Science in School
The European journal for science teachers

ISSUE 54 | 01/09/2021 **Topics** Chemistry

Little wonder: pH experiments the microscale way

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Changing drop by drop: Learn about pH indicator chemistry and neutralization reactions, and produce wonderful colours using microscale chemistry methods that are cheap, quick, and easy to do

The visible display made by the various colours of indicators is a wonderful way of introducing chemistry to students. The concept will be used continually throughout their studies. Indicators are used in titration studies; in the medical field, such as pH variations in urine caused by kidney infections; in water-supply analysis; and in the environmental analysis of water in streams, rivers, and aquarium tanks, as well as establishing the pH of soil. These activities are suitable for students aged 11–16.

Activity 1: Indicator colour changes

The microscale approach saves valuable time for student activities and in clearing up afterwards. Students are seated, which adds to laboratory management.

This activity uses a template similar to that on the right, which can be found in the Worksheet Templates file. There is also a Practical Notes document that provides tips on equipment and making templates, along with instructions for preparing different buffer solutions.

Safety note

The solutions used are of low hazard, but eye protection should be worn.

Insert the sheet into a plastic folder and put the drops on the plastic. Place 1 drop of the indicator in each of the circles along the row. Now add 1 drop of the reagent shown at the head of the column.

	0.02M hydrochloric acid	Tap Water of pH Buffer 7	0.02M sodium hydroxide
Methyl orange	○	○	○
Bromothymol blue	○	○	○
Phenolphthalein)	○	○	○
Litmus solution	○	○	○

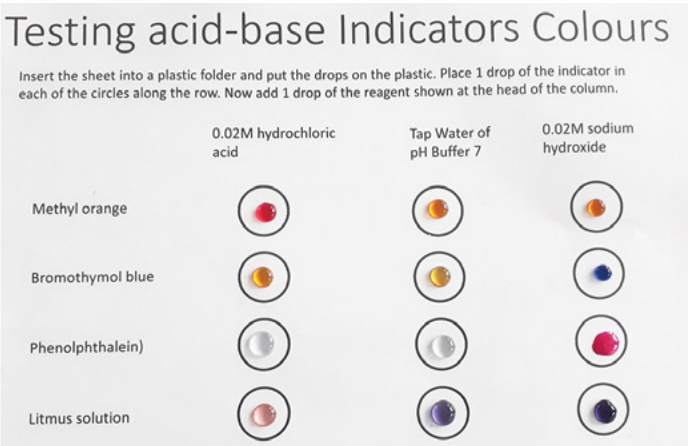
Materials

- Reaction sheet, laminated or in a plastic wallet
- Bromothymol blue indicator solution
- Methyl orange indicator solution
- Phenolphthalein solution
- Litmus solution
- pH buffer 7 (tap water may be suitable, but the procedure needs to be tested; for example, tap water in areas with soft water may have an acidic pH value)
- Hydrochloric acid (0.02 M)
- Sodium hydroxide (0.02 M)
- Dropper bottles containing the above solutions or Pasteur pipettes and a beaker of water to rinse pipettes

Procedure

1. Insert the worksheet into the plastic folder.
2. Add drops of the reagent down the columns using transfer pipettes or dropper bottles.
3. Add the relevant indicators across the row.
4. Record/photograph the results.
5. Disposal: wipe the plastic surface with a paper towel and dispose of the towel in the waste.

Litmus and bromothymol blue change colour at pH 7. However, students must realize that not all indicators change colour at pH 7, even though this is a 'neutral' solution, where the concentration of hydrogen and hydroxide ions are the same.



Microscale pH indicator results on a laminated sheet

Image courtesy of Beth Sutherland and Pixie Murray

Variations

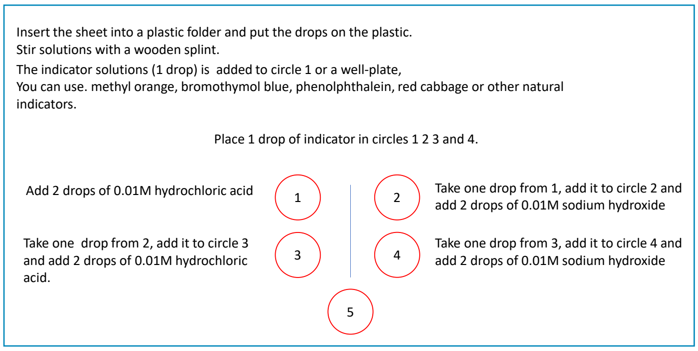
The method can be adjusted, depending on the chemicals available:

- Instead of 0.02 M hydrochloric acid, use 0.05–0.1 M ethanoic acid (clear vinegar can also be used);
- Instead of 0.02 M sodium hydroxide, use 0.1 M sodium carbonate.

