 INTRODUCTION

Nylon's first real success came with its use in women's stockings, in about 1940. They were a big hit, but they became hard to get, because a year later the United States entered World War II, and nylon was needed to make war materials, like parachutes and ropes. However, polyesters can be both plastics and fibres.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- identify materials made of polyester and polyamide fibres
- explain the chemical principles involved in the production of polyester and polyamide fibres
- describe the applications of polyester and polyamide fibres.

3.0 MAIN CONTENT

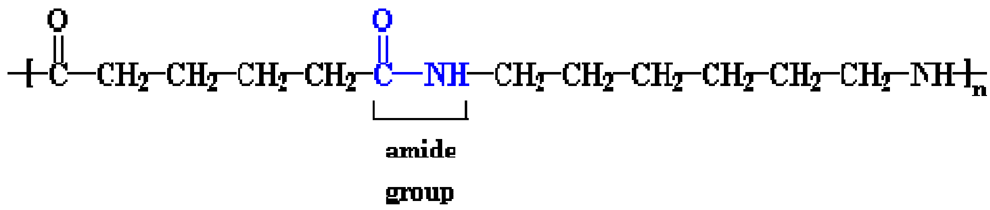
3.1 Definitions of Nylon and Polyester

Nylons are also called polyamides, because of the characteristic amide groups in the backbone chain.

Polyesters are the polymers, in the form of fibres, which were used back in the seventies to make wonderful disco clothing.

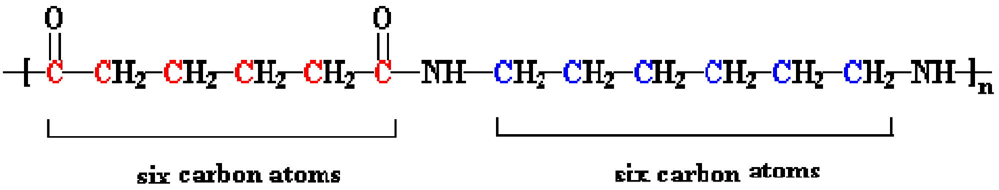
3.2 Nylons

Nylons are one of the most common polymers used as a fibre. Nylon is found in clothing all the time, but also in other places, in the form of a thermoplastic.

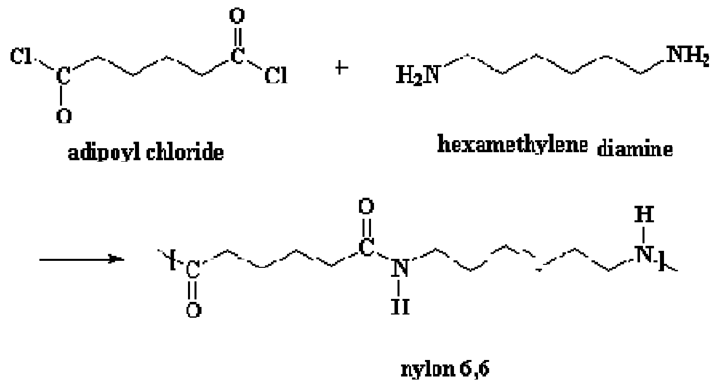


Nylons are also called polyamides, because of the characteristic amide groups in the backbone chain. Proteins, such as the silk nylon, are also polyamides. These amide groups are very polar, and can hydrogen bond with each other. Because of this, and because the nylon backbone is so regular and symmetrical, nylons are often crystalline and make very good fibres.

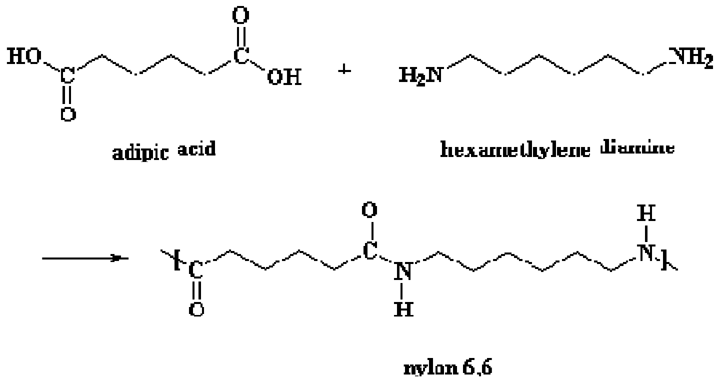
The nylon below is called nylon 6,6, because each repeat unit of the polymer chain has two stretches of carbon atoms, each being six carbon atoms long. Other nylons can have different numbers of carbon atoms in these stretches.



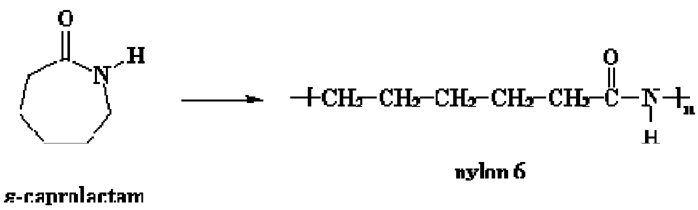
Nylons can be made from diacid chlorides and diamines. Nylon 6,6 is made from the monomers adipoyl chloride and hexamethylene diamine



The industrial synthetic methods make use of the reaction of adipic acid with hexamethylene diamine;

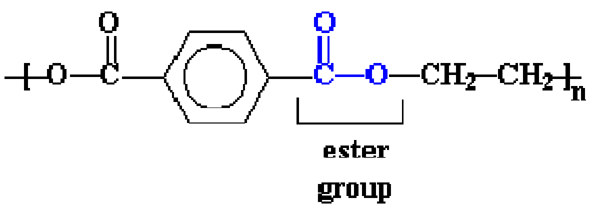


Another kind of nylon is nylon 6. It is similar to nylon 6,6 except that it only has one kind of carbon chain, which is six atoms long. It's made by a ring opening polymerization.

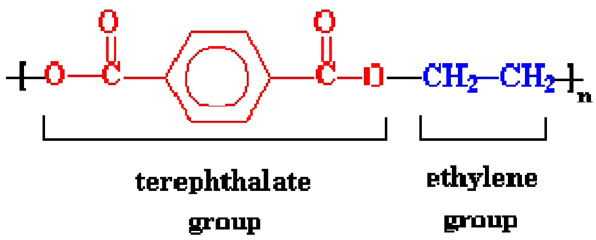


3.3 Polyesters

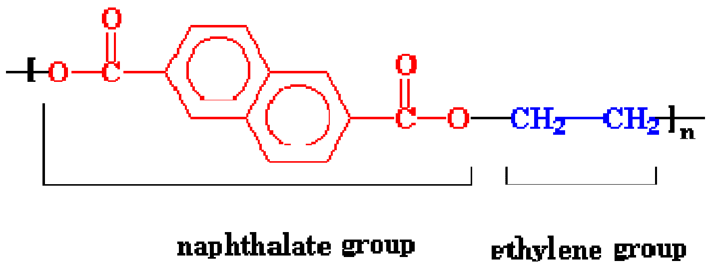
Polyesters are the polymers, in the form of fibres, that were used in the seventies to make wonderful clothing. But since then, the nations of the world have striven to develop more tasteful uses for polyesters, like those nifty shatterproof plastic bottles that hold our favorite refreshing beverages. Another place you find polyester is in balloons. The common ones used to make water balloons are made of natural rubber. It's actually the fancy ones we use in the hospital. These are made of a polyester film made by DuPont called Mylar. The balloons are made of a sandwich, composed of Mylar and aluminum foil. Materials like this, made of two kinds of material, are called composites. Polyesters have hydrocarbon backbones which contain ester linkages, hence the name.



The structure in called poly (ethylene terephthalate), or PET for short, because it is made up of ethylene groups and terephthalate groups.



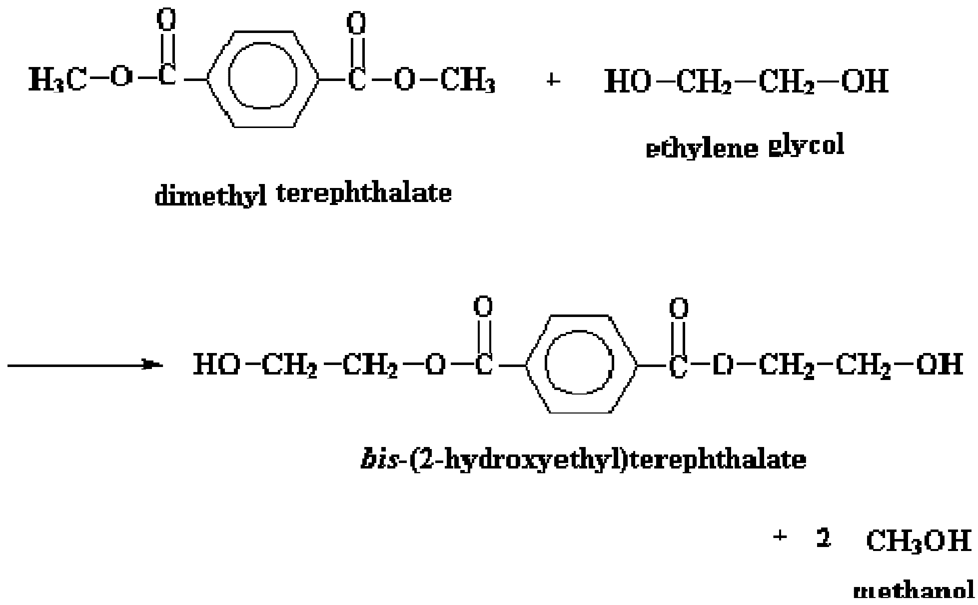
The ester groups in the polyester chain are polar, with the carbonyl oxygen atom having a somewhat negative charge and the carbonyl carbon atom having a somewhat positive charge. The positive and negative charges of different ester groups are attracted to each other.



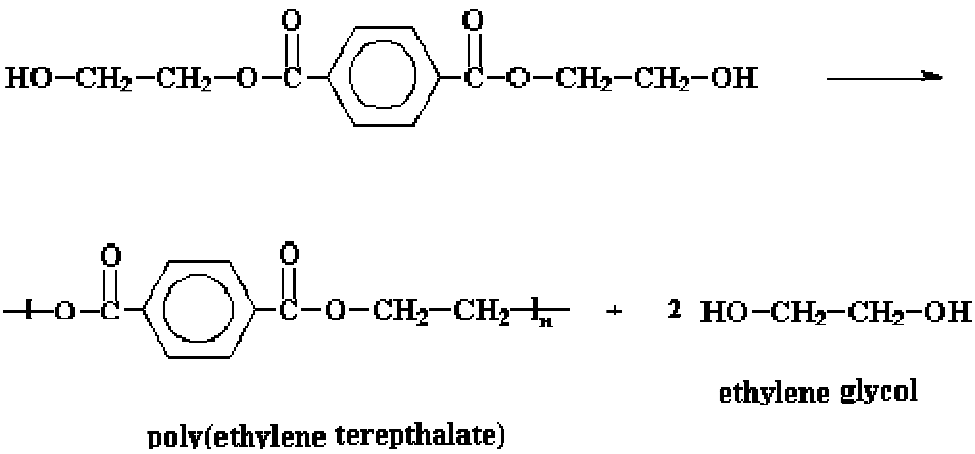
Poly(ethylene naphthalate), the polymer that bestows upon us the plastic jelly jar.

This allows the ester groups of nearby chains to line up with each other in crystal form, which is why they can form strong fibres. The inventor who first discovered how to make bottles from PET was Nathaniel Wyeth.

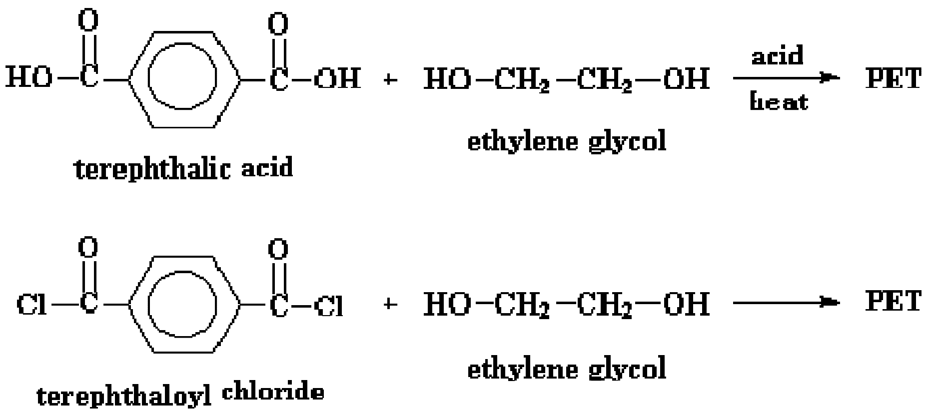
There is a new kind of polyester that is been used for jelly jars and burnable bottles. It is poly(ethylene naphthalate), or PEN. In the big industrial plants where polyester is produced, it is normal to start off with a compound called dimethyl terephthalate. This is reacted with ethylene glycol in a reaction called *transesterification*. The result is bis-(2-hydroxyethyl)terephthalate and methanol. But if we heat the reaction to 210 ^{o}C the methanol will boil away.



