Chapter 6
Indicators

Chapter 7
Environmental pollution and acidity

Chapter 8
Acids and pH

Chapter 9
Theories of acids and volumetric analysis

Chapter 10
Esterification

THE ACIDIC ENVIRONMENT

HSC MODULE 2

Chapter 6 INDICATORS

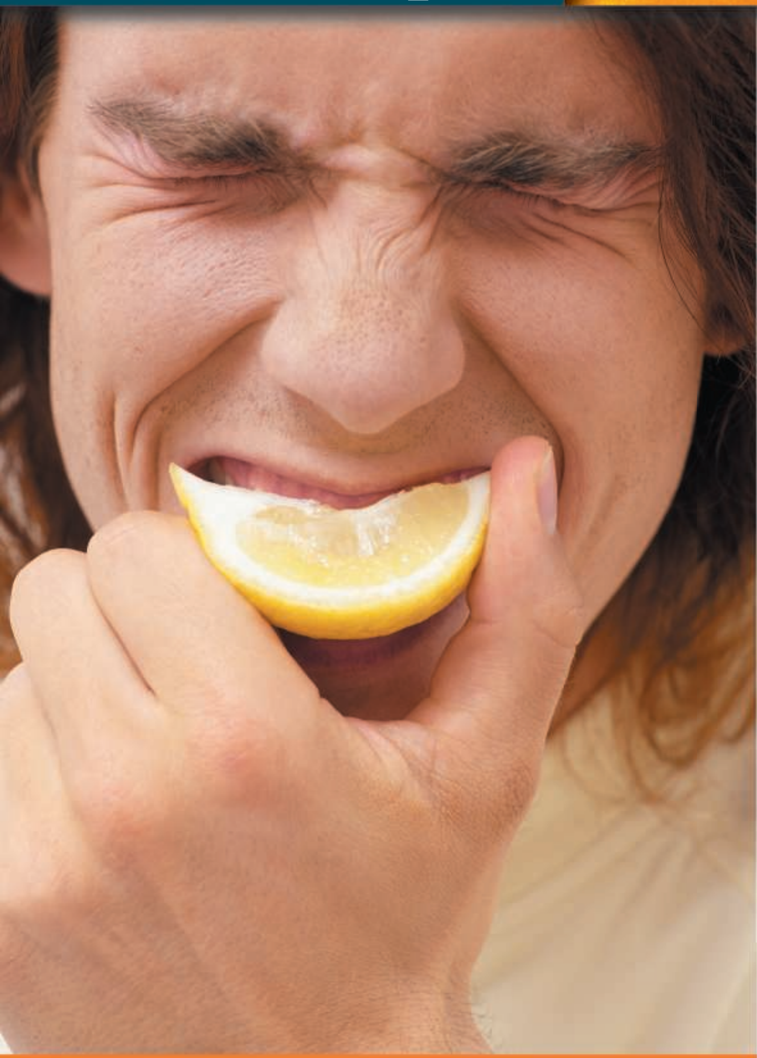

Figure 6.1

The juice of many citrus fruits tastes sour. These fruits contain organic acids such as citric acid.

Introduction

Fruits such as lemons and limes are very sour. The term 'acid' is derived from the Latin word for sour ('acere'). Laboratory acids also taste sour; however, an experiment to test this would be dangerous unless the solutions were very dilute.

In the seventeenth century, Robert Boyle was the first chemist to summarise the properties of acids. He wrote that not only did acids have a sour taste and a corrosive nature, but they also turned vegetable dyes, such as the syrup of violets, red. Following Boyle's example, chemists eventually developed ways of identifying acids and distinguishing them from basic and neutral substances using solutions of plant extracts. These extracts or 'indicators' changed colour when an acid was present or when an acid was neutralised by a base.

In this chapter

6.1 Using indicators to classify substances page 111

6.1 USING INDICATORS TO CLASSIFY SUBSTANCES

Remember

Before beginning this section, you should be able to:
- define the terms solute, solvent and solution
- identify that matter is made of particles that are continuously moving and interacting.