Many other synthetic indicators can be used as well, such as bromophenol blue or thymolphthalein.

Extension: An example of a reversible reaction

Experiments can be repeated to focus on a different aspect of chemistry. Although colour changes are appealing to younger students, this change can also be used to explain the very difficult concept of reversible reactions.



Indicators are weak acids, but the colour of the acid form ($HIn_{(aq)}$) is different from that of the conjugate base ($In^-_{(aq)}$).

$$HIn_{(aq)} \rightleftarrows H^+_{(aq)} + In^-_{(aq)}$$

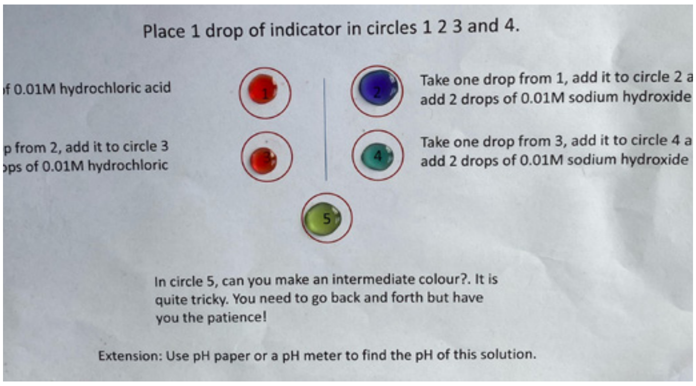
Here is a method of switching between the two coloured forms by repeated addition of acid and alkali.

This means that the change can be explained by the Le Chatelier principle. However, it is better to explain these effects using the equation that defines the equilibrium constant, a value that is constant at the same temperature:

$$Kc = \frac{[H^+]_{eq}\,[In^-]_{eq}}{[HIn]_{eq}}$$

If the concentration of hydrogen ions is increased, then for K_c to remain constant the value of $[HIn]_{eq}$ has to increase. If hydroxide ions are added, then the value of $[H^+]$eq decreases, so the value of $[In^-]_{eq}$ has to increase for Kc to remain constant.

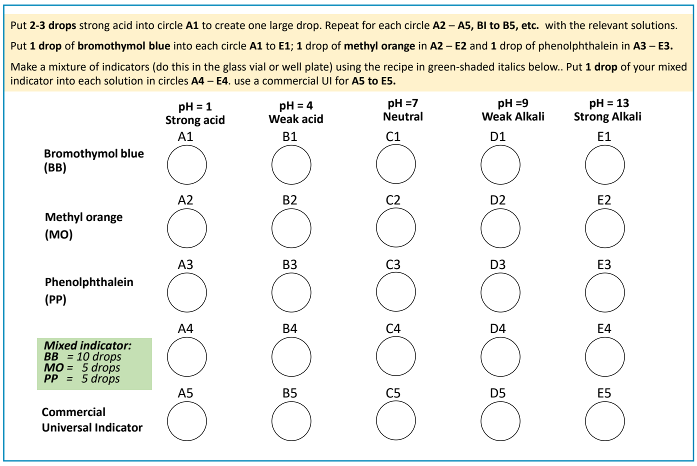
The use of dilute dyes, and especially natural dyes, to illustrate reversible reactions is an example of 'green' chemistry. A reversible reaction often quoted in textbooks involving dichromate/chromate exchange occurs as a result of changes to acidity. However, chromium(VI) compounds are very hazardous to both humans and the environment, so a 'green' replacement is welcome.



Microscale reversible reactions of acids and bases

Image courtesy of Beth Sutherland and Pixie Murray

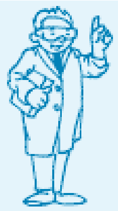
Activity 2: Investigating pH indicators



A synthetic indicator, such as methyl orange, changes colour very dramatically over a narrow pH range.

A universal indicator shows a smooth colour change over a wide range of pH values. This type of indicator is made by mixing different indicators, so that there is a range of colours over a wide pH range. The commercial mixture is based on methyl red with thymol blue, bromothymol blue, and phenolphthalein. Students can make a version with methyl orange using the template provided. The colours have an immediate impact on students and can lead onto an investigation into natural indicators.

This activity would use over 20 test tubes in a traditional setup, but here some students could even work alone. This activity has the instructions in full view under the experiment, reduces the load on short-term memory, and hopefully some information will be retained in long-term memory.