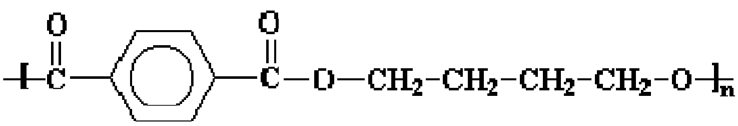
Then the bis-(2-hydroxyethyl)terephthalate is heated up to a balmy 270 ^{o}C, which reacts further to give the poly(ethylene terephthalate) and, oddly, ethylene glycol as a by product.



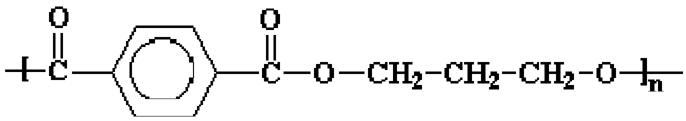
But in the laboratory, PET is made by other reactions. Terephthalic acid and ethylene glycol can polymerize to make PET when heated with an acid catalyst. It is also possible to make PET from terephthoyl chloride and ethylene glycol. This reaction is easier, but terephthoyl chloride is more expensive than terephthalic acid, and even more dangerous.



There are two more polyesters in the market that are related to PET. There is poly(butylene terephthalate) (PBT) and poly(trimethylene terephthalate) (PTT). They are usually used for the same type of things as PET, but in some cases these perform better.



poly(butylene terephthalate)



poly(trimethylene terephthalate)

SELF ASSESSMENT EXERCISE

1. Differentiate between a nylon and a polyester.
2. What are the main chemical functional groups in both nylon and polyester?

4.0 CONCLUSION

Polyesters can be both plastics and fibres while nylon is mainly made up of fibres. They both contained repeating units of the corresponding monomeric unit. Nylons are also called polyamides, because of the characteristic amide groups in the backbone chain. There are different kinds of these products which have impacted positively to human life.

5.0 SUMMARY

In this unit, we have learnt that:

- nylons are some of the most common polymers used as fibre. Nylon is found in clothing all the time, but also in other places, in the form of a thermoplastic
- nylons are also called polyamides, because of the characteristic amide groups in the backbone chain
- polyesters are the polymers, in the form of fibres
- the commonly use forms of polyesters are: poly (ethylene terephthalate), or PET, poly (ethylene naphthalate), or PEN
- there are two more polyesters in the market that are related to PET. They are poly (butylene terephthalate) (PBT) and poly (trimethylene terephthalate) PTT. They are usually used for the same type of things as PET, but in some cases these perform better.

6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between PET and PEN.
2. Propose a simple laboratory procedure for the manufacturing of nylon 6.

7.0 REFERENCE/FURTHER READING

Synthetic Fibres: Nylon, Polyester, Acrylic, Polyolefin: Edited by J E McIntyre, Woodhead Textiles Series No. 36, Woodhead Publishing Limited (2009).

UNIT 4 POLYURETHANES, CELLULOSE AND POLYACRYLONITRILE

CONTENTS

1.0 INTRODUCTION

If you are sitting on a padded chair right now, the cushion is more than likely made of polyurethane foam. Cellulose is one of many polymers found in nature. Wood, paper, and cotton all contain cellulose. Cellulose is an excellent fibre.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- identify the substances making up a polyurethanes
- define cellulose and its compositions
- discuss the nature, properties and uses of polyacrylonitrile.

3.0 MAIN CONTENT

3.1 Definition of Polyurethane, Cellulose and Polyacrylonitrile

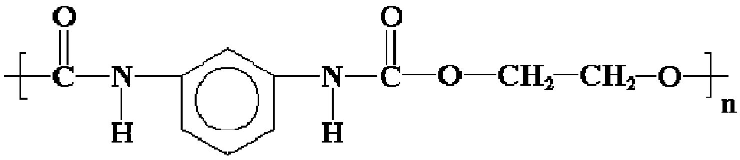
Polyurethanes are the most well known polymers used to make foams. Polyurethanes are more than foam.

Cellulose is made of repeat units of the monomer glucose.

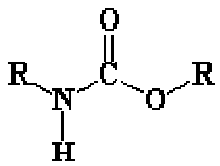
Polyacrylonitrile is a vinyl polymer, and a derivative of the acrylate family of polymers.

3.2 Polyurethanes

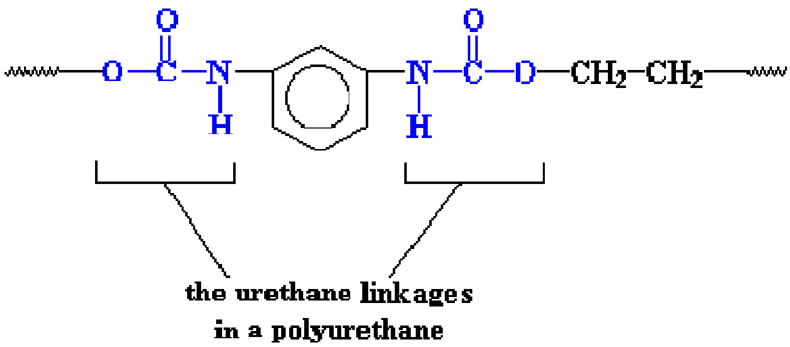
Polyurethanes are the single most versatile family of polymers there is. Polyurethanes can be elastomers, and they can be paints. They can be fibres, and they can be adhesives. A wonderful bizarre polyurethane is spandex. Of course, polyurethanes are called polyurethanes because in their backbones they have a *urethane* linkage.



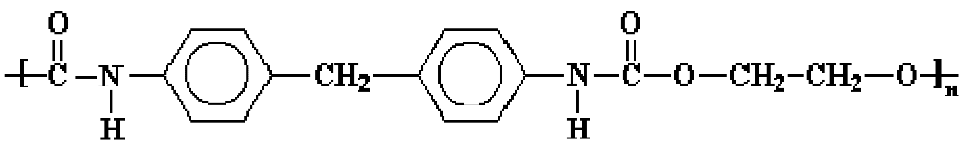
The structure above shows simple polyurethane, but polyurethane can be any polymer containing the urethane linkage in its backbone chain.



a urethane

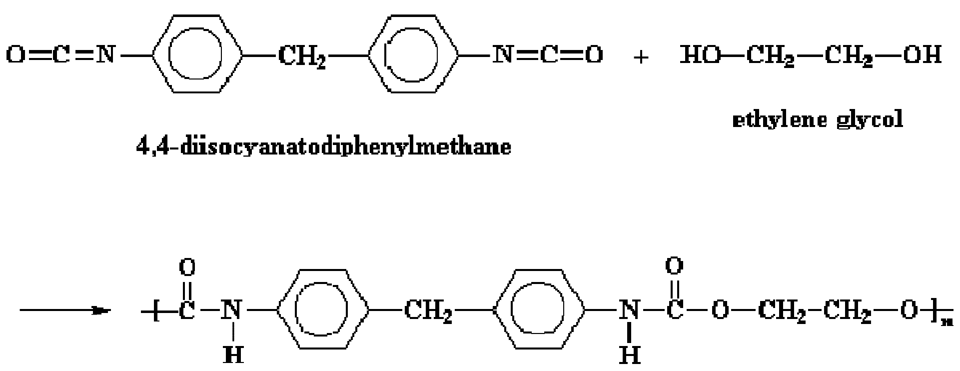


More sophisticated polyurethanes are possible, for example

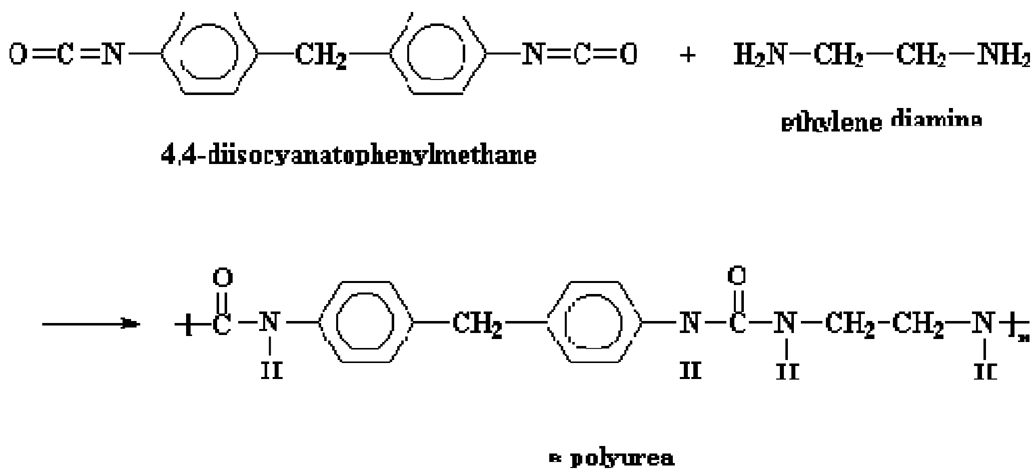


a more sophistacated polyurethane

Polyurethanes are made by reacting diisocyanates with di-alcohols;



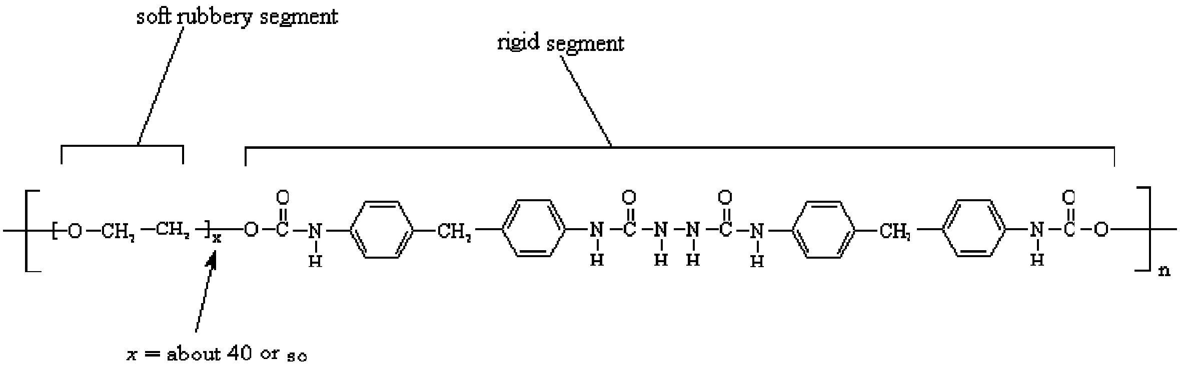
Sometimes, the dialcohol is replaced with a diamine, and the polymer we get is a polyurea, because it contains a urea linkage, rather than a urethane linkage. But these are usually called polyurethanes, because they probably would not sell well with a name like polyurea.



Polyurethanes can hydrogen bond very well and thus can be very crystalline. For this reason they are often used to make block copolymers with soft rubbery polymers. These block copolymers have properties of thermoplastic elastomers.

3.2.1 Spandex

One unusual polyurethane thermoplastic elastomer is spandex, which DuPont sells under the trade name Lycra. It has both urea and urethane linkages in its backbone. What gives spandex its special properties is the fact that it has hard and soft blocks in its repeat structure. The short polymeric chain of a polyglycol, usually about forty or so repeats units long, is soft and rubbery. The rest of the repeat unit, the stretch with the urethane linkages, the urea linkages, and the aromatic groups, is extremely rigid. This section is stiff enough that the rigid sections from different chains clump together and align to form fibres. Of course, they are unusual fibres, as the fibrous domains formed by the stiff blocks are linked together by the rubbery soft sections. The result is a fibre that acts like an elastomer! This allows us to make fabric that stretches for exercise clothing and the like.