Key content

By the end of this section, you should be able to:
- classify common substances as acidic, basic or neutral
- identify that indicators such as litmus, phenolphthalein, methyl orange and bromothymol blue can be used to determine the acidic or basic nature of a material over a range, and that the range is identified by change in indicator colour
- identify and describe some everyday uses of indicators including the testing of soil acidity/basicity
- perform a first-hand investigation to prepare and test a natural indicator
- identify data and choose resources to gather information about the colour changes of a range of indicators
- solve problems by applying information about the colour changes of indicators to classify some household substances as acidic, neutral or basic.

acid–base indicator: a solution of a pigment or dye that changes colour in the presence of acids and bases

Classifying everyday substances

In the Preliminary Course we classified substances in a variety of ways. Elements were classified as metals, semi-metals or non-metals. Compounds could be classified as ionic, molecular or covalent networks. Another way of classifying substances is to group them according to their ability to change the colour of a natural dye or **acid–base indicator**. Historically, this method of classification was related to other observable properties of these substances, such as their taste and ability to attack and corrode other materials such as iron or limestone.

These historical investigations allowed substances to be classified as acidic, alkaline (basic) or neutral. One of the first indicators to be used to classify substances was an aqueous extract from a lichen. This extract is called 'litmus'. Lichens resemble plants but are more complex. They are an association of a fungus and an alga. Litmus extracts are naturally blue-purple in neutral water. Table 6.1 shows the association between the properties of a substance and the colour its solutions turn when tested with litmus extract.

Table 6.1 Using litmus extract to classify substances

Substances	Properties	Litmus colour change when mixed with the substance	Classification
white vinegar, soda water, lemon juice	• tastes sour • attacks and dissolves some reactive metals • attacks limestone • does not react with fats	blue-purple to red	acid
water	• no taste • does not react with most metals • does not react with fats	remains blue-purple	neutral
ammonia solution, washing soda solution, baking soda solution, lime water	• tastes bitter • does not attack metals • reacts slowly with fats	blue-purple to blue	base

In the school laboratory, litmus may be provided as the aqueous extract or in the form of red and blue litmus paper. Blue litmus papers are prepared by soaking white paper in litmus solution and then allowing them to dry. The red papers are prepared by soaking the white papers in the litmus solution that has been made red by the addition of dilute acid. Litmus has its limitations; for example it is not able to distinguish neutral solutions from those that are very weakly acidic or very weakly basic. It is best used for solutions that are moderately or strongly acidic or basic.

Almost all commercial litmus is produced in Holland. *Roccella tinctoria* is a small, dry lichen, which is found mainly on the Mediterranean coast. It and other species are the main source of commercial litmus.

