ANSWERS: NCEA exam questions on titration curves

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| **2017** | **Evidence** | **Achievement** | **Merit** | **Excellence** |
| (a)(b) (i)(ii)(c) | Phenolphthalein.CH3COOH + H2O ⇌ CH3COO– + H3O+*n*(NaOH) added = 0.112 mol L–1 × 0.01 L = 1.12 × 10–3 molInitial *n*(CH3COOH) = 0.166 mol L–1 × 0.02 L = 3.32 × 10–3 mol*n*(CH3COOH) remaining in 30 mL = 3.32 × 10–3 mol – 1.12 × 10–3 mol = 2.2 × 10–3 mol*n*(CH3COO–) in 30 mL = 1.12 × 10–3 molCH3COO–, Na+, CH3COOH, OH–, H3O+Both titrations produce a basic salt at the equivalence point because [OH–] > [H3O+] / pH > 7 / equations.At the equivalence point the ethanoic acid is converted into the ethanoate ion and the methanoic acid is converted into the methanoate ion.The methanoic acid titration has a lower pH than the ethanoic acid titration at the equivalence point because:methanoate ions are a weaker base / produce fewer OH– ions than ethanoate ionsORHCOOH has a larger *K*a than CH3COOH, as it is a stronger acid. As a result, its conjugate base, HCOO–, is weaker than CH3COO, so the pH will be lower at the equivalence point. | • Correct indicator.• Correct process with minor error.• Correct *n*(NaOH)ORInitial *n*(CH3COOH).THREE species.Both are basicHCOOH is a stronger acid thanCH3COOHORHCOO– is weaker than CH3COO– | • Correct calculation.• Two steps correctLinks equivalence point pH for either, to the relative strength ofthe conjugate baseORrelative concentrations of hydroxide ions. | • Correct pH, including three significant figures.Compares and contrasts the equivalence point for both titrations. |

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| **2016** | **Evidence** | **Achievement** | **Achievement with Merit** | **Achievement with Excellence** |
|  (a) | *(Ammonium chloride)* is acidicORNH4+ + H2O  H3O+ + NH3So therefore[H3O+] > [OH-] | * H3O+ is produced.

ORIt is acidic. | * BOTH concepts correct.
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| (b) | [NH4+] = 0.320 × 20 / 30 = 0.213 molL-1*(Ka = 10–9.24 = 5.75 × 10–10)*[H3O+] = √(5.75 × 10–10 × 0.213) = 1.11 × 10–5 molL-1pH = –log[H3O+]pH = 4.96 | * One step correct.
 | * TWO steps correct.
 | * All correct.
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| (c)(d) | Since B is half way to the equivalence point, [NH4 +] = [NH3]. OR p*K*a = pH + log [acid]÷[c.base] *so Ka = [H3O+]* therefore p*K*a = pH.*The solution at the equivalence point is NH4Cl.* NH4+ solution is acidic since, NH4+ + H2O  NH3 + H3O+ | * EITHER

*Ka* expression rearrangedOR[NH4 +] = [NH3] at BORpH = p*K*a* NH4+ is acidic.

ORCorrect equation. | * [NH4+] = [NH3]

AND pH = p*K*a* NH4+ is acidic AND equation in either symbols or words.
 | * Complete explanation.
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| **2015** | **Evidence** | **Achievement** | **Achievement with Merit** | **Achievement with Excellence** |
| (a)(i) | Na+, F–, H2O, HF, OH–, H3O+. | * Three species listed.
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| (ii) | A weak base, F–, is present at the equivalence point:F– + H2O ⇌ HF + OH–This increase in [OH–] causes the pH to be greater than 7. | * Recognises F– is the weak base responsible for pH > 7.

 OR  Correct equation. | * Links pH at equivalence to increased [OH–], including an equation for the dissociation of F–.
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| (iii) | pH = p*K*a + log [F–] / [HF] = 3.17 + log 0.5 = 2.87[H3O+] = 2 × 10–3.17 = 1.35 × 10–3 mol L–1pH = –log (1.35 × 10–3) = 2.87.Since there are significant concentrations of the weak acid and its conjugate base the solution can resist added acid or base.However, since the pH of the buffer solution is less than the p*K*a, / [HF] > [F–], it is more effective against added base than acid. | * Correct process for determining the pH.
* Recognises solution is more effective against added base.

 OR  Describes function of a buffer by resisting added acid and base. | * Correct pH

OREvaluates the function of the buffer.  | * Correct pH and full evaluation.
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| (iv) |  [OH–] = 0.258 × 4 / 44 = 0.02345 mol L–1 pOH = –log (0.02345) = 1.63pH = 14 – pOH = 12.4  | * Correct *n*(NaOH).