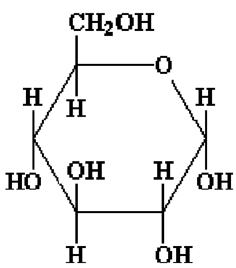
Spandex has a complicated structure, with both urea and urethane linkages in the backbone chain.

SELF ASSESSMENT EXERCISE 1

1. What are polyurethanes?
2. Mention two uses of the polyurethanes

3.3 Cellulose

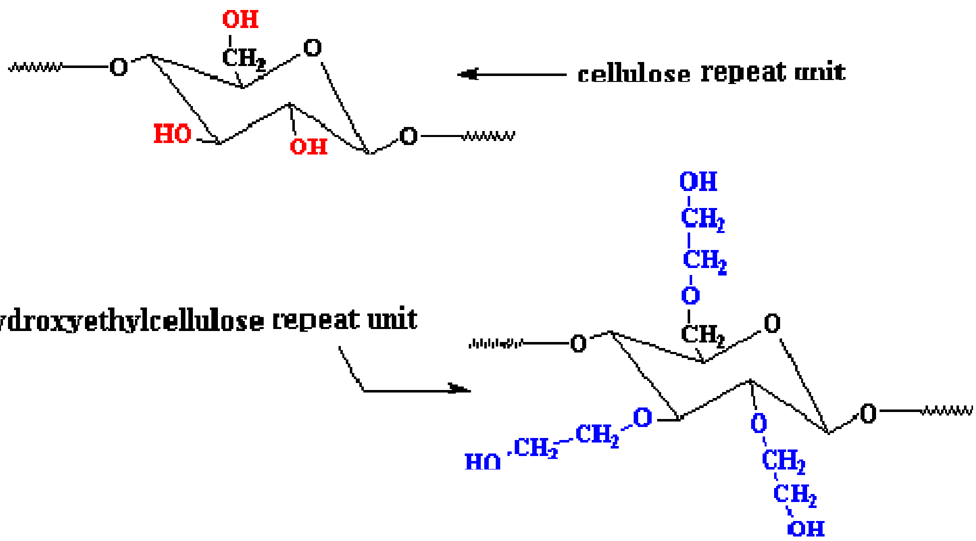
Cellulose is one of many polymers found in nature. Wood, paper, and cotton all contain cellulose. Cellulose is an excellent fibre. Wood, cotton, and hemp rope are all made of fibrous cellulose. Cellulose is made of repeat units of the monomeric glucose. This is the same glucose which the body metabolizes in order to live, but you cannot digest it in the form of cellulose. Because cellulose is built out of a sugar monomer, it is called a polysaccharide



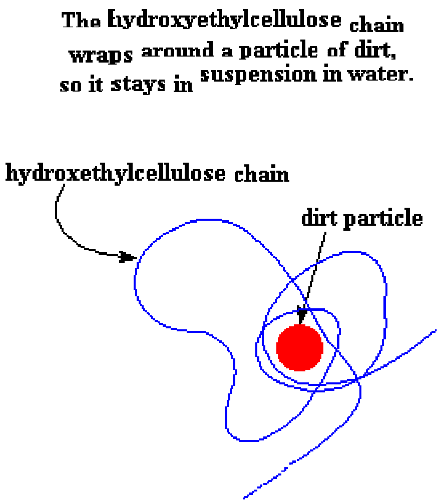
glucose

Cellulose has an important place in the story of polymers because it was used to make some of the first synthetic polymers, like cellulose nitrate, cellulose acetate, and rayon.

Another cellulose derivative is hydroxyethylcellulose. It differs from plain old regular cellulose in that some or all of the hydroxyl groups of the glucose repeat unit have been replaced with hydroxyethyl ether groups



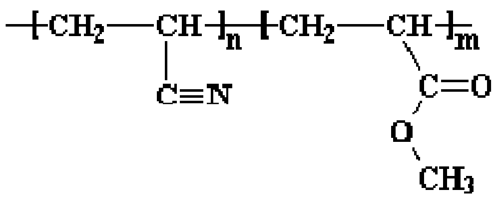
These hydroxyethyl groups get in the way when the polymer tries to crystallize. Because it cannot crystallize, hydroxyethylcellulose is soluble in water. In addition to being a great laxative, it's used to thicken shampoos as well. It also makes the soap in the shampoo less foamy, and helps the shampoo clean better by forming *colloids* around dirt particles.



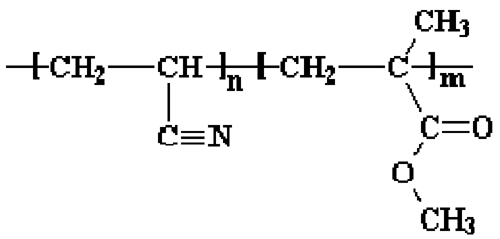
Normally, particles of dirt are insoluble in water. But a chain of hydroxyethylcellulose can wrap itself around a dirt particle. This mass can be thought of as a snack cake, with the polymer chain as the cake and the dirt as the creamy filling. This snack cake is soluble in water, so by wrapping around the dirt like this, the hydroxyethylcellulose tricks the water into accepting the dirt. In this way, the dirt gets washed away instead of being deposited back onto your hair.

3.4 Polyacrylonitrile

Polyacrylonitrile is used for very few products an average consumer would be familiar with, except to make another polymer, carbon fibre. Homopolymers of polyacrylonitrile have been uses as fibres in hot gas filtration systems, outdoor awnings, sails for yachts, and even fibre reinforced concrete. But mostly copolymers containing polyacrylonitrile are used as fibres to make knitted clothing, like socks and sweaters, as well as outdoor products like tents. If the label of some piece of clothing says "acrylic", then it is made out of some copolymer of polyacrylonitrile. Usually they are copolymers of acrylonitrile and methyl acrylate, or acrylonitrile and methyl methacrylate:

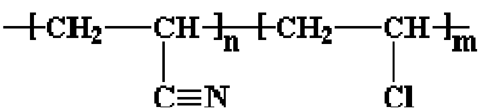


poly(acrylonitrile-*co*-methyl acrylate)



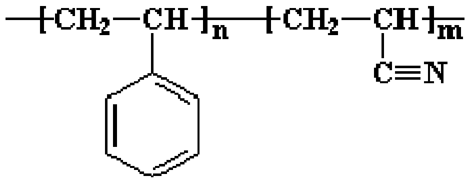
poly(acrylonitrile-*co*-methyl methacrylate)

Also, sometimes we make copolymers of acrylonitrile and vinyl chloride. These copolymers are flame-retardant, and the fibres made from them are called *modacrylic* fibres.



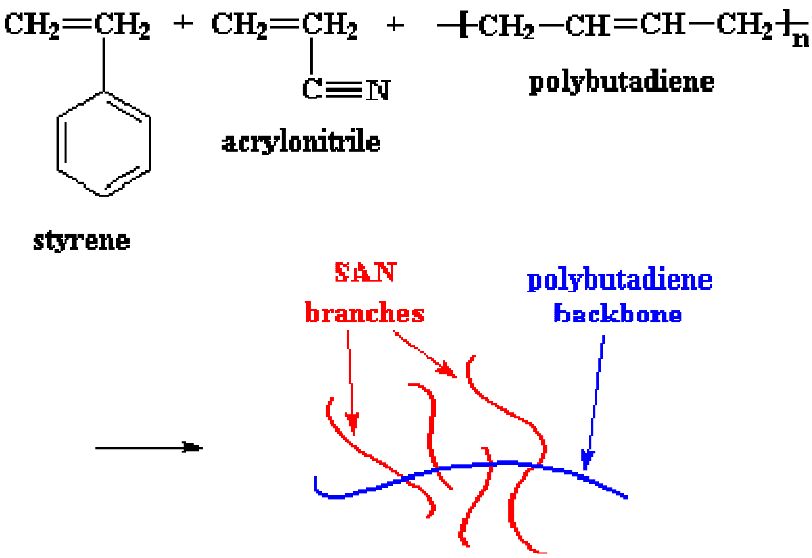
poly(acrylonitrile-*co*-vinyl chloride)

But the slew of copolymers of acrylonitrile does not end there as well. Poly(styrene-*co*-acrylonitrile) (SAN) and poly(acrylonitrile-*co*-butadiene-*co*--styrene) (ABS), are used as plastics.



SAN

SAN is a simple random copolymer of styrene and acrylonitrile. But ABS is more complicated. It's made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. Polybutadiene has carbon-carbon double bonds in it, which can polymerize, too. So we end up with a polybutadiene chain with SAN chains grafted onto it.

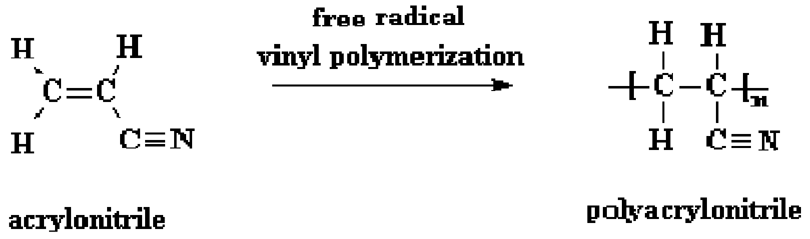


ABS

ABS is very strong and lightweight. It is strong enough to be used to make automobile body parts. Using plastics like ABS makes automobiles lighter, so they use less fuel, and therefore they pollute less.

ABS is a stronger plastic than polystyrene because of the nitrile groups of its acrylonitrile units. The nitrile groups are very polar, so they are attracted to each other. This allows opposite charges on the nitrile groups to stabilize each other. This strong attraction holds ABS chains together tightly, making the material stronger. Also the rubbery polybutadiene makes ABS tougher than polystyrene.

Polyacrylonitrile is a vinyl polymer, and a derivative of the acrylate family of polymers. It is made from the monomer acrylonitrile by free radical vinyl polymerization.



3.5 Polymers an Application

Table 4.1: Plastics and Fibre Polymers

Polymers used as plastics	Polymers used as fibres
Polypropylene	Polypropylene
Polyesters	Polyesters
Polystyrene	Polyethylene
Polycarbonate	Kevlar and Nomex
PVC	Polyacrylonitrile
Polyethylene	Cellulose
Poly(methyl methacrylate)	Polyurethanes

SELF ASSESSMENT EXERCISE 2

1. What are the chemical constituents of cellulose and polyarylonitrile.
2. Differentiate between Spandex and ABS.

4.0 CONCLUSION

Polyurethanes can be fibres, and they can be adhesives. These block copolymers have properties of thermoplastic elastomers. Cellulose is one of many polymers found in nature. Wood, paper, and cotton all contain cellulose. Cellulose is an excellent fibre. Cellulose has an important place in the story of polymers because it was used to make some of the first synthetic polymers, like cellulose nitrate, cellulose acetate, and rayon.

Polyacrylonitrile is a vinyl polymer, and a derivative of the acrylate family of polymers. It is made from the monomer acrylonitrile by free radical vinyl polymerization. SAN is a simple random copolymer of styrene and acrylonitrile. But ABS is more complicated. It is made by polymerizing styrene and acrylonitrile in the presence of polybutadiene.

5.0 SUMMARY

In this unit, we have learnt that:

- polyurethanes are the most well known polymers used to make foams
- cellulose is made of repeat units of the monomer glucose
- polyacrylonitrile is a vinyl polymer, and a derivative of the acrylate family of polymers
- poly (styrene-*co*-acrylonitrile) (SAN) and poly(acrylonitrile-*co*-butadiene-*co*--styrene) (ABS), are copolymers of polyacrylonitrile which are used as plastics.

6.0 TUTOR-MARKED ASSIGNMENT

1. Write short notes on the following:

(a) Polyurea (b) SAN (c) ABS

2. What are the functions of hydroxyethylcellulose

7.0 REFERENCE/FURTHER READING

Synthetic Fibres: Nylon, Polyesters, Acrylic and Polyolefins; Edited by J.E McIntyre, Woodhead Textiles Series No. 36, Woodhead Publishing Limited, 2009.

UNIT 5 ARAMIDS, POLY (METHYLMETHACRYLATE) AND POLYCARBONATE

CONTENTS

1.0 INTRODUCTION

The diverse nature of polymers allow for diverse applicable usage of the materials produced from them.

2.0 OBJECTIVES

By the end of this unit, you should be able to state:

the meaning of aramids, Kevlar and Nomex
the meaning of poly (methyl methacrulate) and Polycarbonate
the chemical structures of these polymers and their uses.

