Proton transfer reactions

Reactivity 3.1 · SL

What do vinegar and cleaning ammonia share?

Brønsted–Lowry acid–base reactions transfer protons.

- Vinegar turns blue litmus red; ammonia turns red litmus blue.
- In both, a proton moves from one particle to another.
- This unit: acids and bases $\rightarrow$ pH $\rightarrow$ strength $\rightarrow$ titrations.

Donors and acceptors

Brønsted–Lowry acid

Proton donor.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

Brønsted–Lowry base

Proton acceptor.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

A base need not be a soluble alkali

Apply the proton-transfer definition before naming the products.

- CuO is a basic oxide; it neutralizes acid but is not a soluble alkali.
- $NH_3(aq)$ accepts H^+ from water, producing OH^-: it is an alkali.
- $NH_3 + HCl \rightarrow NH_4Cl$; **neutralization** need not produce water.

Amphiprotic means two possible roles

Identify the proton donor and acceptor in the particular reaction.

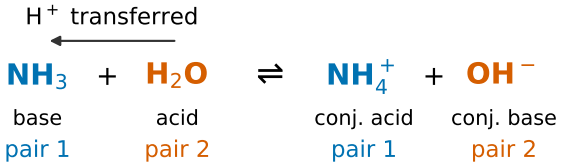
- $HCO_3^- + H_2O \rightleftharpoons CO_3^{2-} + H_3O^+$.
- $HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$.
- Each equation conserves atoms and charge; conjugate pairs differ by one H^+.

Conjugate pairs differ by one proton

Acid	**Conjugate base**
HCl	Cl^-
H_3O^+	H_2O
H_2O	OH^-
NH_4^+	NH_3

Conjugate pairs

Proton transfer in water



Each conjugate pair differs by one H^+

Reference examples at 298 K

0.050 M HCl	pH 1.30
pure water	pH 7.00
0.010 M NaOH	pH 12.00

Neutral means $[H^+] = [OH^-]$

0–14 is not a universal pH bound

pH: 0.05 M HCl 1.30; water 7; 0.01 M NaOH 12.0

The pH scale

- One pH unit lower means ten times more H^+.
- Decimal places in pH match significant figures in $[H^+]$.

$$\mathrm{pH} = -\log_{10}[\mathrm{H}^+] \qquad [\mathrm{H}^+] = 10^{-\mathrm{pH}}$$

0.050 mol dm^{-3} HCl: pH = 1.30.

Measure pH at the precision the method supports

pH 0–14 is a familiar range, not a universal bound.

- Universal indicator gives approximate chart-based pH and can be affected by sample colour.
- A probe needs buffer calibration, rinsing, stabilization and temperature control.
- A two-decimal display does not establish accuracy of 0.01 pH unit.

Neutral does not always mean pH seven

1. **Supplied temperature value.** $K_w = 4.00 \times 10^{-14}$.
2. **Neutral concentrations.** $[H^+] = [OH^-] = \sqrt{K_w} = 2.00 \times 10^{-7}$ mol dm^{-3}.
3. **Logarithm.** $\mathrm{pH} = -\log(2.00 \times 10^{-7}) \approx 6.70$.

Decision

Equal ion concentrations establish neutrality at this temperature.

The ionic product of water

1. **Constant.** $K_w = [\mathrm{H}^+][\mathrm{OH}^-] = 1.00 \times 10^{-14}$ at 298 K
2. **Alkali.** 0.010 mol dm^{-3} NaOH: $[\mathrm{OH}^-] = 0.010$
3. **Divide.** $[\mathrm{H}^+] = 1.0 \times 10^{-12}$

Decision

pH = 12.00

Strong against weak

0.10 mol dm^{-3}	**HCl (strong)**	**CH_3COOH (weak)**
pH	1.0	about 2.9
conductivity	high	low
rate with Mg	fast	slow

Use the evidence

Equal acid amounts can give equal gas amounts when acid is limiting, reaction is complete and gas conditions match.

Check: strength or concentration?