Safety notes

The solutions used are of low hazard, but eye protection should be worn.

Materials

- Reaction sheet, laminated or in a plastic wallet
- Bromothymol blue indicator solution
- Methyl orange indicator solution
- Phenolphthalein solution
- Hydrochloric acid (0.1 M)
- Sodium hydroxide (0.1 M)
- Buffers pH 4 and 9 (see Practical Notes)
- Dropper bottles containing the above solutions or Pasteur pipettes and a beaker of water to rinse pipettes

Procedure

1. Put 4 drops of 0.1 M hydrochloric acid into circle A1 to create one large drop. Repeat for each circle from B1 to D1.
2. Now use the solutions named at the top of the other columns (i.e. instead of the acid) to repeat Step 1 for A2–D2, A3–D3, A4–D4, and A5–D5.
3. Put 1 drop of bromothymol blue into each circle from A1 to A5, 1 drop of methyl orange in B1–B5, and 1 drop of phenolphthalein in C1–C5.
4. Make a mixture of indicators (do this in the glass vial or well plate) using the recipe in the green-shaded box on the worksheet.
5. Put 1 drop of your mixed indicator into each solution in circles D1–D5. Make a note of your observations (taking a photo is desirable).

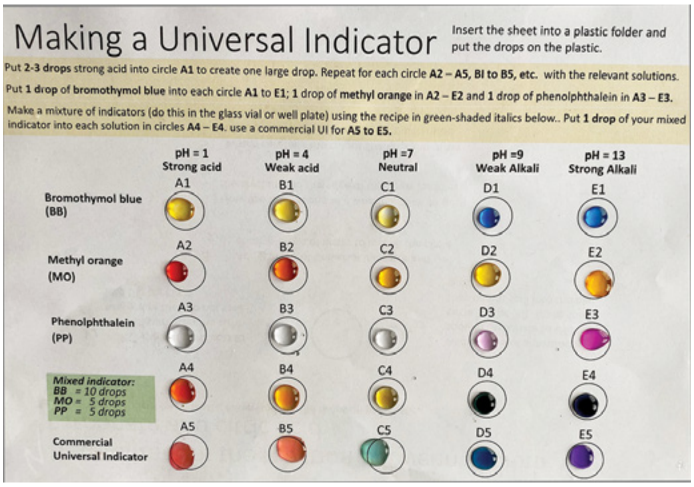
Discussion

Discuss the following questions with your students:

- What colour changes did you observe with different indicators when they were added to different solutions?
- At what pH did each indicator start to change colour?
- When the three indicators were mixed and added to the solutions what did you observe? Which other indicator that you may have come across does this mixture appear to be similar to?

Explanation

In the activity, students should see the following colour changes:



Making a universal indicator

Image courtesy of Beth Sutherland and Pixie Murray

Bromothymol blue, methyl orange, and phenolphthalein change colour at one or sometimes two pH values and often give sharp colour changes, and thus, they are suitable for titration experiments.

These colour changes occur because indicators are molecules that can have different colours, depending on the pH of the solution. The pH range for the colour changes can vary for each indicator:

Indicator	pH range for colour change
Bromothymol blue	6.0–7.6
Methyl orange	3.2–4.4
Phenolphthalein	8.3–10.0

If indicators are mixed, then we can get a range of different colours at varying pH values. This is the principle of a universal indicator, which can be used to determine the pH of a substance.

As an extension activity, students can use indicators extracted from plants.

Activity 3: The colourful bubbly puddle

The is a really beautiful reaction, where an indicator is added to a circular puddle of water placed on plastic. Citric acid and sodium carbonate are introduced from each side. Immediately, different colours appear, but, as the colours meet, bubbles of carbon dioxide begin to appear.

Safety notes

The solutions and solids used are of low hazard, but eye protection should be worn.

Materials

- Reaction sheet, laminated or in a plastic wallet
- Citric acid
- Sodium carbonate
- Universal indicator solution
- Water
- Spatula
- Wooden splints or toothpicks
- Dropper bottles containing the above solutions or Pasteur pipettes

Procedure

1. Put 10 drops of water into the large circle in the middle of the sheet.
2. Put 1 drop of universal indicator solution into the large drop of water.
3. Using a spatula, place a few crystals of citric acid into the small circle to the left of the water drop.
4. Using a spatula, place a few crystals of sodium carbonate into the small circle to the right of the water drop.
5. Carefully push a couple of crystals of citric acid into the left-hand side of the large water drop using a wooden splint or toothpick.
6. Carefully push a couple of crystals of sodium carbonate into the right-hand side of the large water drop using a wooden splint or toothpick.
7. Observe the large water drop carefully over the next few minutes.