3.0 MAIN CONTENT

3.1 Definitions of Aramids, Poly (methyl methacrylate) and Polycarbonate

Aramids are a family of nylons, including Nomex® and Kevlar®.

Poly (methyl methacrylate), which lazy scientists call PMMA, is a clear plastic, used as a shatterproof replacement for glass.

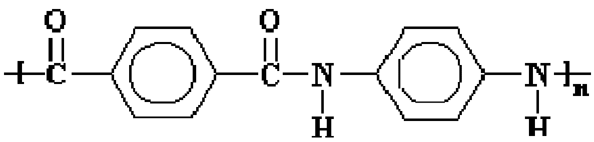
Polycarbonate, or specifically polycarbonate of bisphenol A, is a clear plastic used to make shatterproof windows, lightweight eyeglass lenses

3.2 Aramids

Aramids are a family of nylons, including Nomex® and Kevlar®. Aramids are used in the form of fibers. They form into even better fibers than non-aromatic polyamides, like nylon 6,6.

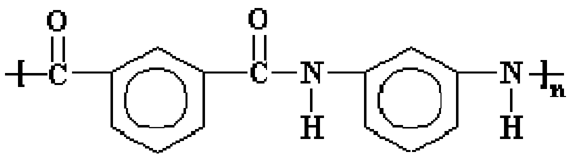
Kevlar® is used to make things like bullet proof vests and puncture resistant bicycle tyres. It is also possible to produce bullet proof bicycle tyres from Kevlar® if one felt the need. Blends of Nomex® and Kevlar® are used to make fireproof clothing. Nomex® is what keeps the monster truck and tractor drivers from burning to death should their fire-breathing rigs breathe a little too much fire. Polymers play another part in the monster truck show in the form of elastomers from which those giant tires are made. Nomex®-Kevlar® blends also protect fire fighters.

Kevlar® is a polyamide, in which all the amide groups are separated by *para*-phenylene groups, that is, the amide groups attach to the phenyl rings opposite to each other, at carbons 1 and 4.



In Kevlar the aromatic groups are all linked into the backbone chain through the 1 and 4 positions. This is called *para*- linkage.

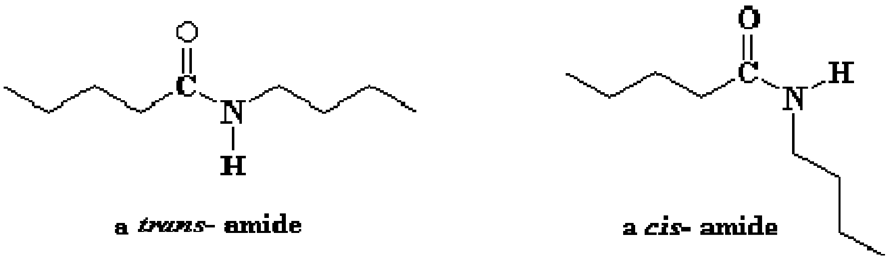
Nomex®, on the other hand, has *meta*-phenylene groups, that is, the amide groups are attached to the phenyl ring at the 1 and 3 positions.



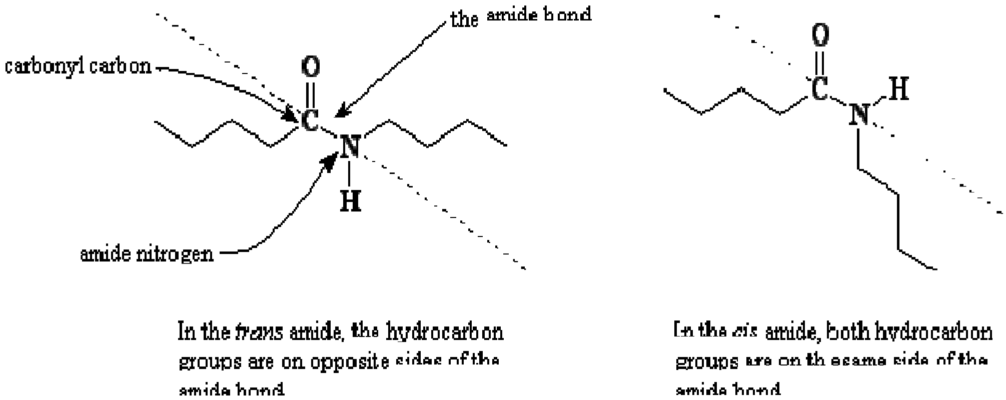
In Nomex the aromatic groups are all linked into the backbone chain through the 1 and 3 positions. This is called *meta*- linkage.

Kevlar® is a very crystalline polymer. It took a long time to figure out how to make anything useful out of Kevlar® because it would not dissolve in anything. So processing it as a solution was out. It would not melt below 500 ^{o}C, so melting it down was out, too. Then a scientist named Stephanie Kwolek came up with a brilliant plan.

Aramids are used in the form of fibers. They form into even better fibers than non-aromatic polyamides, like nylon 6,6. They have the ability to adopt two different shapes, or *conformations*. The two shapes below are the same compound, in two different conformations. The one on the left is called the *trans* conformation, and the one on the right is the *cis*-conformation.

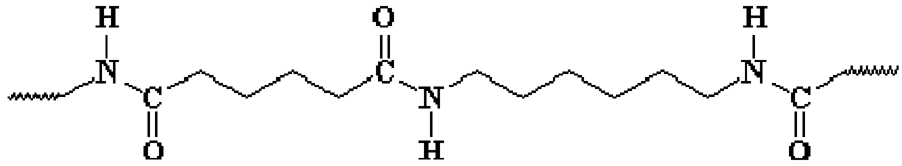


In Latin, *trans* means "on the other side". So when the hydrocarbon groups of the amide are on opposite sides of the *amide bond*, the bond between the carbonyl oxygen and the amide nitrogen, it's called a *trans*-amide. Likewise, *cis* in Latin means "on the same side", and when both hydrocarbon groups are on the same side of the amide bond, we call it a *cis*-amide.

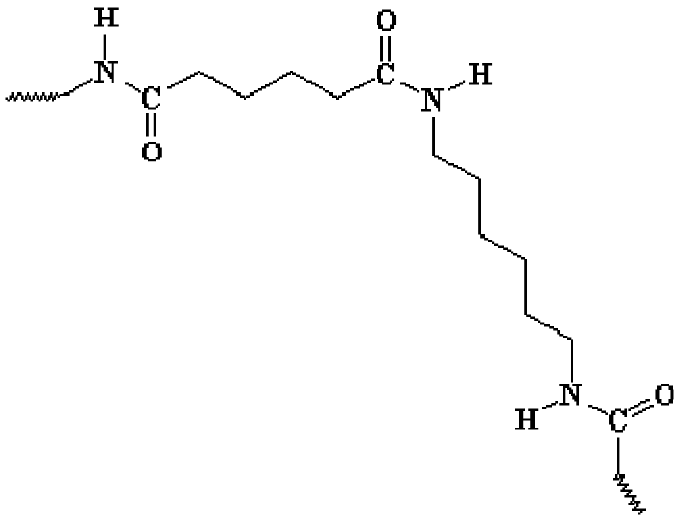


The same amide molecule can twist back and forth between the *cis*- and *trans*- conformations, given a little bit of energy.

The same *cis*- and *trans*-conformations exist in polyamides, too. When all the amide groups in a polyamide, like nylon 6,6 for example, are in the *trans* conformation, the polymer is fully stretched out in a straight line. This is exactly what we want for fibers, because long, straight, fully extended chains pack more perfectly into the crystalline form that makes up the fiber. But sadly, there is always at least some amide linkages in the *cis*-conformation. So nylon 6,6 chains never become fully extended.

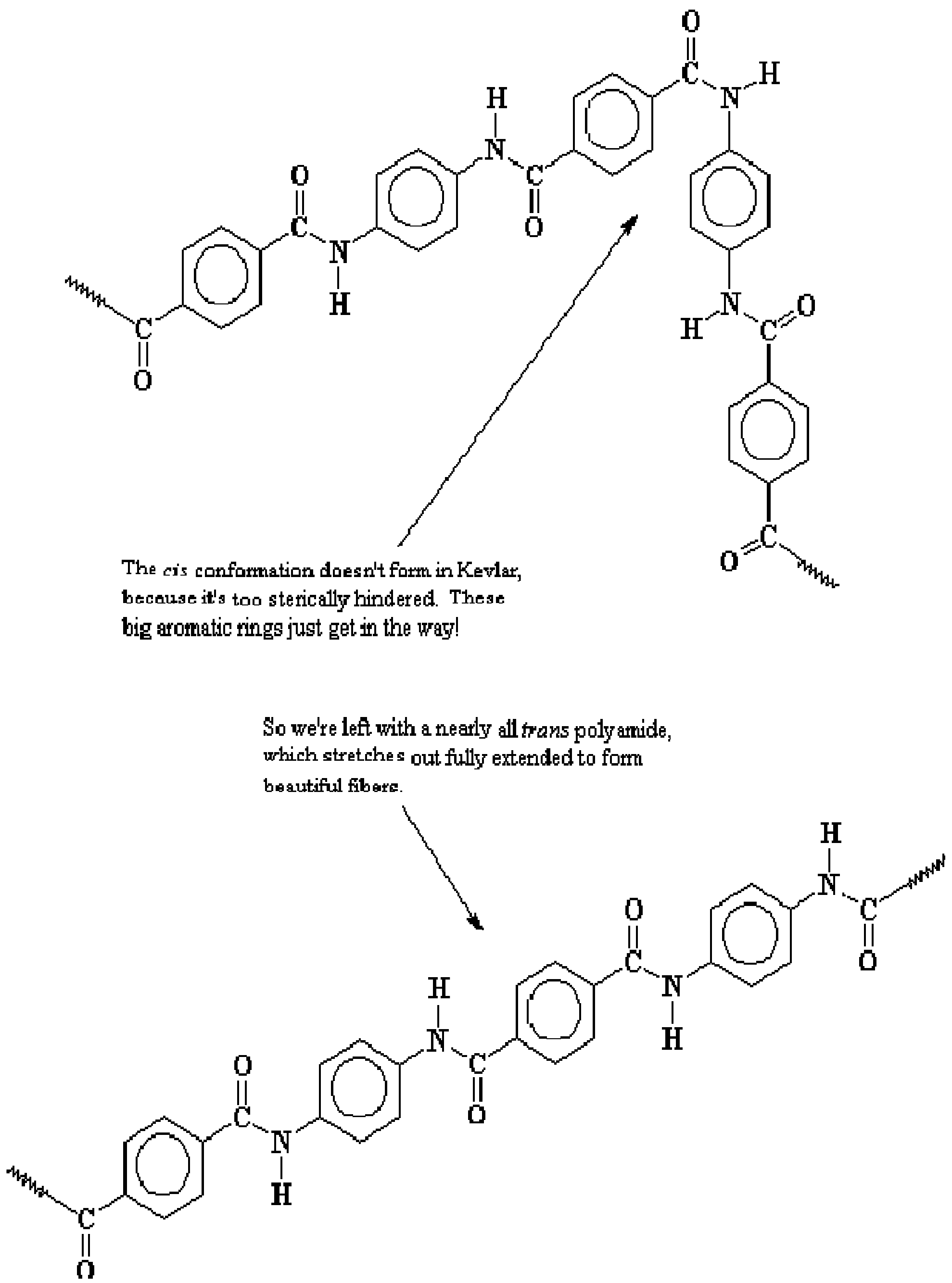


Nylon 6,6 can stretch into fibers easily when all the amide groups are in the *trans* conformation...

