IB Diploma

CHEMISTRY

HL

Paper 2

2017 — 2023

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1 - (CHEMI/21_HL_Summer_2017_Q2) - *Chemical Bonding & Structure, Stoichiometric Relationship, Atomic Structure*

Titanium and vanadium are consecutive elements in the first transition metal series.

(a) Describe the bonding in metals. [2]

(b) Titanium exists as several isotopes. The mass spectrum of a sample of titanium gave the following data:

Mass number	% abundance
46	7.98
47	7.32
48	73.99
49	5.46
50	5.25

Calculate the relative atomic mass of titanium to two decimal places. [2]

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(c) State the number of protons, neutrons and electrons in the $^{48}_{22}Ti$ atom. [1]

Protons:

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Neutrons:

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Electrons:

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(d) (i) State the full electron configuration of the $^{48}_{22}Ti^{2+}$ ion. [1]

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(ii) Suggest why the melting point of vanadium is higher than that of titanium. [1]

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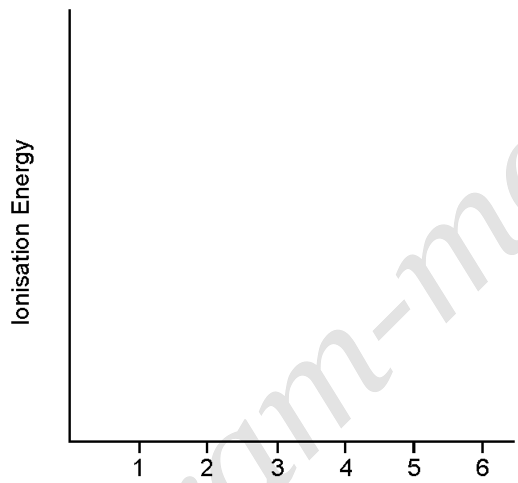
(iii) Sketch a graph of the first six successive ionization energies of vanadium on the axes provided. [1]



(iv) Explain why an aluminium-titanium alloy is harder than pure aluminium. [2]

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(e) Describe, in terms of the electrons involved, how the bond between a ligand and a central metal ion is formed. [1]

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(f) Outline why transition metals form coloured compounds. [4]

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(g) (i) State the type of bonding in potassium chloride which melts at 1043 K. [1]

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(ii) A chloride of titanium, $TiCl_4$, melts at 248 K. Suggest why the melting point is so much lower than that of KCl. [1]

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(h) $TiCl_4$ reacts with water and the resulting titanium(IV) oxide can be used as a smoke screen.

(i) Formulate an equation for this reaction. [2]

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(ii) Suggest **one** disadvantage of using this smoke in an enclosed space. [1]

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2 - (CHEMI/22_HL_Summer_2017_Q1) - *Stoichiometric Relationship, Atomic Structure*

There are many oxides of silver with the formula Ag_xO_y. All of them decompose into their elements when heated strongly.

(a) (i) After heating 3.760 g of a silver oxide 3.275 g of silver remained. Determine the empirical formula of Ag_xO_y. [2]

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(ii) Suggest why the final mass of solid obtained by heating 3.760 g of Ag_xO_y may be greater than 3.275 g giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

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(b) Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag.

The relative atomic mass of silver is 107.87. Show that isotope ^{107}Ag is more abundant. [1]

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(c) (i) Some oxides of period 3, such as Na_2O and P_4O_{10}, react with water. A spatula measure of each oxide was added to a separate 100 cm^3 flask containing distilled water and a few drops of bromothymol blue indicator.
The indicator is listed in section 22 of the data booklet.

Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide. [3]

Flask containing	Colour of solution	Product formula
Na_2O	....	....
P_4O_{10}	....	....

(ii) Explain the electrical conductivity of molten Na_2O and P_4O_{10}. [2]

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(d) Outline the model of electron configuration deduced from the hydrogen line emission spectrum (Bohr's model). [2]

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3 - (CHEMI/22_HL_Summer_2017_Q8) - *Acids & Bases, Stoichiometric Relationship*

Soluble acids and bases ionize in water.

(a) Sodium hypochlorite ionizes in water.

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

(i) Identify the amphiprotic species. [1]

....

(ii) Identify one conjugate acid-base pair in the reaction. [1]

Acid	Base
....	....

(b) A solution containing 0.510 g of an unknown monoprotic acid, HA, was titrated with 0.100 mol dm^{-3} NaOH (aq). 25.0 cm^3 was required to reach the equivalence point.