OR One correct step.  | * Correct process but one error in calculation.
 | * Correct answer.
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| (b) | Since CH3COOH has a higher p*K*a, it is a weaker acid than HF. Therefore its conjugate base, CH3COO–, will be a stronger base than F–. This means [OH–] will be higher at the equivalence point for the CH3COOH vs NaOH titration, so the equivalence point pH will be higher. | * States CH3COOH is a weaker acid than HF.

OR States equivalence point is higher with some evidence.  | * Links higher equivalence point for CH3COOH to the strength of the weak acid, its p*K*a, and the relative strength of its conjugate base.
 | * Contrasts the equivalence point for both titrations.
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| **2014** | **Evidence** | **Achievement** | **Achievement with Merit** | **Achievement with Excellence** |
| (a) | At point **A**, [CH3NH2] ≈ [CH3NH3+]. So the solution has buffering properties in the proximity of point **A**. When HBr is added, the H3O+ is consumed:H3O+ + CH3NH2 → CH3NH3+ + H2OSince the H3O+ is removed from the solution (neutralised), the pH does not change significantly.  | * Recognises near point **A** solution is a buffer /

[CH3NH2] ≈ [CH3NH3+].* Identifies H3O+ or HBr is neutralised / removed by CH3NH2.
* Calculates [OH–] / [H3O+] / *K*b
* Uses suitable process with more than one error.

ORRearranges *K*b / *K*a expression so [CH3NH2] is the subject.  | * Correct equation linked to neutralisation / absorption of H3O+.
* Correct method but an error in the calculation.
 | * Correct answer with a clear method.
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|  (b) | [H3O+] = 10–11.8 = 1.58 x 10-12*K*a =  = [OH-]2.29 × 10–11 = [CH3NH2] = = 0.0912 mol L–1**OR** [OH–] =  = 6.31 × 10–3 mol L–1*K*b = 4.37 × 10–4 = [CH3NH2] = [CH3NH2] = 0.0912 mol L–1 |
| (c)(i)(ii) | CH3NH3+, Br–, CH3NH2, H3O+ | TWO OF:* ALL species correct.
* Recognises ions are required for electrical conductivity in a solution.
* One correct equation.
 | * Full explanation of the electrical conductivity and species present of either the initial CH3NH2 solution or the solution at point B.

OR for an answer discussing each solution separately: TWO OF:Species and comparative concentrations within each solution for both solutions / two of the three equations / conductivity of each solution with reasons. | * Compares and contrasts the electrical conductivity of BOTH the initial CH3NH2 solution and the solution at point **B**, including a consideration of the differing concentrations of each solution.
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| **At the start**, before addition of HBr there is a solution of weak base (CH3NH2) which only partially reacts with water to produce a relatively low concentration of ions. As a result, the initial CH3NH2 solution will be a poor electrical conductor.**CH3NH2 + H2O ⇌ CH3NH3+ + OH-**Therefore species present are CH3NH2 > OH– ≥ CH3NH3+ > H3O+**At point B,** there is a solution of the salt CH3NH3Br present which is dissociated completely into ions. Therefore there is a relatively high concentration of ions (CH3NH3+ and Br–) present in the solution, so it will be a good electrical conductor / electrolyte.**CH3NH3Br → CH3NH3+ + Br–** CH3NH3+ reacts with water according to the equation**CH3NH3+ + H2O ⇌ CH3NH2 + H3O+**Species present are Br– > CH3NH3+ > H3O+ ≥ CH3NH2 > (OH–) |

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| **2013** | **Evidence** | **Achievement** | **Achievement with Merit** | **Achievement with Excellence** |
|  (a) |  | * Correct process.
 | * Correct pH.
 | (a) & (b) correct. |
| (b) | Halfway to equivalence point, half of the ethanoic acid has been used up. There are now equimolar quantities of ethanoic acid and sodium ethanoate. According to the equation when [CH3COOH] = [CH3COO–] then *K*a = [H3O+]So p*K*a = pH. | * Recognises that there are equimolar quantities of ethanoic acid and sodium ethanoate.
 | * Relates equation correctly to explanation.
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| (c)(i) | NaOH(*aq*) + CH3COOH(*aq*) → NaCH3COO(*aq*) + H2O(*l*) (1)[CH3COO–] increases as it is formed in reaction (1).[Na+] increases as NaOH is added (1). [CH3COOH] decreases as it reacts with NaOH (1).[H3O+] decreases because [CH3COO–] / [CH3COOH] increases and *K*a is a constant.[OH–] increases because [H3O+] decreases and [H3O+] [OH–] is constant. | * Correct equation *minor error.*
* Correct statement relating to change in concentration of 1 species.
 | Correct equation and correctly describes the change in concentration of 2 species.  | * Correct equation.