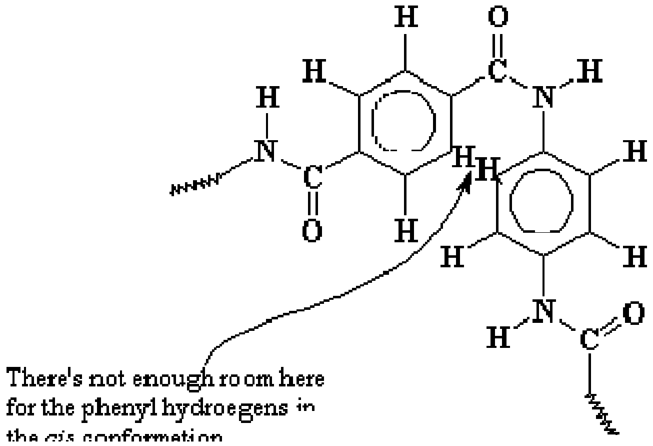


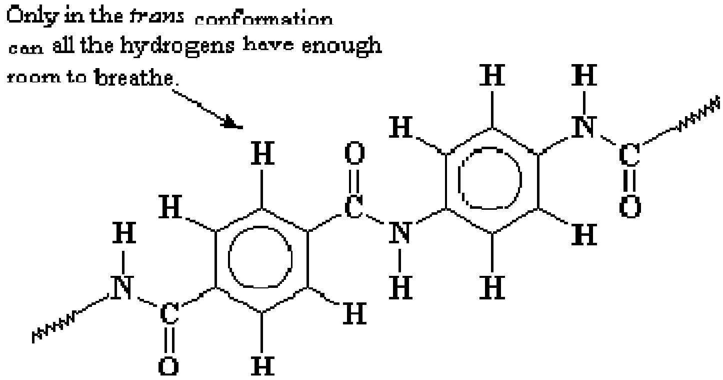
...but one *cis* linkage causes a kink which messes everything up!

But Kevlar® is different. When it tries to twist into the *cis*-conformation, the hydrogens on the big aromatic groups get in the way! The *cis* conformation puts the hydrogens just a little closer to each other than they want to be. So Kevlar® stays nearly fully in the *trans*-conformation. So Kevlar® can fully extend to form beautiful fibers.



When Kevlar® tries to form the *cis*-conformation, there's not enough room for the phenyl hydrogens. So only the *trans*-conformation is usually found.





SELF ASSESSMENT EXERCISE 1

1. Distinguish chemically between Kevlar and Nomex
2. Mention two uses of each of the aramids.

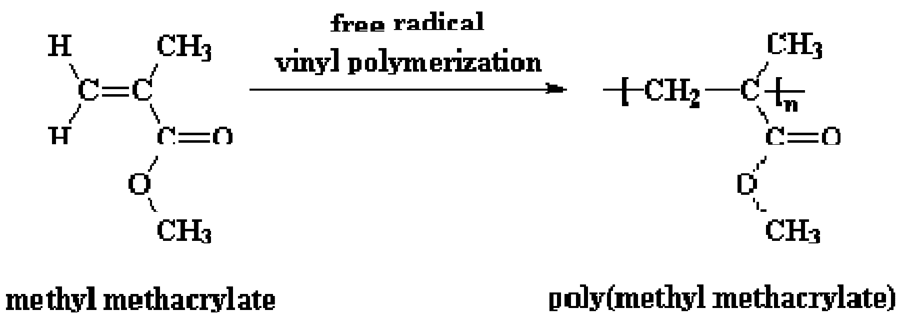
3.3 Poly (methyl methacrylate), PMMA

Poly (methyl methacrylate), or PMMA, is a clear plastic, used as a shatterproof replacement for glass. The barrier at the ice rink which keeps hockey pucks from flying in the faces of fans is made of PMMA. The chemical company Rohm and Haas makes windows out of it and calls it Plexiglas. Ineos Acrylics also makes it and calls it Lucite. Lucite is used to make the surfaces of hot tubs, sinks, and the ever popular one piece bathtub and shower units, among other things.

When it comes to making windows, PMMA has another advantage over glass. PMMA is more transparent than glass. When glass windows are made too thick, they become difficult to see through. But PMMA windows can be made much thicker and they are still perfectly transparent. This makes PMMA a wonderful material for making large aquariums, whose windows must be thick in order to contain the high pressure due to millions of gallons of water. In fact, the largest single window in the world, an observation window at California's Monterrey Bay Aquarium, is made of one big piece of PMMA which is 54 feet long, 18 feet high, and 13 inches thick (16.6 m long, 5.5 m high, and 33 cm thick).

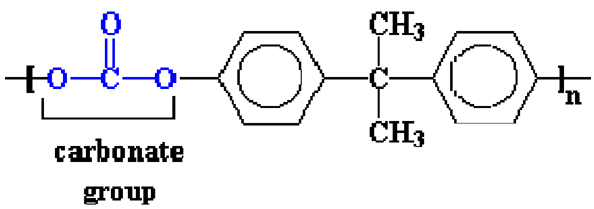
PMMA is also found in paint. Acrylic "latex" paints often contain PMMA suspended in water. PMMA does not dissolve in water, so dispersing PMMA in water requires another polymer to make water and PMMA compatible with each other. But PMMA is more than just plastic and paint. Often lubricating oils and hydraulic fluids tend to get really viscous and even gummy when they get really cold. This is a real pain when you are trying to operate heavy equipment in really cold weather. But when a little bit PMMA is dissolved in these oils and fluids, they do not get viscous in the cold, and machines can be operated down to -100 ^{o}C (-150 ^{o}F), that is, presuming the rest of the machine can take that kind of cold!

PMMA is a vinyl polymer, made by free radical vinyl polymerization from the monomer methyl methacrylate.



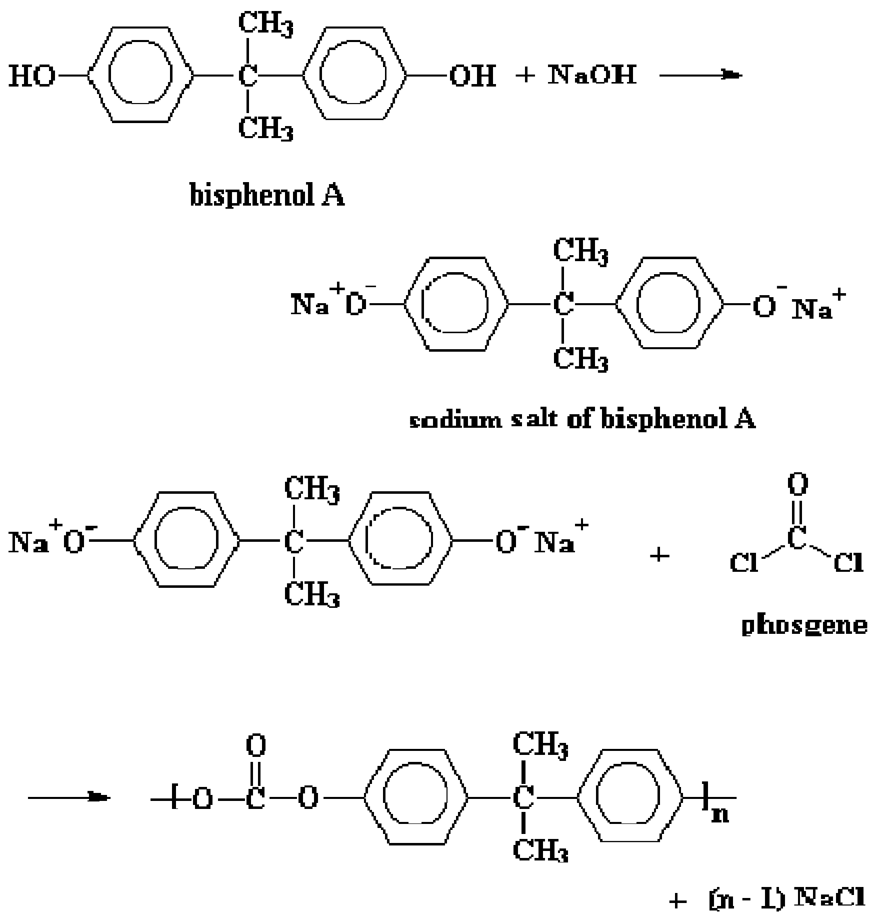
3.4 Polycarbonate

Polycarbonate, or specifically polycarbonate of bisphenol A, is a clear plastic used to make shatterproof windows, lightweight eyeglass lenses, and similar products. General Electric makes this stuff and sells it as Lexan.

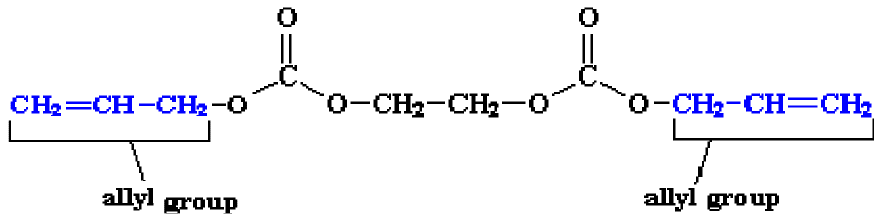


Polycarbonate gets its name from the carbonate groups in its backbone chain. It is known as polycarbonate of bisphenol A because it is made from bisphenol A and phosgene. This starts out with the reaction of bisphenol A with sodium hydroxide to get the sodium salt of bisphenol A.

The sodium salt of bisphenol A is then reacted with phosgene, a right nasty compound which was a favorite chemical weapon in World War I, to produce the polycarbonate.

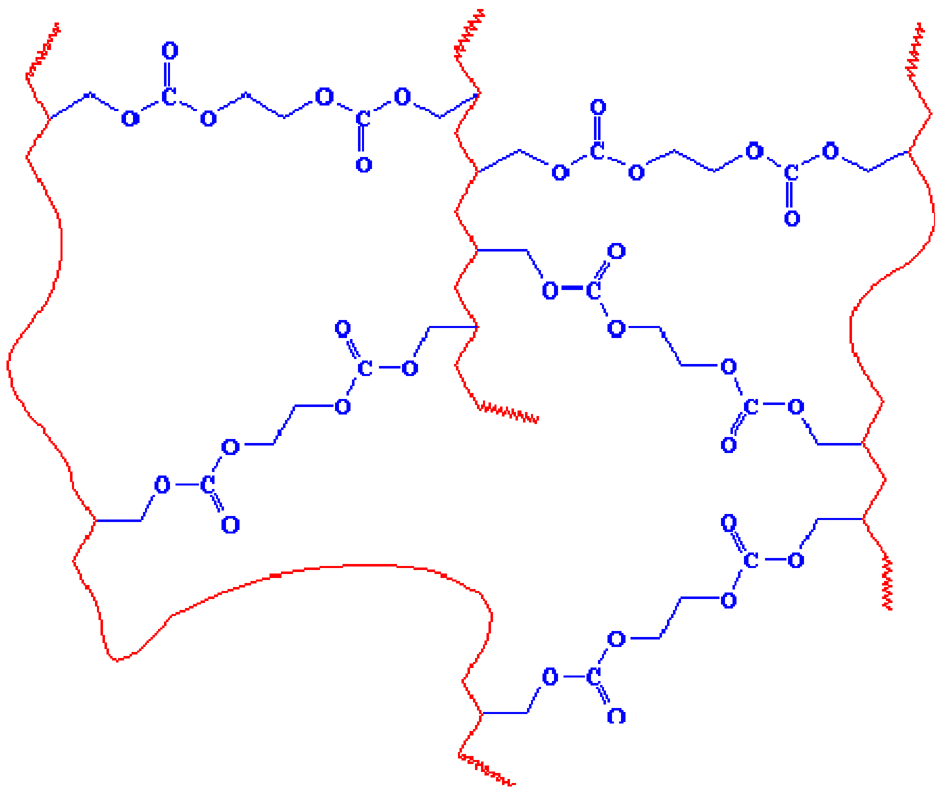


But there is another polycarbonate. This is the polycarbonate that is used to make ultra-light eyeglass lenses. For people with really bad eyesight, if the lenses were made out of glass, they would be so thick that they would be too heavy to wear. But this new polycarbonate changed all that. Not only is it a lot lighter than glass, but it has a much higher *refractive index*. That means it bends light more than glass.



It has two allyl groups on the ends. These allyl groups have carbon-carbon double bonds in them. This means they can polymerize by free radical vinyl polymerization. Of course, there are two allyl groups on each monomer. The two allyl groups will become parts of different polymer chains. In this way, all the chains will become tied together to form a cross linked material. The carbonate-containing groups (shown in blue) form the cross links between the polymer chains (shown in red). This cross linking makes the material very strong, so it would not break nearly as easily as glass will. This is really important for kids' glasses!

There is a fundamental difference in the two types of polycarbonate described here. Polycarbonate of bisphenol A is a thermoplastic. This means it can be molded when it is hot. But the polycarbonate used in eyeglasses is a thermoset. Thermosets do not melt, and they can't be remolded. They are used to make things that need to be really strong and heat resistant.



SELF ASSESSMENT EXERCISE 2

1. Propose a short equation for the preparation of poly (methyl methacrylate).
2. What are the striking features of a polycarbonate used in eyeglasses?