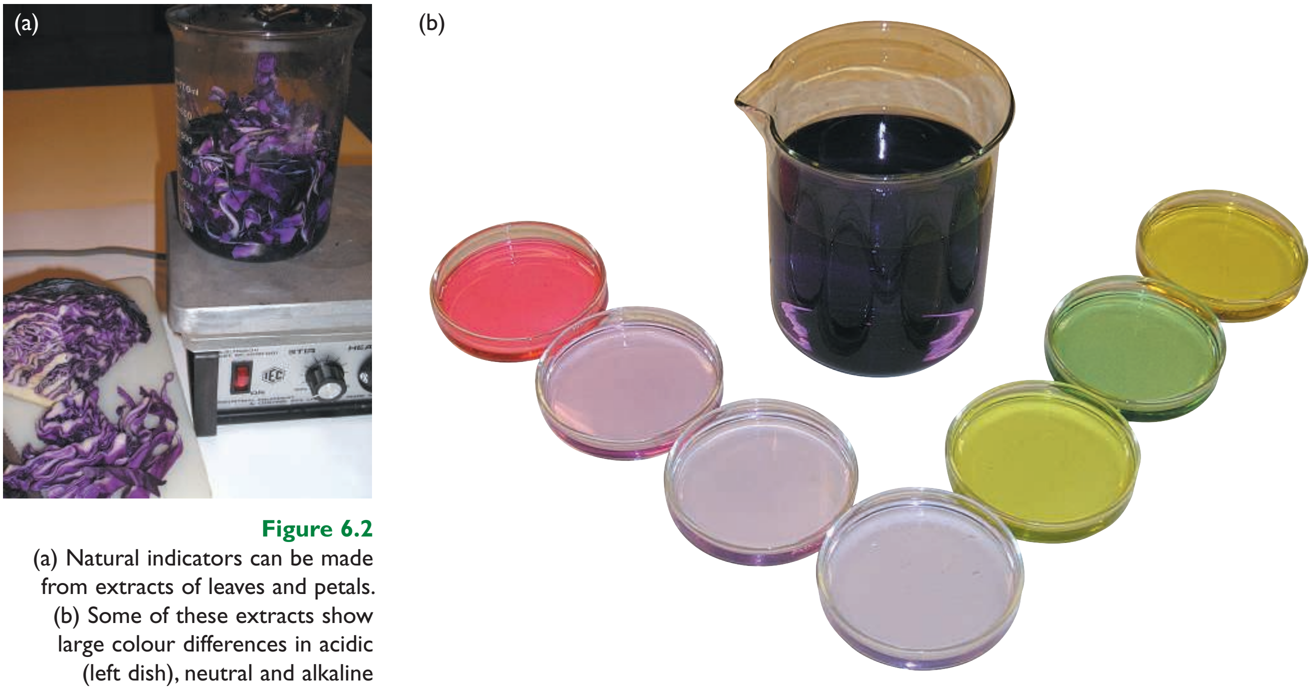

Figure 6.2
(a) Natural indicators can be made from extracts of leaves and petals. (b) Some of these extracts show large colour differences in acidic (left dish), neutral and alkaline (right dish) solutions.

Figure 6.3
Indicators such as litmus allow solutions of substances to be classified as (left to right) acidic, neutral or basic.

SYLLABUS FOCUS

13. USING INSTRUCTION TERMS CORRECTLY

When answering questions, it is important to know what the instruction terms ('verbs') require you to do. Here are some examples:

'Classify'
This instruction word requires you to group things into categories. Thus, pure substances can be grouped into elements and compounds.

Example:
Classify grape fruit juice as acidic, basic or neutral

Answer:
Acidic.

SAMPLE PROBLEM 6.1

Ishani tested an unknown colourless solution with pieces of red and blue litmus paper. The red paper stayed red and the blue paper stayed blue. Ishani decided that the solution was neutral. Justify her conclusion.

SOLUTION

The red paper would stay red if the solution was neutral or acidic. The blue paper would stay blue if the solution was neutral or basic. Thus the solution must be neutral.

As a result of these indicator experiments, chemists can produce a list of common acidic, neutral and basic substances. Table 6.2 lists some of these substances.

Table 6.2 Common acidic, neutral and basic substances in water

Acidic substances	Neutral substances	Basic substances
vinegar	water	ammonia solutions
fruit juices	salt water	washing soda solution
carbonated soft drinks	glucose solution	baking soda solution
car battery acid	alcohol–water solutions	oven cleaners
lactic acid	lactose solution	limewater

Common indicators

In addition to using natural plant extracts, chemists have developed a wide range of synthetic acid–base indicators. These indicators allow chemists to determine the range of acidity or basicity within very narrow limits. Using the techniques of systematic dilution, chemists can prepare solutions of acids or bases of decreasing molarity. Tables 6.3 and 6.4 show the colours of some of these common indicators as a function of the acid or base concentrations of the solution.

Table 6.3 Colour ranges of common acid–base indicators in HCl (acidic) solutions of increasing dilution

HCl concentration (mol/L)	Methyl orange	Litmus	Bromothymol blue	Phenolphthalein
1.0	red	red	yellow	colourless
10^{-1}	red	red	yellow	colourless
10^{-2}	red	red	yellow	colourless
10^{-3}	orange-red	red	yellow	colourless
10^{-4}	orange-red	red	yellow	colourless
10^{-5}	orange	bluish-red	yellow	colourless
10^{-6}	yellow	blue-purple	yellow-green	colourless
0 (water)	yellow	blue-purple	green	colourless

Table 6.4 Colour ranges of common acid–base indicators in NaOH (basic) solutions of increasing dilution