(i) Calculate the amount, in mol, of NaOH (aq) used. [1]

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(ii) Calculate the molar mass of the acid. [1]

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(iii) Calculate [H$^+$] in the NaOH solution. [1]

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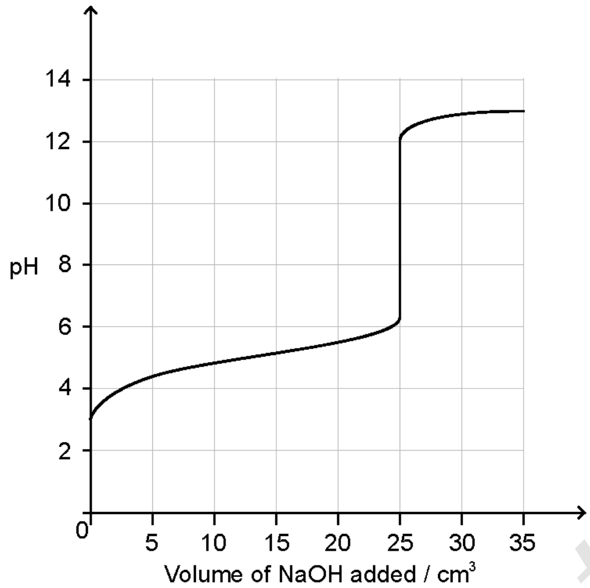
(iv) The following curve was obtained using a pH probe.



State, giving a reason, the strength of the acid. [1]

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(v) State a technique other than a pH titration that can be used to detect the equivalence point. [1]

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(vi) Deduce the pK_a for this acid. [1]

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(c) The pK_a of an anthocyanin is 4.35. Determine the pH of a $1.60 \times 10^{-3}\,mol\,dm^{-3}$ solution to two decimal places. [3]

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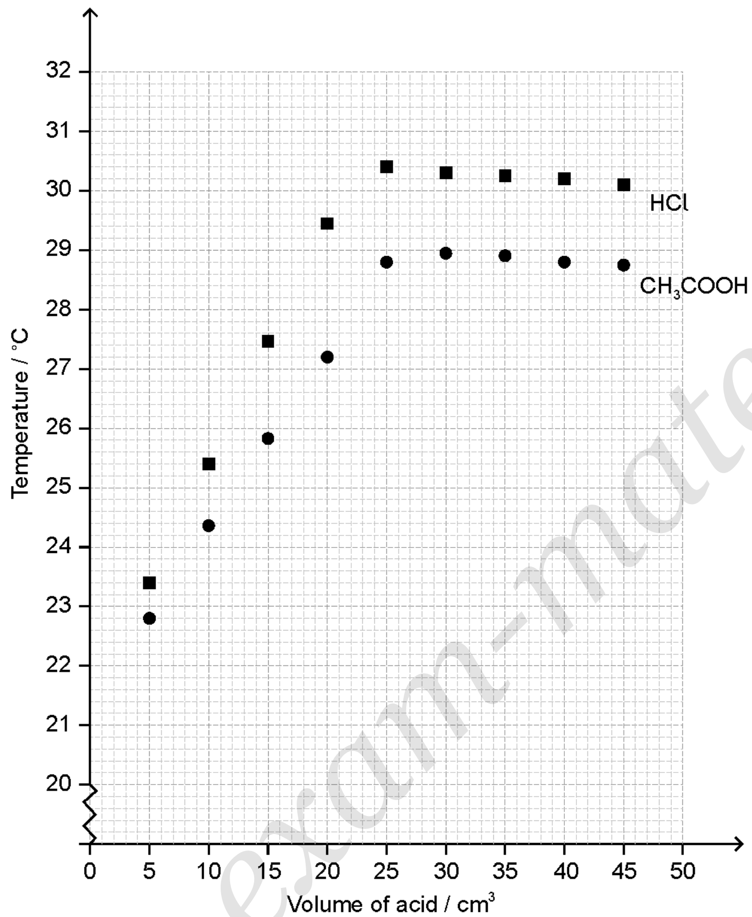
4 - (CHEMI/20_HL_Winter_2017_Q1) - *Stoichiometric Relationship, Energetics / Thermochemistry , Chemical Kinetics*

A student titrated two acids, hydrochloric acid, HCl (aq) and ethanoic acid, CH_3COOH (aq), against 50.0 cm^3 of 0.995 mol dm^{-3} sodium hydroxide, NaOH (aq), to determine their concentration. The temperature of the reaction mixture was measured after each acid addition and plotted against the volume of each acid.