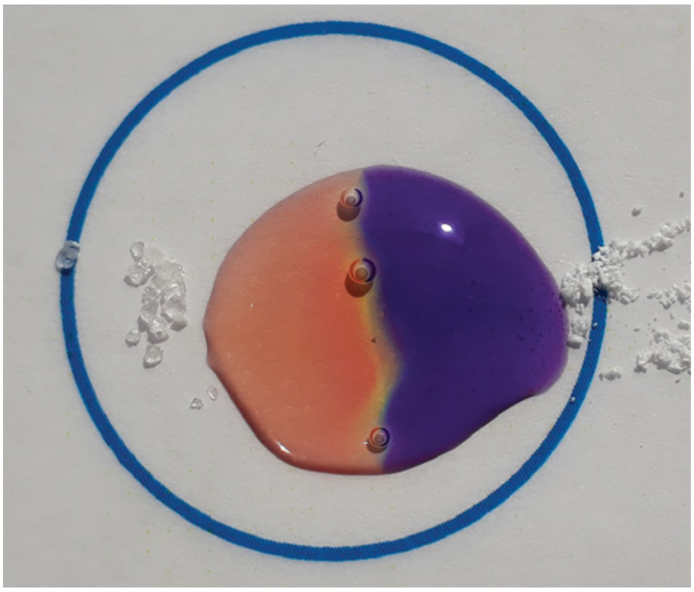
Discussion

Discuss the following questions with your students:

- What colour changes did you observe when citric acid and sodium carbonate were added to water?
- What do the colour changes tell you about the types of substances citric acid and sodium carbonate are?
- Why is water required for solid citric acid to react with sodium carbonate?
- What gas is present in the bubbles produced?
- What other products are produced when citric acid reacts with sodium carbonate in addition to the gas?

Explanation

During the activity, students should see the following colour changes:



Microscale neutralization with citric acid and sodium carbonate
Image courtesy of Beth Sutherland and Pixie Murray

This is a neutralization reaction, in which citric acid reacts with a metal carbonate base – in this case, sodium carbonate. Water is required for the reaction to occur because it is needed to break up the ionic lattices of the reactants, as they are pushed in from the sides and begin to dissolve. This allows ions to diffuse towards each other and participate in a neutralization reaction. The products of this reaction are a salt (sodium citrate) plus water and carbon dioxide.

Point out to the students that the bubbles of carbon dioxide are appearing from the green/yellow neutral zone, where the neutralization reaction is occurring.

Show the authors what you can do

Many teachers are reluctant to try these methods. Just talking and writing about these techniques like a 'sage on stage' is all very well but getting down and trying them out is what really matters. Adrian and I have found that placing photographs from teachers and students on social media, such as Twitter and Facebook groups, provides a springboard for further interest.

Do you have a picture of this activity to share with us? Tag us on your favourite social media platform (Twitter, Facebook, or Instagram), and we will make a collection on our Facebook and Instagram pages.

Acknowledgements

The authors would like to acknowledge Beth Sutherland and Pixie Murray for their efforts in testing the procedures and taking images of their results, as well as Howard Tolliday for providing plants to test at Dornoch Academy, Scotland, UK.

Resources

- Learn how to make indicators from butterfly tea:
  Prolongo M, Pinto G (2021) Tea-time chemistry. *Science in School* **52**.
- Read an introduction to microscale chemistry in the classroom:
  Worley B (2021) Little wonder: microscale chemistry in the classroom. *Science in School* **53**.
- Try a classroom activity to extract essential oils from fragrant plants:
  Allan A, Worley B, Owen M (2018) Perfumes with a pop: aroma chemistry with essential oils. *Science in School* **44**:40–46.
- View a fantastic infographic by Compound Interest on the colours and chemistry of indicators.
- Read a ChemEd X article on the many uses of red cabbage extracts.

AUTHOR BIOGRAPHY

Dr Adrian Allan is a teacher of chemistry at Dornoch Academy, UK. He was selected to represent the UK at the Science on Stage conferences in 2017 and 2019. He has presented Science on Stage webinars on microscale chemistry and using magic to teach science.

Bob Worley, FRSC, is the (semi-retired) chemistry advisor for CLEAPSS in the UK. He taught chemistry for 20 years, and in 1991 he joined CLEAPSS, which provides safety and advisory support for classroom experiments. In carrying out these duties, he gained an interest in miniaturizing experiments to improve safety and convenience.