NaOH concentration (mol/L)	Methyl orange	Litmus	Bromothymol blue	Phenol-phthalein
1.0	yellow	blue	blue	crimson
10^{-1}	yellow	blue	blue	crimson
10^{-2}	yellow	blue	blue	crimson
10^{-3}	yellow	blue	blue	crimson
10^{-4}	yellow	blue	blue	deep pink
10^{-5}	yellow	blue	blue	pink
10^{-6}	yellow	blue-purple	green-blue	pale pink
0 (water)	yellow	blue-purple	green	colourless

SAMPLE PROBLEM 6.2

Mitch used a variety of indicators to test a sample of rainwater collected in a highly industrialised city. Use Mitch's results to determine:

(a) whether the rainwater is acidic or basic

(b) the equivalent concentration of HCl or NaOH that would achieve the same results with these indicators.

Indicator	Methyl orange	Bromothymol blue	Phenolphthalein	Litmus
Colour	orange	yellow	colourless	bluish-red

SOLUTION

(a) The rainwater is acidic as the methyl orange is normally yellow in water and in basic solution. The orange colour indicates slight acidity. The bluish-red colour of litmus indicates that the water is slightly acidic.

(b) The equivalent HCl concentration is about 10^{-5} mol/L. (see Table 6.3)

Figure 6.4
Methyl orange indicator is useful in monitoring the neutralisation point when a weak base such as ammonia is neutralised by a strong acid such as hydrochloric acid.

pH: a logarithmic scale used to measure the acidity or alkalinity of a solution. On this scale, 7 represents a neutral solution. As the acidity increases, the pH decreases from 7 to 0. As the alkalinity increases, the pH increases from 7 to 14.

Everyday uses of indicators

Acid–base indicators are used widely in industry, research and in various domestic and horticultural applications.

Chemical research

In a chemical laboratory, indicators are used to:

- determine whether solutions are acidic, basic or neutral
- monitor the change in acidity during volumetric analysis when an acid is being used to neutralise a base.

Testing the acidity of water

Acid–base indicator papers or aqueous solutions of various indicators can be used to monitor the acidity or basicity of water (**pH**). A *universal indicator* is a very useful mixed indicator. It is suitable for field testing of water samples as its extensive colour range allows small changes in acidity to be noted.

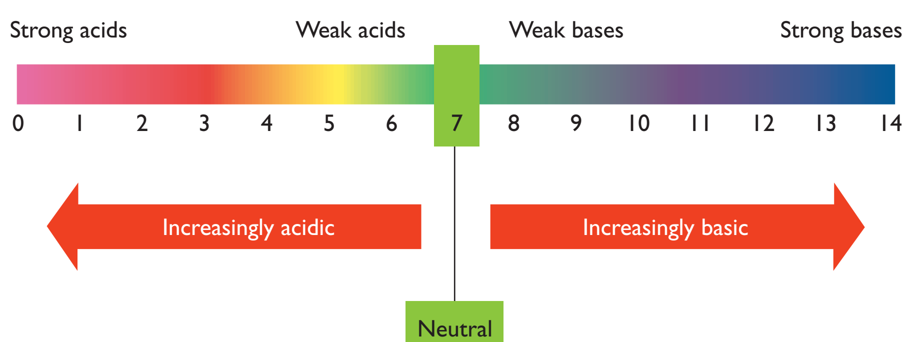

Figure 6.5
Acidic solutions have a pH of less than 7; basic solutions have a pH greater than 7.

In swimming pools, the acidity levels must also be monitored. Sodium hypochlorite (NaOCl) is added to swimming pools to kill microbes. The hypochlorite ion reacts with water to produce unstable hypochlorous acid

(HOCl) and hydroxide ions. HOCl is the active form, which kills microbes but is relatively unstable.