(a) Using the graph, estimate the initial temperature of the solutions. [1]

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(b) Determine the maximum temperature reached in each experiment by analysing the graph. [2]

HCl:

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CH_3COOH:

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(c) Calculate the concentration of ethanoic acid, CH_3COOH, in $mol\,dm^{-3}$. [2]

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(d) (i) Determine the heat change, q, in kJ, for the neutralization reaction between ethanoic acid and sodium hydroxide.
Assume the specific heat capacities of the solutions and their densities are those of water. [2]

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(ii) Calculate the enthalpy change, ΔH, in $kJ\,mol^{-1}$, for the reaction between ethanoic acid and sodium hydroxide. [2]

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(e) Suggest why the enthalpy change of neutralization of CH_3COOH is less negative than that of HCl. [2]

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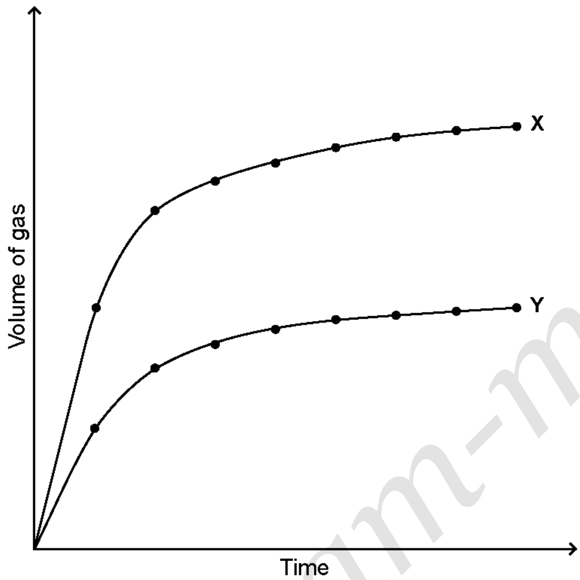
(f) Curves **X** and **Y** were obtained when a metal carbonate reacted with the same volume of ethanoic acid under two different conditions.



(i) Explain the shape of curve **X** in terms of the collision theory. [2]

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(ii) Suggest **one** possible reason for the differences between curves **X** and **Y**. [1]

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ANSWERS

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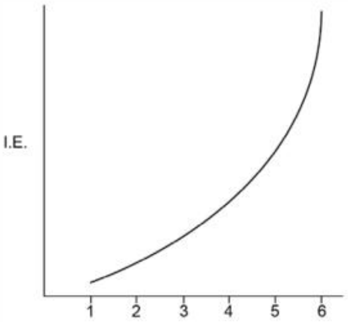
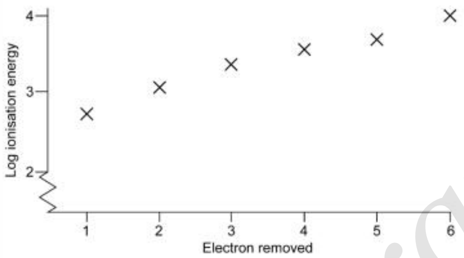
1 ▪ (CHEMI/21_HL_Summer_2017_Q2) ▪ *Chemical Bonding & Structure, Stoichiometric Relationship, Atomic Structure*

a		electrostatic attraction ✓ between «a lattice of» metal/positive ions/cations ***AND*** «a sea of» delocalized electrons ✓	*Accept "mobile electrons".* *Do **not** accept "metal atoms/nuclei".*
b		$\frac{(46 \times 7.98) + (47 \times 7.32) + (48 \times 73.99) + (49 \times 5.46) + (50 \times 5.25)}{100}$ ✓ = 47.93 ✓	*Answer must have two decimal places with a value from 47.90 to 48.00.* *Award [2] for correct final answer.* *Award [0] for 47.87 (data booklet value).*
c		*Protons:* 22 ***AND*** *Neutrons:* 26 ***AND*** *Electrons:* 22 ✓	
d	**i**	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^2$ ✓	
d	**ii**	vanadium has smaller ionic radius «leading to stronger metallic bonding» ✓	*Accept vanadium has «one» more valence electron«s» «leading to stronger metallic bonding».* *Accept "atomic" for "ionic".*
d	**iii**	  regular increase for first five ***AND*** sharp increase to the 6th ✓	*A log graph is acceptable.* *Accept log plot on given axes (without amendment of y-axis).* *Award mark if gradient of 5 to 6 is greater than "best fit line" of 1 to 5.*
d	**iv**	titanium atoms/ions distort the regular arrangement of atoms/ions ***OR*** titanium atoms/ions are a different size to aluminium «atoms/ions» ✓ prevent layers sliding over each other ✓	*Accept diagram showing different sizes of atoms/ions.*