4.0 CONCLUSION

It has been clearly shown how new scientific discovery has brought an improvement into the nature and uses of polymers either as plastics or fibres.

5.0 SUMMARY

In this unit, we have learnt that:

- aramids are a family of nylons, including Nomex® and Kevlar®
- kevlar® is a polyamide, in which all the amide groups are separated by *para*-phenylene groups, that is, the amide groups attach to the phenyl rings opposite to each other, at carbons 1 and 4. Kevlar® stays nearly fully in the *trans*- conformation
- nomex®, on the other hand, has *meta*-phenylene groups, that is, the amide groups are attached to the phenyl ring at the 1 and 3 positions
- poly (methyl methacrylate), or PMMA, is a clear plastic, used as a shatterproof replacement for glass
- there is a fundamental difference in the two types of polycarbonate described here. Polycarbonate of bisphenol A is a thermoplastic. But the polycarbonate used in eyeglasses is a thermoset.

6.0 TUTOR-MARKED ASSIGNMENT

1. Distinguish between Kevlar and Nomex.
2. Propose a simple laboratory step for the synthesis of polycarbonates.
3. Mention four uses of each of the aramids.

7.0 REFERENCE/FURTHER READING

Synthetic Fibres: Nylon, Polyesters, Acrylic and Polyolefins; Edited by J.E McIntyre, Woodhead Textiles Series No. 36, Woodhead Publishing Limited, 2009.

MODULE 4 DYEING MECHANISMS

UNIT 1 TEXTILE DYEING PROCESS

CONTENTS

1.0 INTRODUCTION

In every sphere of industrial activity colour is needed. Dyeing machine is the device that is used by different industries for imparting colours. From paper to plastic to textiles everywhere there is use of Dyeing Machinery. According to the need of each type of substrate, different set of machines are put to use. The applications of these machinery give an impetus to the products related to dyeing. However, rising energy prices is having a knock-on effect on manufacturing expenditure for dyeing machinery. Therefore, there will be greater interest globally in machinery that have a lower energy consumption along with heat recovery systems that are able to preheat the incoming cold feed water.

2.0 OBJECTIVES

By the end of the unit, you should be able to state the:

- types of dyeing machine
- mechanism and operation of the batch dyeing process
- type and mechanism of continuous dye process.

3.0 MAIN CONTENT

3.1 Types of Dyeing Process

There are different types of dyeing machine depending on convenience and choice of materials to be dyed. Today computers are used to control and monitor all aspects of dyeing. Over the last twenty to thirty years, developments in dye chemistry have enabled the man-made fibre to be dyed with better fastness to light and washing, and in an ever increasing range of colours.

3.2 Batch Dyeing Process

Batch Dyeing Process is the most popular and common method used for dyeing of textile materials. Batch dyeing is also sometimes referred to as *Exhaust dyeing*. This is because in this process, the dye gets slowly transferred from a comparatively large volume dye bath to the substrate or material that is to be dyed. The time taken is also longer.

The dye is meant to 'exhaust' from dye bath to the substrate. In batch processes, textile substrates can be easily dyed at any stage of their assembly into the desired textile product. This includes fiber, yarn, fabric or garment. Some type of batch dyeing machines can function at temperatures only up to 1000^{o}C. For example cotton, rayon, nylon, wool etc. can be dyed at 1000^{o}C or lower temperatures, while polyester and some other synthetic fibers are dyed at 1000 ^{o}C or even higher temperatures. There are three general types of batch dyeing machines. The first, is the one where there is circulation of fabric. Second, is the one where the dye bath gets circulated while the material that is being dyed remains stationary, and finally the third, where both the bath and material to be dyed gets circulated. Examples of dyeing machines that utilises batch dyeing process are Beck, Jet, Jigs, Beam Package dyeing machines etc.

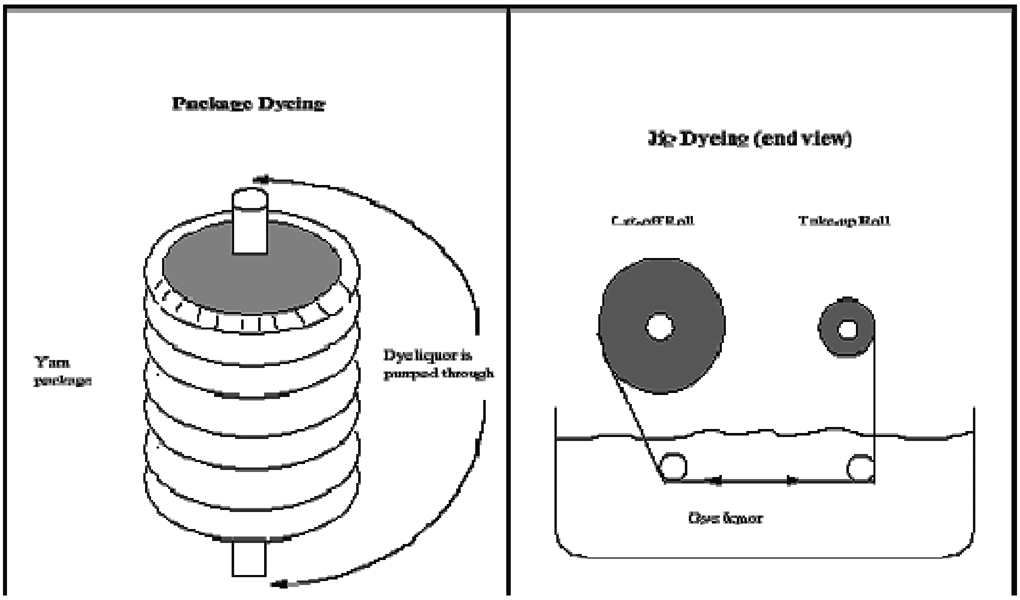


Fig. 1.1: Image Showing Popular Machines Utilising the Batch Dyeing Method

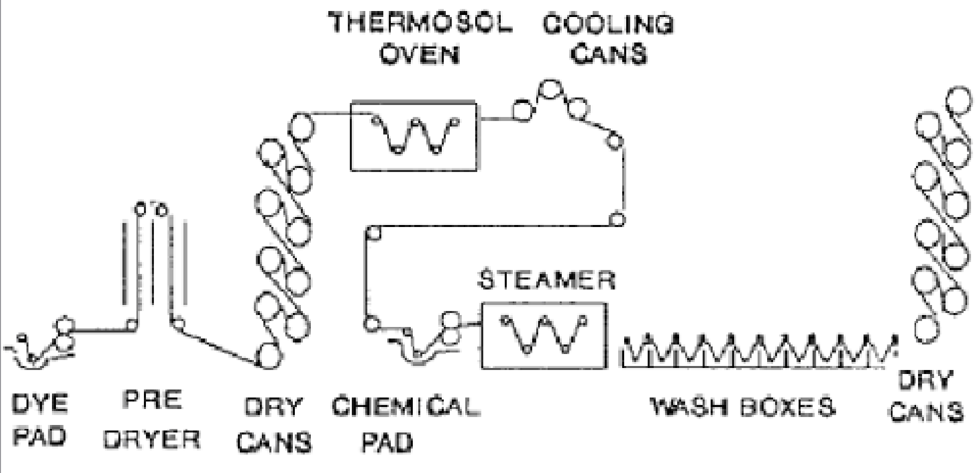
Source: www.dyespigments.com.

3.3 Continuous Dyeing Process

The working of a continuous dyeing process is described here. The textile substrates are fed continuously into a dye range. The speed can vary between 50 to 250 metres per minute. According to Industry estimates continuous dyeing is a popular dyeing method and accounts for around 60% of total average yardage of the products that are dyed.

A continuous dyeing process typically consists of the following. Dye application, dye fixation with heat or chemicals and finally washing. Continuous Dyeing has been found to be most suitable for woven fabrics. Mostly continuous dyeing is designed for blends of polyester and cotton. The step of padding plays a key role in the operation of continuous dyeing. Sometimes nylon carpets are also dyed in continuous processes, but the design ranges for them is unlike that for flat fabrics. Warps are also dyed in continuous process. Very good examples of such warp dyeing are long chain warp dyeing and slather dyeing using indigo.

A continuous dye range has been found useful and economically sustainable for dyeing long runs of a given shade. One important factor that separates continuous dyeing from batch dyeing is the tolerance factor for colour variation. That is more for continuous dyeing as compared to batch dyeing. This is so because of two reasons (a) the speed of the process; (b) presence of a large number of process variables which affects dye application. The process that is illustrated below is designed for dyeing of blended fabric of polyester and cotton.



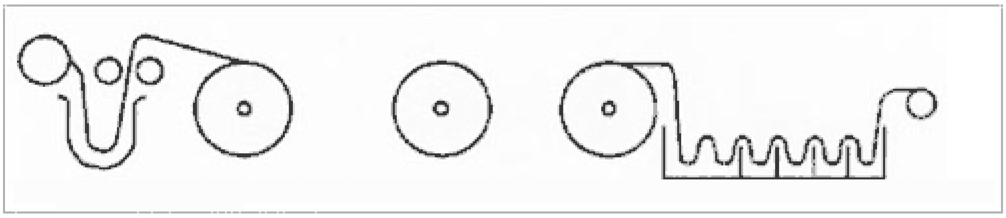
Schematic diagram of a continuous dyeing range.

Fig 1.2: Schematic Diagram of a Continuous Dyeing Machine
Source: www.dyespigments.com

Some of the popular methods in continuous dyeing process are Pad-steam, Wet-steam, thermosol dyeing, TAK dyeing, space dyeing, and pad-steam dyeing, long chain warp dyeing etc.

3.3.1 Semi-Continuous Dyeing

In the process of semi-continuous dyeing that consists of pad-batch, pad-jig, pad-roll, the fabric is first impregnated with the dye-liquor, in what is called a padding machine. Then it is subjected to batch wise treatment in a jigger. It could also be stored with a slow rotation for many hours. In the pad-batch this treatment is done at room temperature while in pad-roll it is done at increased temperature by employing a heating chamber. This helps in fixation of the dyes on to the fibres. After this fixation process, the material in full width is thoroughly cleansed and rinsed in continuous washing machines. There is only one point of difference between continuous and semi-continuous dyeing process: in semi-continuous dyeing, the dye is applied continuously by padding. The fixation and washing remain discontinuous. Liquor ratio in semi-continuous dyeing is not of much importance and is not taken as a parameter. One of the widely used techniques for semi-continuous dyeing process is the Pad Batch Dyeing. A schematic diagram is given here for the semi-continuous dyeing process.



The following table shows some of the important machinery for semi-continuous and continuous dyeing processes.

Table 1.1: Main Features of Continuous and Semi-Continuous Processes

<table>
<tr><th>Make up</th><th>Process</th><th colspan="3">Equipment</th></tr>
<tr><td rowspan="3">Woven and Knitted Fabric, tufted carpet</td><td>Rope</td><td colspan="2">Continuous</td><td>Padding Machine for Piece in rope form</td></tr>
<tr><td rowspan="2">Open width</td><td rowspan="3">Semi Continuous</td><td>Pad batch (or carp-o-roll for carpet)</td><td>Padding Machine+ Washing Machine</td></tr>
<tr><td>Pad batch (or carp-o-roll for carpet)</td><td>Padding Machine+ Washing Machine</td></tr>
<tr><td colspan="2" rowspan="3"></td><td>Pad -jig</td><td>Padding Machine+ Jigger+ Washing Machine</td></tr>
<tr><td rowspan="2">Continuous</td><td>Pad stream</td><td>Padding Machine+ Steamer+ Washing Machine</td></tr>
<tr><td>Pad Dry</td><td>Padding Machine+ Stenter frame+ Washing Machine</td></tr>
</table>

Source: www.dyespigments.com

3.4 Pad Batch Dyeing

Pad Batch Dyeing is one of the widely used techniques for semi-continuous dyeing process. It is mainly used in the dyeing of cellulosic fibre like cotton or viscose (knit and woven fabric) with reactive dyes. Pad batch dyeing is a textile dyeing process that offers some unique advantages in the form of versatility, simplicity, and flexibility and a substantial reduction in capital investment for equipment. It is primarily a cold method that is the reason why it is sometimes referred to as the cold pad batch dyeing.