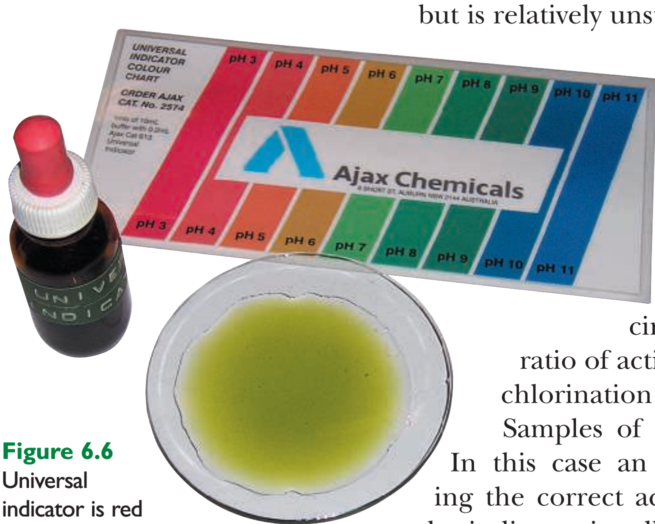

Figure 6.6 Universal indicator is red in highly acidic solutions and orange to yellow in weakly acidic solutions. It is green in near neutral solutions. The indicator turns blue, then violet, as the alkalinity increases.

$$OCl^- + H_2O(l) \rightarrow HOCl + OH^-$$

The presence of hydroxide ions raises the basicity of the water. Hydrochloric acid can be added to return the water to near neutrality (pH 7.2–7.6). This must be done to protect the eyes and throats of swimmers from becoming irritated. If the pH drops to 6.5, then metal fittings of the pool circulation system will be attacked. At a pH of 7.5 the ratio of active HOCl to inactive OCl^- is about 1 : 1 and maximum chlorination efficiency is achieved.

Samples of the pool water can be tested using a pool test kit. In this case an indicator called *phenol red* is suitable in determining the correct acidity level of the water. If the pH is too low (<6.8), the indicator is yellow. If the pH is too high (>8.4), the indicator turns red-purple. When the indicator is pink or orange, the acidity of the pool water is appropriate. Colours are compared with the supplied standard colour cards.

SYLLABUS FOCUS

14. USING INSTRUCTION TERMS CORRECTLY

When answering questions, it is important to know what the instruction terms ('verbs') require you to do. Here are some examples:

'Outline'

This verb requires you to indicate the main features of a concept or procedure.

Example:

Outline the steps a student would take to determine whether the pH of water in a swimming pool was in the pH range 7–8.

Answer:

Collect a water sample and add drops of phenol red indicator solution. Compare the colour of the indicator with the phenol red colour range chart. The indicator should be orange.

Testing the acidity of soil

Some plants grow best in slightly acidic soils (pH < 7) while others prefer slightly alkaline soils (pH > 7). Soils that are too acidic can be partly neutralised by adding bases such as crushed calcium carbonate or dolomite. Soils that are too basic can be partly neutralised with fertilisers such as sulfate of ammonia or by adding rotting plant material (compost) and manures containing natural acids. Table 6.5 shows some common examples of plants and their preferred pH range.

Table 6.5 Soil pH range for optimal growth of plants

pH range	Plant	pH range	Plant
4.5–5.5	camellias	5.8–6.8	cabbage
5.8–6.8	apples	5.5–6.8	carrots
5.0–5.7	potato	6.0–6.3	chrysanthemum

Soil pH can be measured using electronic instruments, but it can also be measured using universal indicator and suitable narrow-range indicators. The common indicators used by horticulturalists are listed in Table 6.6.

Table 6.6 Narrow-range indicators used in soil pH analysis

Indicator	pH range	Colour range
methyl orange	3.1–4.4	red-yellow
bromocresol green	3.8–5.4	yellow-blue
chlorophenol red	5.2–6.8	yellow-red
bromothymol blue	6.0–7.6	yellow-blue
phenol red	6.8–8.4	yellow-red

A test tube is one-third filled with soil. Distilled water is added to within 2 cm of the top. The tube is stoppered and shaken, and the soil is allowed to settle for 3 minutes. A small amount of white barium sulfate suspension can be added to aid the settling process. A Pasteur pipette is then used to withdraw a sample of the supernatant water into two clean tubes. Universal indicator is added to the first tube and the colour compared with a pH chart. A narrow range indicator from Table 6.5 is then selected to test the other water sample to determine a more accurate soil pH.