AND Correctly describes the change in concentration of the 4 species.  |
| (c)(ii) | *n*(CH3COOH at start) = 0.0896 × 20 ×10–3  = 1.79 × 10–3 mol *n*(NaOH added) = 0.1 × 5 × 10–3  = 5 × 10–4 molAfter 5 mL NaOH added:*n*(CH3COOH) = 1.29 × 10–3 mol*n*(CH3COO–) = 5 × 10–4 mol[CH3COOH] = 0.0516 mol L–1[CH3COO–] = 0.0200 mol L–1[H3O+] = 4.48 × 10–5 mol L–1pH = 4.35Candidates will not be penalised for not calculating concentrations. | * Correct n for CH3COOH OR NaOH at the start.
 | * Correct process to identify either of the species after 5 mL has been added (mol or mol L–1).
 | * Correct answer.
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| **2012** | **Evidence** | **Achievement** | **Merit** | **Excellence** |
| **(a) (i)****(ii)** | n (NaOH) = 0.180 mol L–1 × 0.04 L = 0.0072 mol1NaOH : 1HCOOHc (HCOOH) = 0.0072 mol / 0.025 L = 0.288 mol L–1HCOOH + H2O ⇌ HCOO– + H3O+*K*a = [HCOO–][H3O+] / [HCOOH][H3O+] = √(0.288 mol L–1 × 1.82 × 10–4) = 7.24 × 10–3 mol L–1pH = 2.14Half way to the equivalence point (20 mL), the NaOH has reacted with half the HCOOH, so [HCOOH] = [HCOO–].*K*a = [HCOO–] [H3O+] / [HCOOH]Since [HCOOH] = [HCOO–], substitution into *K*a gives:*K*a = [H3O+]Taking –log of each side:p*K*a = pHSo the pH half way to the equivalence point = p*K*a of HCOOH = 3.74According to the titration curve, the pH at the equivalence point isapproximately 8.4. Indicators change colour at their p*K*a +/–1. Sobromocresol green changes colour over a pH range of 3.7-5.7 and alizarin yellow will change colour over a pH range of 10.0 – 12.0. This means bromocresol green would therefore change colour before the equivalence point and alizarin yellow would change colour after the equivalence point.Both of these indicators would therefore be unsuitable for this titration.Cresol red will change colour over a pH range of 7.3 – 9.3. This includes the pH at the equivalence point. Cresol red would therefore be a suitable indicator to detect the endpoint since it changes colour at the equivalence point. | Any TWO of:• Shows [HCOOH] = 0.288 molL–1• Method to find pH correct withminor arithmetic error.• EITHER:States [HCOOH] = [HCOO–]ORpH = p*K*aEITHER:Identifies correct or incorrectindicator(s) with limited reasoning.ORIdentifies that the endpoint needs to be close to the equivalence point. | Any TWO of:• Correct pH.States [HCOOH] = [HCOO–] so pH = p*K*a when half-way to the equivalence point / in buffer zone.Identifies the correct indicator and an incorrect indicator, includingconsequences of wrong choice, but gaps in discussion (i.e. have talkedin general terms about anincorrect choice). | 1 answer to merit levelANDDiscussion of indicators links theequivalence point pH to the effective p*K*a over which eachindicator will change colour (range may be for either the indicator colour change occurring over a rangeOR for it’s p*K*a falling within the range of the vertical part of graph). |

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| **2011** | **Evidence** | **Achievement** | **Merit** | **Excellence** |
|  | **A**At point A, there is an equi-molar mixture of HEt and Et–. On addition of OH– ions, the acid part of the buffer neutralises the OH– ions, by donating a proton. The acid reacts with the base:HEt + OH– → Et– + H2OOn addition of H3O+, the ethanoate will accept a proton from the hydronium ion:Et– + H3O+ → HEt + H2OCandidate may discuss equilibrium shift.p*K*a = pH = 4.76 (accept 4.5 – 4.9)**B**At the equivalence point all the HEt has beenneutralised by NaOH.HEt + NaOH → EtNa + H2OThe Et– reacts further to a small extent with water.Et– + H2O ⇌ HEt + OH–Thus the pH of the equivalence point is above 7 due topresence of OH–. | ONE of:• Recognises that at point A there is a buffer solution.• States that equimolar amounts ofacid / base conjugate are present at A.• States that pH will not change when small amounts of acid or base are added.• Correct p*K*a / KaANDONE of:• Recognises that all the HEt has beenused up at B.• That the pH of equivalence point isgreater than 7. (must have clearlyindicated that point B is theequivalence point) | Describes how a buffer works(for when both acid AND baseare added) by:EITHER• Giving equations for the specific bufferOR• Writing about how a buffer works in general termsOR• Links that due to equimolarHEt and Et– thus pKa = pHAND• Recognises that none of theoriginal HEt remains as ithasall reacted with NaOHOR• That the pH of equivalencepoint is greater than 7 with avalid reason. | Shows recognition of equimolarHEt and Et– thus p*K*a = pH and discusses how the buffer solution works and links to equations.ANDUses two equations to explainwhy the pH is above 7. (Oneequation may be implied in thecandidate’s written answer.) |

