Investigation 29

Relative strength of acids

Rationale

Students choose their own equipment, select a range of acids of the same concentration and measure the pH. They use the measured pH values to calculate hydrogen ion concentration, and rank the acids according to their relative strength.

Syllabus

Plan and perform a first-hand investigation to measure the pH of identical concentrations of strong and weak acids.

Background knowledge

Students know the meaning of pH and how to calculate the concentration of H^+ ions from the measured pH value. They have learned about concentrated and dilute solutions of strong and weak electrolytes.

This investigation may reinforce the above knowledge or could be used as an introduction to weak acid equilibrium and the Bronsted–Lowry theory.

Hints

- Students should use pH probes with pH meters or dataloggers. These should be calibrated against pH 4 and pH 7 buffers before starting the investigation.
- Use a range of acids such as citric, ethanoic, hydrochloric, sulfuric and phosphoric, all of the same concentration.

Results

(measured with pH probe and datalogger)
0.1 M acetic acid, pH = 3.3
0.1 M citric acid, pH = 2.7
0.1 M hydrochloric acid, pH = 2.1
(Note that these were not standard solutions and their concentrations may not be accurate.)

Discussion

1 Ethanoic acid has much higher pH than hydrochloric. It is a weak acid and does not ionise completely in water, while hydrochloric acid is a strong acid that highly ionises in water.
$CH_3COOH(aq) + H_2O(l) \Leftrightarrow H_3O^+(aq) + CH_3COO^-(aq)$
$HCl(aq) + H_2O(l) \rightarrow H_3O(aq) + Cl^-(aq)$

2 a HCl, citric, ethanoic

b ethanoic acid CH_3COOH;
hydrochloric acid HCl; citric acid $C_6H_8O_7$

3 All with a pH higher than that for hydrochloric acid.

4 a Structural formula of citric acid:

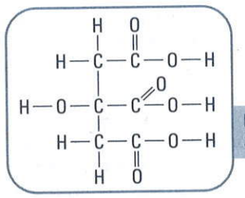

FIGURE 1
Structural formula of citric acid

b three

c Theoretically, all three hydrogen atoms attached to oxygen in the carboxylic acid groups could be ionised in water. In reality, only a few are fully ionised as these hydrogens are used in hydrogen bonding between citric acid molecules.

5 a Dilute solutions conduct better than concentrated. In concentrated solutions there is no water present to split the molecules apart into ions, while in dilute solutions water molecules interact with acid molecules making them ionise into free ions (see Figure 2).

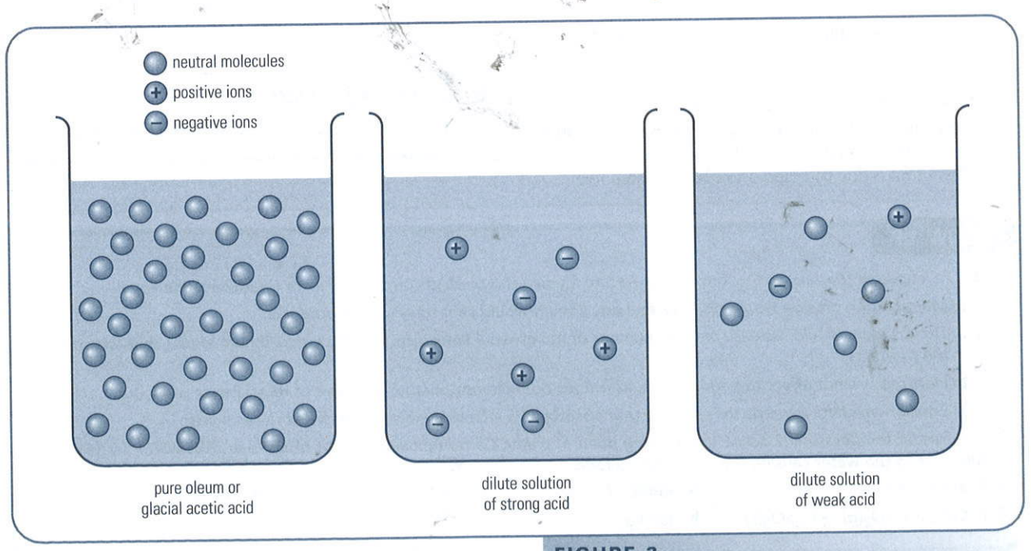

FIGURE 2
Model for concentrated and dilute solutions

b Sulfuric acid releases two H^+ ions per molecule. As it is strong acid it completely ionises in water, giving twice as many ions as HCl of the same concentration.

c The measured pH of sulfuric acid is 2, therefore the total concentration of H^+ ions is 10^{-2} mol/L or 0.01 M. If every molecule of H_2SO_4 produces two hydrogen ions, the concentration of sulfuric acid is 0.01 / 2 = 0.005 mol/L.