An alternative method is to saturate a soil sample in a dish with distilled water. White barium sulfate powder is added to the surface, and the soil water is allowed to soak into the barium sulfate. Drops of indicator are then added to the wet barium sulfate and the colour observed.

SAMPLE PROBLEM 6.3

6.2 DATA ANALYSIS
Problem solving

Marcus places a soil sample in a test tube with a little barium sulfate powder and deionised water. The mixture is shaken and allowed to settle. Marcus then carefully removes the supernatant water, and tests it with a range of indicators. His results are tabulated below, together with the pH-indicator colour table for universal indicator. Use this information and Table 6.7 to determine the soil pH.

Indicator	universal indicator	chlorophenol red	bromothymol blue
Colour in soil water	yellow	orange-red	yellow-green

Table 6.7 Universal indicator colour table.

pH	0–4	5	6	7	8	9	10	11–14
UI colour	red	orange	yellow	green	green-blue	blue-green	blue	violet

SOLUTION

The universal indicator results suggest that the soil pH is about 6. The chlorophenol red suggests the pH is between 6.0 and 6.8. The bromothymol blue suggests the pH is between 6.0 and 6.8. Thus, these indicator tests show that the soil pH is between 6.0 and 6.8.

6.1 Questions

1. Select the statement that is true of vinegar.
   A Vinegar turns red litmus blue.
   B Vinegar readily dissolves fats.
   C Vinegar will very slowly attack minerals such as limestone.
   D Vinegar tastes bitter.
2. Drops of litmus extract are added to deionised water in a beaker. A small amount of sodium metal is then added to the beaker. A rapid effervescence occurs and the sodium reacts completely. The litmus turned from blue-purple to blue during the reaction. Select the answer that correctly identifies an inference that can be made from this experiment.
   A The sodium reacts with water to produce a basic solution.
   B Sodium is a base.
   C Sodium is an acid.
   D The final solution contains sodium ions and hydroxide ions.
3. Pieces of moist red and blue litmus paper were held in turn at the mouth a test tube containing a white solid that was being heated strongly with a blue Bunsen burner flame. The white crystals crackled as they were heated and a faint irritating odour was noticed. The red litmus paper stayed red and the blue litmus paper gradually turned red. Select the answer that correctly identifies an inference that can be made from this experiment.
   A The white crystals are acidic.
   B The white crystals have decomposed to produce an acidic gas.
   C The white crystals have decomposed to produce carbon dioxide.
   D The gas released from the heated crystals is neutral.
4. Identify the list that contains only acidic substances.
   A vinegar, lemonade and baking soda
   B white wine, lemon juice and limewater
   C orange juice, glucose solution and drain cleaner
   D lime juice, carbonated soft drink and vinegar
5. Pradisha investigated four aqueous extracts (W, X, Y and Z) from plants to determine which one(s) could be best used as an acid–base indicator. He tested each extract in solutions of salt water, lemonade and washing soda. Pradisha's results are shown in the table.

Extract	Colour in salt water	Colour in lemonade	Colour in washing soda solution
W	orange	dark orange	orange
X	green	pink	violet
Y	pink	yellow	yellow
Z	yellow	yellow	orange

   The extract which best acts as an acid–base indicator is:
   A W
   B X
   C Y
   D Z
6. The optimal pH for soil in which potatoes are to be grown is 5.4. The following table lists some indicators and their pH ranges.

Indicator	pH range	Colour range
bromocresol green	3.8–5.4	yellow–blue
methyl red	4.4–6.2	pink–yellow
bromothymol blue	6.0–7.6	yellow–blue
phenol red	6.8–8.4	yellow–red
phenolphthalein	8.3–10.0	colourless–crimson

   (a) Identify the indicators that could be used to determine that the soil pH was between 5.4 and 6.0.
   (b) Describe how a student could conduct a soil pH test.
7. An unknown colourless solution is tested with three common indicators. Phenolphthalein remains colourless when drops are added to the solution. Phenol red is orange-red in the presence of this solution whereas methyl orange is yellow. Classify this solution as strongly acidic, weakly acidic, neutral, weakly basic or strongly basic. Justify your response.

8. The water in swimming pools should be maintained with a pH between 7.2 and 7.6.
   (a) Is such a solution neutral, weakly acidic or weakly basic?
   (b) Explain how this level of pH is monitored and maintained.