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| **2010** | **Evidence** | **Achieve** | **Merit** | **Excellence** |
| (a) | Since B is half way to the equivalence point,[NH4+] = [NH3]*K*a =  so *K*a = [H+] p*K*a = pH. Note: [NH4+] = [NH3] must include [ ] or the word **concentration**. | Any TWO of:* EITHER

pH = p*K*aOR[NH4+] = [NH3]at B. | Any TWO of:* Relates pH half way to equivalence point to species present to give pH = p*K*a
 |  |
| (b) | p*K*b(NH3) = 4.76 *K*b = 1.74 × 10–5NH3 + H2O sm eq arrow NH4+ + OH–*K*b =  [OH–] =  = 1.67 × 10–3 mol L–1pOH = 2.8 (accept 2.77) **pH = 11.2** (accept 11.22)OR *K*a = 5.75 × 10–10 | * EITHER

Rearranges *K*a / *K*b expression so [H3O+] / [OH–] is subject.OR*K*b / p*K*b calculatedORRecognition that *K*w= [H3O+] [OH–]ORRecognition that14 = pH + pOH. | * EITHER

Correct method with error in calculation. OR Calculates [H3O+] / [OH–]. | Calculates pH at point A. |
| (c) | Solution at equivalence point is NH4Cl. This solution is weakly acidic since NH4+ + H2O sm eq arrow NH3 + H3O+.so pH < 7. | * EITHER

pH < 7 as all of initial NH3 has reacted / **equal amount** of HCl has been added. OR‘e’ answer without statement that pH < 7. | * Correct pH related to species present.
 | ANDpH < 7 as all of initial NH3 has reacted to form NH4+ / NH4Cl AND that NH4+ is a weak acid AND equation for NH4+ dissociation. |

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| **2009** | **Evidence** | **Achievement** | **Merit** | **Excellence** |
| (a) | NaOH → Na+ + OH– CH3NH2 + H2O ⇌ CH3NH3+ + OH– CH3NH3Cl → CH3NH3+  + Cl–CH3NH3+  + H2O ⇌ CH3NH2 + H3O+ | * Any 2 equations correct.
* Recognises reasons for pH variation are due to differences in H3O+ or OH– concentrations

**OR** * Recognises conductivity is related to the concentration of ions in solution.
 | * Equations correct for all solutions.
* Recognises reasons for variations in pH and conductivity and makes one valid comparison.

**OR** * Difference in conductivity

correctly discussed relating to the specific solutions**OR*** Difference in pH correctly discussed relating to the specific solutions.
 | * Discussion addresses variation in BOTH pH and conductance using correct reasons.
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| (b) | NaOH is a strong base and completely dissociates into its ions. Strong base, so produces more OH– ions in solution than CH3NH2. pH > 7 and greater than for CH3NH2.CH3NH2 is a weak base, so only some ions react with water to produce OH– ions. pH > 7.CH3NH3Cl is an acidic salt that completely dissociates into its ions producing CH3NH3+.CH3NH3+  is a weak acid, so partially dissociates in water to produce H3O+ ions. So pH < 7.Conductivity relates to the number of ions in a solution.NaOH and CH3NH3Cl completely dissociate, so produce a large number of ions, so high conductivity.CH3NH2 has an equilibrium reaction with water, so only a few ions are produced, so low conductivity.  |

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| 2008 | **Evidence** | **Achievement** | **Achievement with Merit** | **Achievement with Excellence** |
| (a)(i) | X drawn **on curve** at pH 9 (accept 8.5–9.5). | pH or graph correct.Graph line must go above 12 and not touch 13. Line must also not trend upwards at the end. | Both correct. |  |
| (ii) | End of graph is drawn towards an asymptote line at pH 13.14121086420

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| pH |  |  |  |  |  |  |
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| (b) | HN3(*aq*) + H2O H3O+(*aq*) + N3–(*aq*)*K*a(CH3COOH) = [H3O+] [N3–] [HN3]pH = 2.6 so [H3O+(*aq*)] = **2.51 × 10–3 mol L–1** = [N3–(*aq*)]p*K*a(HN3) = 4.72, *K*a(HN3) = **1.91 × 10–5***K*a(HN3) = 1.91 × 10–5  = (2.51 × 10–3)2 *x****x* = 0.331 ie [HN3 (*aq*)] = 0.331 mol L–1** (Allow 0.330 and 0.33) |  [H3O+] determined from pHOR*K*a determined from p*K*a.(As long as solution is identified.) | Concentration of acid solution correctly determined. (Must have correct unit) |  |

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