3.4.1 Workings of a Cold Pad Dyeing Process

The technique or process used in pad-batch dyeing starts with saturating first the prepared fabric with pre-mixed dye liquor. Then it is passed through rollers. The rollers, or padders, effectively force the dyestuff into the fabric. In the process, excess dye solution is also removed. After removal of excess dye stuff the fabric is subsequently "batched". This batching is done by either storing it in rolls or in boxes. It takes a minimum of 4-12 hours. The batches are generally enclosed by plastic films. This prevents absorption of carbon dioxide and water evaporation. Finally as the reaction is complete the fabrics are washed. This is done by becks, beams, or any other washing devices.

3.4.2 Special Features of Pad Batch Dyeing Process

1. Significant cost and waste reduction as compared to other conventional dyeing processes.
2. Total elimination of the need for salt and other specialty chemicals. For example there is no need for anti-migrants, leveling agents and fixatives that are necessary in conventional dye baths.
3. Optimum utilization of dyes that eliminates specialty chemicals cuts down chemical costs and waste loads in the effluent. All this results in a formidable reduction in wastewater treatment costs.
4. Excellent wet fastness properties.
5. Pad batch dyeing cuts energy and water consumption owing to low bath ratio (dye: water) required for the process. This is because unlike other dyeing processes it does not function at high temperatures.
6. A uniform dye quality is achieved with even colour absorbency and colour fastness.
7. As compared to rope dyeing, pad batch dyeing produces much lower defect levels.
8. In pad batch dyeing, qualities like high shade reliability and repeatability are common. This is because of high reactivity dyes with rapid fixation rate and stability.
9. Lastly pad batch dyeing can also improve product quality. The fabric undergoing the cold pad batch dyeing process is able to retain a uniformly coloured appearance. It shows added luster and gives a gentle feel. The fabric gives a brighter look in shades.

4.0 CONCLUSION

It could be seen that the understanding of the dyeing mechanism has significantly improved the type of materials resulting from the dyeing processes.

5.0 SUMMARY

In this unit, we have learnt that:

- today computers are used to control and monitor all aspects of dyeing
- developments in dye chemistry have enabled the man-made fibre to be dyed with better fastness to light and washing, and in an ever increasing range of colours
- a continuous dyeing process typically consists of the following. Dye application, dye fixation with heat or chemicals and finally washing
- pad Batch Dyeing cuts energy and water consumption owing to low bath ratio (dye: water) required for the process
- pad Batch Dyeing is mainly used in the dyeing of cellulosic fibre like cotton or viscose (knit and woven fabric) with reactive dyes.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the mechanism of batch dyeing process.
2. Enumerate the advantages of pad batch dyeing process over other types in the same category.

7.0 REFERENCE/FURTHER READING

Industrial Dyes, Chemistry, Properties, Applications; edited by Klaus Hunger (2003). Wiley-VCH.

UNIT 2 BEAM DYEING MACHINE, HANK DYEING MACHINE AND JIG DYEING MACHINE

CONTENTS

1.0 INTRODUCTION

There is no dirt in the type of Textile dyeing machinery that is available these days to a modern dyeing house. Most of these machinery utilise latest advancement in the dyeing technology to give high capacity dyeing along with uniformity and smooth finishes. For our convenience, we have enumerated below some of the popular categories of dyeing machines although no claim is made here that this list is fully exhaustive.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- discuss the mechanism of bean dyeing machine
- identify the main features and process of hank dyeing machine
- describe the process of jig dyeing machine.

3.0 MAIN CONTENT

3.1 Definitions

There are still some more efficient dyeing processes which are highlighted below:

3.2 Beam Dyeing Machine

The beam dyeing machine operates with the same principle as that of package dyeing machine. It can be effectively used to dye yarn or fabric. The process works like this: fabric or yarn in open width is rolled on to a perforated beam. The beam then subsequently slid into a vessel that is closed and pressurized. The colour impregnates the fabric as the dye liquor is allowed to go on circulating through the perforations in the beam. Usually the beam machines are designed in such a manner so as to hold a single beam or multiple beams in a batch.

3.3 Batch Dyeing

3.3.1 Features of Beam Dyeing Machine

a. Able to adjust water level in accordance to fabric volume.
b. Even dyeing and superior dyeing quality.
c. Optimized circulation system along with high performance pumps.

3.3.2 Advantages of Beam Dyeing Machine

i. The fabric is put under controlled tension, and is wound on to a perforated beam. This results in elimination of creases from the fabric. It also ensures total control of dimensions of the roll of fabric.
ii. The fabric is held in a fixed position during the process of dyeing. This actually means that there is no application of mechanical action on to the fabric. As shown in the figure, there is no movement of the fabric as the hydrostatic pressure of the pump forces the dye liquor through the fabric roll.

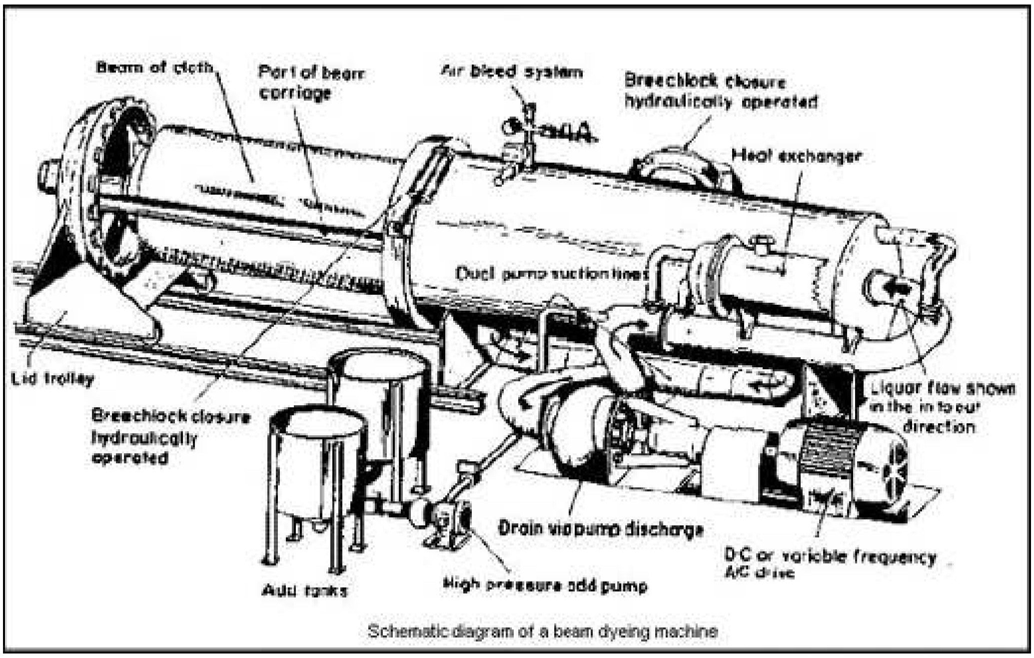


Fig .2.1: Schematic Diagram of a Beam Dyeing Machine
Source: www.dyespigments.com

SELF ASSESSMENT EXERCISE 1

1. Describe the features of a Beam Dyeing Machine.
2. Mention two of its advantages.

3.4 Hank Dyeing Machine

Hank dyeing machine is mostly used for dyeing of patterned wool carpets. There are mainly four types of Hank Dyeing machines used. They are the following: single stick Hussong-Type Machines, the double-stick machine, double-stick cabinet machine, and lastly circular carrier machine. Out of this four, the first category of Hussong-Type Machines is the most popular one.

In the Hussong type machines, a hank needs to be hung on removable sticks, from the underside of the dyeing vessel lid. The lid is then vertically lowered onto the dyeing vessel. The dyeing vessel consists of a simple box that has a perforated false bottom. A reversible impeller, which is placed vertically in a weir chamber at one corner of the machine, is used for circulating liquor. Heat is generated by closed steam coils located beneath the false bottom. While on the smaller machines heat is generated by live steam injection.

3.4.1 Features of Hank Dyeing Machine

a. Temperature control is done by electro-mechanical or programmable logic controllers.
b. Machine capacities can range from 10 kg sample machines -1 ton machines.
c. Yarn loads up to 4000 kg can be dyed by coupling together of machines.
d. Typical liquor ratios are 1:15 to 1:25.

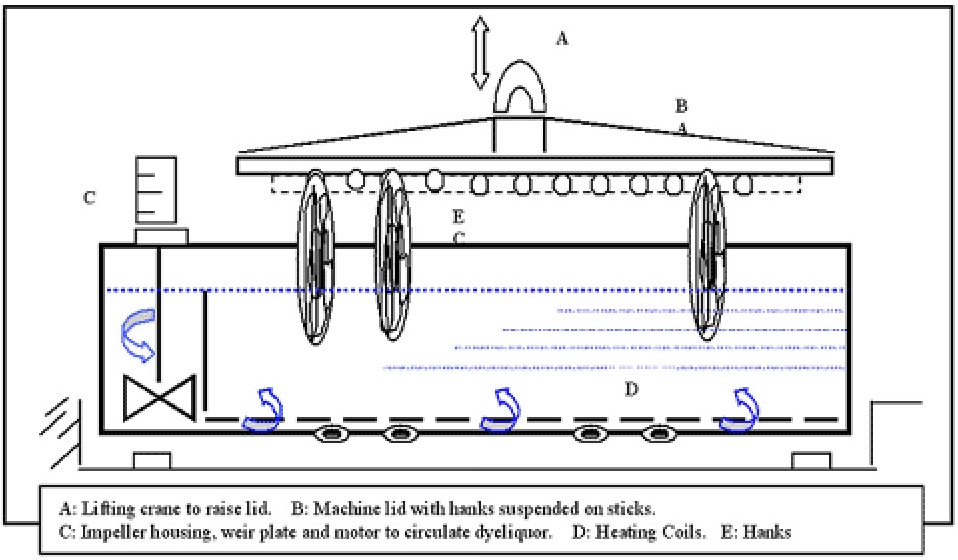


Fig. 2.2: Schematic Diagram of a Hank Dyeing Machine
Source: www.dyespigments.com

3.5 Jig Dyeing Machine

A Jig Dyeing machine is an efficient dyeing technique. It is also known by the name of jigger. Jig Dyeing machine processes fabrics in open width to avoid creasing problems in fabric dyeing. The process works like this. The Jig Dyeing machine operates by transferring the fabric back and forth. This happens from roller to roller via the medium of a dye bath that is located at the base of the machine. As soon as the second roller gets full, the direction of movement of fabric can be reversed. In Jig dyeing, the duration of the process is measured on the basis of the number of passages or ends of the fabric passing through the dye bath from roller to roller. The end in dyeing parlance is known as the passing of fabric through dye liquor from one roller to the other.

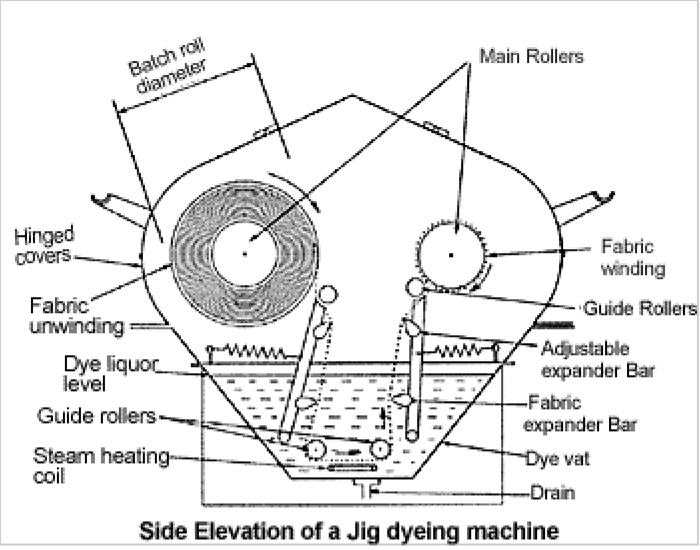


Fig. 2.3: Some Features of a Jig Dyeing Machine
Source: www.dyespigments.com

3.5.1 Types of Jig Dyeing Machine

a. **Atmospheric Jigs-** Atmospheric jigs operate at atmospheric temperatures and pressures. These machines are applied for natural fibres. Here the temperature limit is typically 1000. Centigrade.

b. **High Temperature Jigs-** A high temperature jig functions in the same way as an atmospheric jig, but comes with the addition of a pressure vessel that is designed to function at 1300C. The pressure vessel also helps in having a close control of the dyeing temperature. Typically it is applied for dyeing synthetic fibres.