9. Jeremy tests a sample of pure water with phenol red indicator. The pH range and colour range for this indicator are 6.8 (yellow) to 8.4 (red).
   (a) Predict the colour of this indicator in pure water.
   (b) Jeremy then stirs a small quantity of a white solid into the water–phenol red mixture. The indicator turns red. Classify this solid as acidic, basic or neutral.
   (c) Citric acid crystals are added in excess to the solution in (b). The mixture is stirred. Describe the colour changes that Jeremy would observe in this experiment.

10. Michael collected some pink petals from a flower in his garden. He shredded the petals and heated them with water to extract the pigment. Michael then filtered the mixture and divided the solution into five tubes. To four of the tubes he added some common household substances and recorded the colour of the natural indicator. His results are tabulated below.

Household substances	Colour of aqueous extract
water	pink
lemon juice	red
ammonia	yellow
battery acid	red
drain cleaner	orange

Assess the usefulness of this aqueous extract as an acid–base indicator.

www.jaconline.com.au/chemnsw/chemistry2

SUMMARY

- Indicators can be used to identify acidic, basic and neutral solutions.
- Solutions of indicators can be made from natural pigments. Litmus is an example of a natural indicator.
- Chemists have developed a range of synthetic indicators such as methyl orange, bromothymol blue and phenolphthalein.
- Methyl orange is a useful indicator in acidic solution whereas phenolphthalein is suitable for basic solutions.
- The acidity of a solution can be expressed in terms of pH. On the pH scale, 7 is neutral. A pH greater than 7 indicates a basic solution. A pH less than 7 indicates an acidic solution.
- The acidity of soil influences plant growth. Indicators can be used to determine pH of soil.
- Indicators can also be used to monitor the pH of natural waterways and the water in swimming pools.

PRACTICAL ACTIVITIES

6.1 PRACTICAL ACTIVITIES

NATURAL INDICATORS

Aim

To prepare and test a range of natural indicators

Materials

Plant material such as purple cabbage leaves; flower petals (e.g. roses, camellias, petunias, hibiscus, violets)

- 500 mL beakers
- 150 mL beakers
- test tubes
- glass rod
- test-tube rack
- 0.01 mol/L hydrochloric acid
- 0.01 mol/L sodium hydroxide
- 0.01 mol/L ammonia
- 0.01 mol/L acetic acid
- hotplates
- cutting board
- knife

Safety

- Wear safety glasses throughout this experiment.
- Dilute ammonia solution is mildly toxic. Its fumes should not be inhaled.
- Identify other safety precautions relevant to this experiment by reading the method.

Method

Each group should use the purple cabbage leaves, as well as one flower selected from those provided.

The results from all groups can then be combined to produce a table for all flower petals tested.

1. Use a cutting board and sharp knife to cut the cabbage leaves into fine shreds.
2. Place the shredded cabbage in the large beaker (about 1–2 cm depth) and cover it with water. Heat the mixture on a hotplate to near boiling, and stir with a glass rod. Allow the mixture to cool.
3. Decant the cabbage extract into a clean, labelled beaker and discard the cabbage shreds into a bin.
4. Select the flower and remove its petals. Tear the petals into small pieces and place them in a small beaker. Cover them with water and heat the mixture on the hotplate to extract the pigments. Allow the extract to cool.
5. Decant the petal extract into a clean, labelled beaker and discard the petal shreds into a bin.
6. Divide the cabbage extract into 5 test tubes. One of these tubes will be a control.
7. To the remaining tubes add several drops of each of the following 0.01 molar acids and bases:

hydrochloric acid; acetic acid; ammonia solution; sodium hydroxide solution

Note the colour changes.

8. Repeat steps 6 and 7 with the flower petal extract. Record your observations.
9. Finally, add drops of each indicator to tap water to determine its colour in neutral water.
10. Collect the results from other groups for different flower petals.

Results

Draw up a table, similar to the one on the next page, to record your results.