Your turn

Compare equal volumes of 0.10 mol dm^{-3} ethanoic acid and HCl. Which statement is correct?

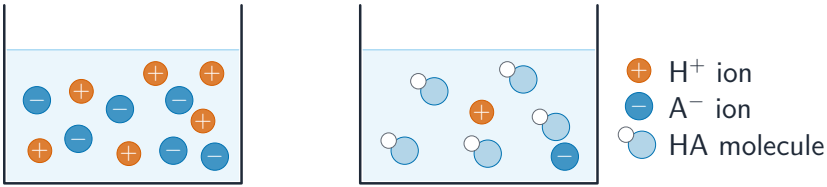
A. It is a strong, dilute acid.

B. It is a weak acid with a higher pH than 0.10 mol dm^{-3} HCl.

C. It needs less NaOH to neutralize than the same HCl solution.

D. It contains more H^+ ions than the same HCl solution.

Strong and weak acids



strong acid

fully dissociated: many ions

weak acid

mostly molecules: few ions

> Strength is about ionisation, not concentration

Balance neutralization products

A carbonate consumes two protons; a hydrogencarbonate consumes one.

- $CuO + 2HCl \rightarrow CuCl_2 + H_2O$.
- $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$.
- $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$.
- $CH_3NH_2 + HCl \rightarrow CH_3NH_3Cl$; no water product.

Identify a salt's parents and isolate it

Avoid contaminating the salt with excess soluble reactant or indicator.

- Sodium ethanoate: ethanoic acid and sodium hydroxide.
- Ammonium nitrate: nitric acid and ammonia.
- With insoluble oxide: add excess, filter, concentrate carefully and crystallize.
- With two soluble reactants: establish reacting amounts, then repeat without indicator.

Titration method and accepted titres

Prepare and read

Wear eye protection. Rinse burette and pipette with their solutions; flask with distilled water.

Read the meniscus at eye level over a white tile.

Deliver and select

Swirl and add titrant dropwise near the endpoint.

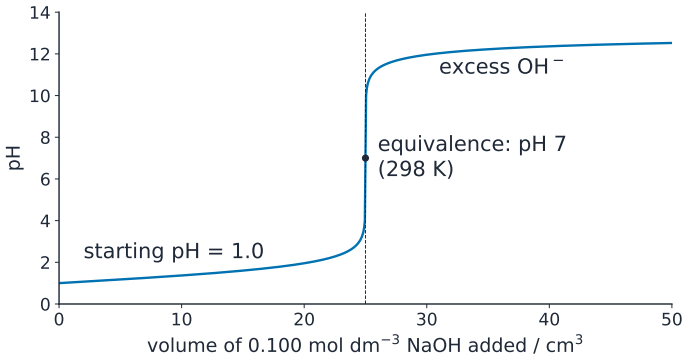
With a stated 0.10 cm^3 range, 18.35, 18.40 and 18.45 cm^3 give mean 18.40 cm^3.

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Concentration from the balanced ratio

1. **Known amount.** $n(\mathrm{NaOH}) = cV = 0.150(18.40/1000) = 0.00276$ mol.
2. **Apply 1:1.** $n(\mathrm{HCl}) = 0.00276$ mol in $25.00/1000 = 0.02500$ dm^3.
3. **Unknown concentration.** $c(\mathrm{HCl}) = n/V = 0.00276/0.02500 = 0.110$ mol dm^{-3}.

The strong acid–strong base pH curve



Strong/strong equivalence is pH 7 at 298 K in this dilute model.

Exam tips

> Never use "strong" to mean "concentrated".

- Acids donate protons; bases accept them.
- Conjugate pairs differ by exactly one H^+.
- Neutral means $[H^+] = [OH^-]$.

Check yourself

Try these

Show that HCO_3^- is amphiprotic with two equations.

Calculate the pH of 0.0025 mol dm^{-3} HCl and 0.050 mol dm^{-3} KOH.

Describe two tests that tell a strong acid from a weak acid.