4.0 CONCLUSION

It could be seen that high technological advancement has produced machinery that are of high quality and gives smooth finishes and beautiful fabrics.

5.0 SUMMARY

In this unit, we have learnt that:

- the beam dyeing machine can be effectively used to dye yarn or fabric
- hank dyeing machines are mostly used for dyeing of patterned wool carpets
- jig Dyeing machine processes fabrics in open width to avoid creasing problems in fabric dyeing.

6.0 TUTOR-MARKED ASSIGNMENT

1. With the aid of a simple diagram, describe the operation of a Hank dyeing machine.
2. Enumerate the advantages of both Jig dyeing and Beam dyeing machines.

7.0 REFERENCES/FURTHER READING

Industrial Dyes, Chemistry, Properties, Applications; Edited by Klaus Hunger (2003).Wiley-VCH.

www.dyespigments.com

UNIT 3 JET DYEING MACHINE

CONTENTS

1.0 INTRODUCTION

In the textile industry a variety of machines are used for dyeing. Some of these machines with minor operational modifications can easily accommodate new types of dyes and take advantage of the latest advances made in the dyeing equipment technology.

2.0 OBJECTIVES

By the end of this unit, you should be able to:

- explain the mechanism of Jet dyeing process
- state the types of Jet dyeing machine
- state advantages of Jet dyeing process.

3.0 MAIN CONTENT

3.1 Definition of Jet Dyeing Machine

In the Jet dyeing machine the reel is completely eliminated. A closed tubular system exists where the fabric is placed. For transporting the fabric through the tube a jet of dye liquor is supplied through a venturi. The Jet creates turbulence. This helps in dye penetration along with preventing the fabric from touching the walls of the tube. As the fabric is often exposed to comparatively higher concentrations of liquor within the transport tube, a small quantity of dye bath is needed in the bottom of the vessel. This is just enough for the smooth movement from rear to front. Aqueous jet dyeing machines generally employs a driven winch reel along with a jet nozzle.

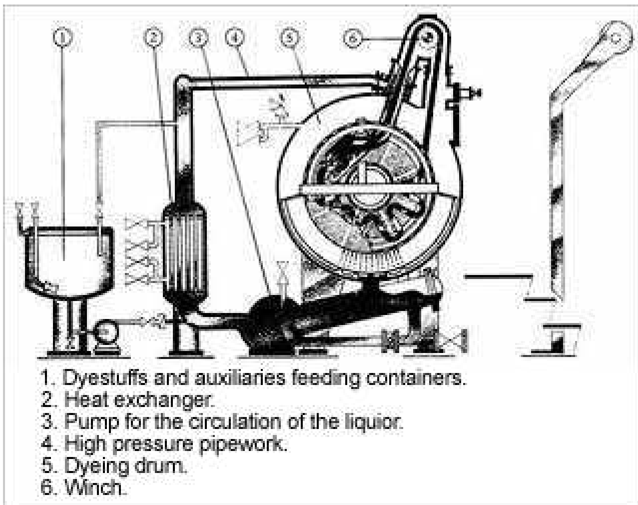


Fig. 3.1: Features of a Jet Dyeing Machine
Source: www.dyespigments.com.

3.2 Types of Jet Dyeing Machine

In deciding the type of dyeing machine the following features are generally taken into consideration for differentiating. They are the following.

- Shape of the area where the fabric is stored i.e. long shaped machine or J-box compact machine
- Type of the nozzle along with its specific positioning i.e. above or below the bath level.

3.3 Overflow Dyeing Machine

Overflow Dyeing Machines are designed for use in delicate knitted and woven fabrics that are made up of natural as well as synthetic fibres. They are also extensively used in the production of carpets. The main difference between jet and overflow machines is that in jet machines the fabric gets transported by a bath that flows at high speed through the nozzle, while in Overflow Dyeing Machine it is the gravitational force of the liquor overflow that is responsible for fabric transportation.

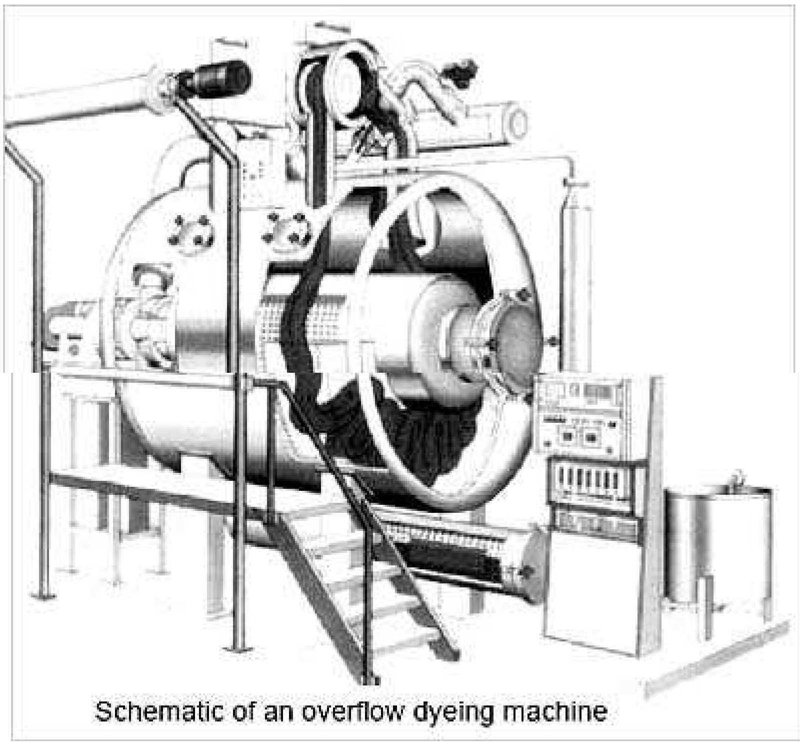


Fig. 3.2: Schematic Diagram of an Overflow Dyeing Machine
Source: www.dyespigments.com

3.3.1 Functioning of an Overflow Dyeing Machine

A typical Overflow Dyeing Machine works like this. A winch that is not motor driven usually is located in the top side of the machine where the fabric is hung. A longer length of textile is made to hang from the exit side of the winch as compared to the inlet side. By applying the force of gravitation the longer length of textile is pulled downward more strongly than the shorter one. Consequently the fabric is soaked in the bath without any sort of tension.

3.3.2 Advantages of Overflow Dyeing Machine

No evaporative losses- As the dyeing vessel is closed, there is no evaporative losses stemming from the dye bath. Further, depending on the situation the temperature may be raised to more than 1000^{o}C.

No build up of steam condensate in the dye bath- The latest technology implies that the dye bath gets heated by a heat transducer which is steam driven. This technology apart from being very efficient ensures that there is no build up of steam condensate in the dye bath.

Low liquor ratios- Dyeing is conducted at relatively low liquor ratios, e.g. 10:1 and may be lesser resulting in substantial savings in water and energy.
Excellent dye liquor contact- Excellent dye liquor contact with the fabric rope results in better and more improved level dyeing.
Computer control- The machines are operated by computers and hence, operator error is eliminated.

3.4 Soft-flow Dyeing Machine

In the soft flow dyeing machine water is used for keeping the fabric in circulation. The conventional difference of this equipment from a conventional jets that operates with a hydraulic system is that the fabric rope is kept circulating during the whole processing cycle (right from loading to unloading). There is no stopping of liquor or fabric circulation for usual drain and fill steps.

The principle working behind the technique is very unique. There is a system for fresh water to enter the vessel via a heat exchanger to a special interchange zone. At the same time the contaminated liquor is channeled out through a drain without any sort of contact with the fabric or for that matter the new batch in the machine.

3.4.1 Key Features of Soft Flow Dyeing Machine

a. Significant savings in processing time.
b. Savings in water that is around 50%.
c. Excellent separation of different streams results in optimum heat recovery and a distinct possibility of further use or a dedicated treatment.

3.4.2 Types of Soft Flow Dyeing Machine

A few of the commercially popular brands along with their particular technical specifications are discussed here. The categories are not exhaustive as such:

(a) Multi Nozzle Soft Flow Dyeing Machine

Technical features:

Very low Liquor ratio - around 1:1 (Wet Fabric)
Can reach high temp. up to 140°C
Easily dye 30 to 450 g/mt.sq. of fabrics (woven & knitted fabrics)
Number of very soft-flow nozzles

No pilling effect
Wide capacity

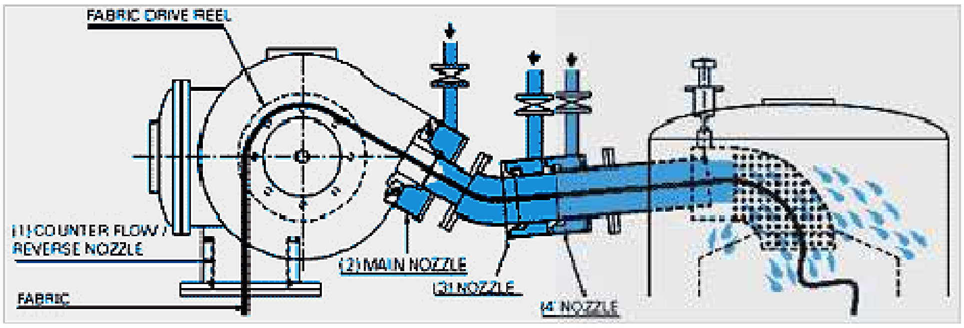


Fig. 3.3: Features of Multi Nozzle Soft Flow Dyeing Machine
Source: www.dyespigments.com

(b) High Temperature High Pressure Soft flow Dyeing Machine

<u>Technical features:</u>

Compact body made of stainless steel.
High efficiency heat exchanger for quick heating/cooling.
Compact body made of stainless steel.
Heating rate - around 4°C/Min up to 900°C - around 3°C/Min up to 135°C At steam pressure of 6 Bar.
Cooling Rate- around 4°C/ Min At water pressure of 4 Bar and 15°C.
Maximum working temp is 135°C.
Maximum working pressure of 3.2 Bar.
Control manual as well as automatic.
Heavy duty stainless steel pump.

3.5 Air Flow Dyeing Machine

This is another development of the very popular jet dyeing machines. The main difference between the Air Flow Machine and Jet Dyeing machine is that the airflow machine utilises an air jet instead of the water jet for keeping the fabric in circulation. Typically the fabric is allowed to pass into the storage area that has a very small amount of free liquor. This results in a reduction in consumption of water, energy and chemicals. The bath level is always under the level of the processed textile. Here the fabric does not remain in touch with the liquor (the bath used is below the basket that holds the fabric in circulation). This invariably means that the bath conditions can be altered without having any impact on the process phase of the substrate.

3.5.1 Advantages of Airflow Dyeing Machine

a. Completely Separated circuit for liquor circulation without getting in touch with the textile
b. Bath less Dyeing operation
c. Rinsing process offers all the added benefits of continuous processing as it is no longer a batch operation
d. Extremely low liquor ratio
e. Virtually nonstop process
f. Comparatively lesserenergy requirement due to faster heating/cooling and optimum heat recovery from the hot exhausted dye liquors
g. Reduction in consumption of the chemicals (e.g. salt) dosage of which is based on the amount of dye bath
h. Lesser water consumption savings up to 50% from the conventional Jet dyeing machines
i. Sensitivity towards ecology
j. Economical operation
k. More safety while dyeing

4.0 CONCLUSION

There are three types of Jet dyeing mechanisms which are Overflow Dyeing Machine, Soft-flow Dyeing Machine and Airflow Dyeing Machine, which differs in the mode and shape of materials being dyed.

5.0 SUMMARY

In this unit, we have learnt that:

- in the Jet dyeing machine the reel is completely eliminated, thus requiring small quantity of dye bath
- overflow Dyeing Machines are designed for use in delicate knitted and woven fabrics that are made up of natural as well as synthetic fibres. They are also extensively used in the production of carpets
- the main difference between the Air Flow Dyeing Machine and Jet Dyeing machine is that the airflow machine utilises an air jet instead of the water jet for keeping the fabric in circulation.

6.0 TUTOR-MARKED ASSIGNMENT

1. Compare and contrast the advantages of Soft and Air flow dyeing machine.
2. Mention the types of Jet flow dyeing machine.

7.0 REFERENCE/FURTHER READING

Industrial Dyes, Chemistry, Properties, Applications; Edited by Klaus Hunger (2003). Wiley-VCH.