Plant material	Colour of extract				
	Water	Hydrochloric acid	Acetic acid	Ammonia solution	Sodium hydroxide solution
cabbage					
flower 1					
flower 2					
flower 3					

Analysis

1. Identify the colour of each plant extract in acidic, neutral and basic solution.
2. Identify which of the extracts may be more suitable to distinguish solutions of varying acidity.
3. Identify which of the extracts may be more suitable to distinguish solutions of varying basicity.
4. Predict the colour of each of your extracts when added to:
   (a) lemonade
   (b) sucrose solution
   (c) sodium hydrogen carbonate solution (baking soda)
   (d) battery acid.

Conclusion

Write a suitable conclusion for your experiment.

PRACTICAL ACTIVITIES

6.2 DATA ANALYSIS

PROBLEM SOLVING

The following problems concern indicators and pH.

Problem 1

Students were provided with 0.10 mol/L solutions of hydrochloric acid and sodium hydroxide. Using pipettes they prepared mixtures of these two solutions and then measured their pHs using narrow range universal indicator paper. The results are tabulated below.

Acid (mL)	Base (mL)	pH
0	100	13.0
10	90	12.9
20	80	12.8
30	70	12.6
40	60	12.4
45	55	10.6
50	50	7.0
55	45	3.0
60	40	1.7
70	30	1.4
80	20	1.2
90	10	1.1
100	0	1.0

(a) Plot a line graph of pH versus the volume of acid added to the mixture.

(b) Determine the pH of the mixture formed on mixing:

(i) 48 mL HCl and 52 mL NaOH

(ii) 52 mL HCl and 48 mL NaOH

(c) The following table shows the colour ranges and pH of different indicators.

Indicator	pH range	Colour range
methyl orange	3.1–4.4	red–yellow
bromocresol green	3.8–5.4	yellow–blue
chlorophenol red	5.2–6.8	yellow–red
bromothymol blue	6.0–7.6	yellow–blue
phenol red	6.8–8.4	yellow–red

Predict the colour of each of these indicators in the following mixtures:

(i) 60 mL HCl + 40 mL NaOH

(ii) 55 mL HCl + 45 mL NaOH

(iii) 50 mL HCl + 50 mL NaOH

(iv) 48 mL HCl + 52 mL NaOH

Problem 2

Clare collected some flower petals and extracted the coloured dye pigment into water. The mixture was filtered and the yellow filtrate poured into three tests tubes (X, Y and Z). She performed the following tests on each tube.

Tube	Test	Observation
X	Drops of hydrochloric acid added	yellow extract turned orange
Y	Drops of sodium hydroxide added	yellow extract turned green
Z	Water added	remained yellow

(a) Identify the colour of the extract in basic solution.

(b) Predict the colour of the extract in soda water.

(c) Predict the colour of the extract in ammonia solution.

(d) Predict the colour of the extract in salt water.

PRACTICAL ACTIVITIES

Problem 3

Two indicators have been codenamed DING and DONG. The following information was collected about these two indicators.

- DING turns green when substance P is present.
- DONG turns orange when substance Q is present.

DING and DONG were added to samples of four colourless solutions (W, X, Y and Z) that have been made using P, Q, or both. The results of this experiment are tabulated below.

Solution	DING	DONG
W	blue	orange
X	green	yellow
Y	green	orange
Z	blue	yellow

Use this information to decide whether each of the following statements is supported or not supported by the data.

(a) Z contains Q but not P.

(b) X contains both P and Q.

(c) Y contains P but not Q.

(d) W contains Q but not P.

Problem 4

Two indicators are codenamed PING and PONG. The colours of these indicators are determined in the presence of two substances (D and E). The results are tabulated.

Indicator	Substance added	Colour
PING	E	red
PING	D + E	orange
PONG	D	yellow
PONG	D + E	yellow

PING and PONG were then added to four colourless solutions (M, N, P, R). These solutions contained D; E; D and E; or neither. The results are tabulated.

Solution added	PING	PONG
M	no change	no change
N	turns orange	turns yellow
P	turns red	no change
R	no change	turns yellow

(a) Identify the solution that contains substance E but none of substance D.

(b) Account for the change in PING's colour when D is added to E.

(c) There was no change to the indicator colours with solution M. Suggest a reason for this observation.