FOLLOW-UP

1 a *$H_3PO_4(aq) + H_2O(l) \Leftrightarrow H_3O^+(aq) + H_2PO_4^-(aq)$*
$H_2PO_4^-(aq) + H_2O(l) \Leftrightarrow H_3O^+(aq) + HPO_4^{2-}(aq)$
$HPO_4^{2-}(aq) + H_2O(l) \Leftrightarrow H_3O^+(aq) + PO_4^{3-}(aq)$

b *Phosphoric acid is weak acid, as it forms an equilibrium with its dissociated ions in solution. If it was a strong acid, it would have a pH less than 1.*

2 *pH = 0.96*

3 a *basic*

b *1.3×10^{-9} mol/L*

4 a *$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$*

b *$HCO_3^-(aq) + H_2O(l) \rightarrow H_3O^+(aq) + CO_3^{2-}(aq)$ (conjugate base is carbonate ion)*

c *$HCO_3^-(aq) + H_2O(l) \rightarrow OH^-(aq) + H_2CO_3(aq)$ (conjugate acid is carbonic acid)*

d *amphiprotic*

Students should complete their own risk assessment record for this investigation, using the record at the back of the book.

Investigation 30

Hydrolysis of salts

Rationale

Students choose their own equipment to measure the pH of various salt solutions using indicators and pH meters, or dataloggers with pH probes. Measured pH is then related to the hydrolysis of salts and the strength of their appropriate conjugate acid or conjugate base.

Syllabus

Choose equipment and perform a first-hand investigation to identify the pH of a range of salt solutions.

Background knowledge

Students are familiar with the terms conjugate acid, conjugate base, and strong/weak acids and bases. They can identify and name some strong acids and strong bases.

Hints

- Students should use pH meters and universal indicator solution to compare colours. If pH meters are not available, narrow range pH papers work well in clear, colourless solutions.
- Students could write their own procedure.
- Students must test water, used for the dissolution of salts, as a control.

Discussion

1 acidic: ammonium chloride, ammonium sulfate,
basic: sodium ethanoate, sodium carbonate
neutral: sodium chloride, potassium nitrate, sodium hydrogen carbonate

2 a $2NH_3(aq) + H_2SO_4(aq) \rightarrow 2NH_4^+(aq) + SO_4^{2-}(aq)$

b $NH_4^+(aq) + H_2O(l) \Leftrightarrow NH_3(aq) + H_3O^+(aq)$
Ammonium ion is the conjugate acid of a weak base (NH_3). NH_4^+ donates a proton to water.

RESULTS **TABLE 1 SAMPLE RESULTS**

Test-tube	Contents	Colour	pH
A	sodium chloride (NaCl)	green	6.5–7
B	potassium nitrate (KNO_3)	green	6.5–7
C	ammonium chloride (NH_4Cl)	orange to yellow	5–6
D	ammonium sulfate ($(NH_4)_2SO_4$)	light pink	4–5
E	sodium hydrogen carbonate ($NaHCO_3$)	green	6.5–7.5
F	sodium ethanoate ($NaCH_3COO$)	blue	8.5–9.5
G	sodium carbonate (Na_2CO_3)	dark blue	11–12

3 a $2NaOH(aq) + H_2CO_3(aq) \rightarrow 2Na^+(aq) + 2H_2O(l) + CO_3^{2-}(aq)$

b $CO_3^{2-}(aq) + H_2O(l) \Leftrightarrow HCO_3^-(aq) + OH^-(aq)$
The carbonate ion is the conjugate base of a weak acid. It is a stronger base than water and forms free hydroxide ions with water.

4 weak, strong; strong, weak; strong, strong, strong or weak, weak

5 a Neutral, pH = 7. The ammonium ion is a weak acid that hydrolyses like the ethanoate ion, which is a weak base.

b Acidic, pH < 7. Nitrate is a stable ion that does not hydrolyse or interact with water. $NH_4^+(aq)$ is a weak acid that donates a proton to water, thus making it slightly acidic.

c Basic, pH > 7. Potassium is stable ion that does not interact with water. The citrate ion is a conjugate base of weak citric acid. The conjugate base is a stronger base than water, thus hydrolyses by accepting a proton from water, leaving free OH^- ions.

d Neutral, pH = 7. Potassium and sulfate ions come from a strong base and strong acid respectively, and are stable ions that do not interact (hydrolyse) with water.