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e		pair of electrons provided by the ligand ✔	*Do **not** accept "dative" or "co-ordinate bonding" alone.*
f		partially filled d-orbitals ✔ «ligands cause» d-orbitals «to» split ✔ light is absorbed as electrons transit to a higher energy level «in d–d transitions» ***OR*** light is absorbed as electrons are promoted ✔ energy gap corresponds to light in the visible region of the spectrum ✔ colour observed is the complementary colour ✔	
g	i	ionic ***OR*** «electrostatic» attraction between oppositely charged ions ✔	
g	ii	«simple» molecular structure ***OR*** weak«er» intermolecular bonds ***OR*** weak«er» bonds between molecules ✔	*Accept specific examples of weak bonds such as London/dispersion and van der Waals.* *Do **not** accept "covalent".*
h	i	$TiCl_4 (l) + 2H_2O (l) \rightarrow TiO_2 (s) + 4HCl (aq)$ correct products ✔ correct balancing ✔	*Accept ionic equation.* *Award M2 if products are HCl and a compound of Ti and O.*
h	ii	HCl causes breathing/respiratory problems ***OR*** HCl is an irritant ***OR*** HCl is toxic ***OR*** HCl has acidic vapour ***OR*** HCl is corrosive ✔	*Accept TiO_2 causes breathing problems/is an irritant.* *Accept "harmful" for both HCl and TiO_2.* *Accept "smoke is asphyxiant".*

2 - (CHEMI/22_HL_Summer_2017_Q1) - *Stoichiometric Relationship, Atomic Structure*

a	i	n(Ag) = «$\frac{3.275\text{ g}}{107.87\text{ g mol}}$ =» 0.03036 «mol» ***AND*** n(O) = «$\frac{3.760\text{g} - 3.275\text{g}}{16.00\text{g mol}^{-1}} = \frac{0.485}{16.00}$ =» 0.03031 «mol» ✔ «$\frac{0.03036}{0.03031}$ ≈ 1 / ratio of Ag to O approximately 1 : 1, so» AgO ✔	*Accept other valid methods for M1.* *Award **[1 max]** for correct empirical formula if method not shown.*
a	ii	temperature too low ***OR*** heating time too short ***OR*** oxide not decomposed completely ✔ heat sample to constant mass «for three or more trials» ✔	*Accept "not heated strongly enough".* *If M1 as per markscheme, M2 can only be scored for constant mass technique.* *Accept "soot deposition" (M1) and any suitable way to reduce it (M2).* *Accept "absorbs moisture «from atmosphere» (M1) and "cool in dessicator" (M2).* *Award **[1 max]** for reference to "impurity" **AND** design improvement.*
b		A_r closer to 107/less than 108 «so more ^{107}Ag» ***OR*** A_r less than the average of (107 + 109) «so more ^{107}Ag» ✔	*Accept calculation that gives greater than 50% ^{107}Ag.*

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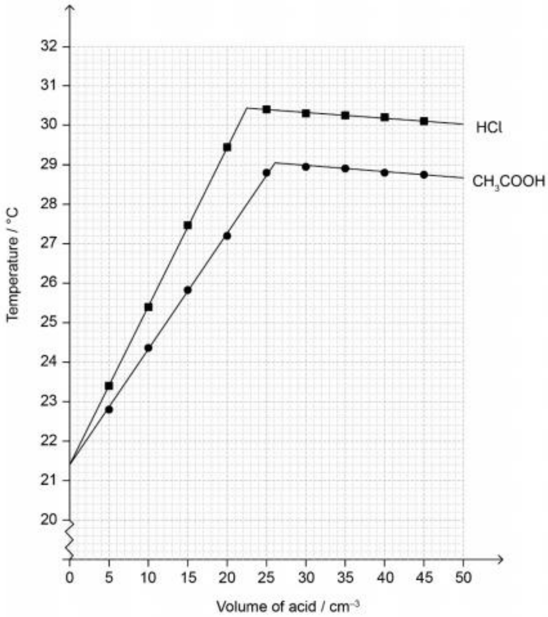
c	i	Flask containing / Colour of solution / Product formula: Na_2O — blue *AND* yellow ✔ — NaOH ✔ P_4O_{10} — blue *AND* yellow ✔ — H_3PO_4 ✔	*Do not accept name for the products.* *Accept "$Na^+ + OH^-$" for NaOH.* *Ignore coefficients in front of formula.*
c	ii	«molten» Na_2O has mobile ions/charged particles ***AND*** conducts electricity ✔ «molten» P_4O_{10} does not have mobile ions/charged particles ***AND*** does not conducts electricity/is poor conductor of electricity ✔	*Do **not** award marks without concept of mobile charges being present.* *Award **[1 max]** if type of bonding or electrical conductivity correctly identified in each compound.* *Do **not** accept answers based on electrons.* *Award **[1 max]** if reference made to solution.*
d		electrons in discrete/specific/certain/different shells/energy levels ✔ energy levels converge/get closer together at higher energies ***OR*** energy levels converge with distance from the nucleus ✔	*Accept appropriate diagram for either M1, M2 or both.* *Do not give marks for answers that refer to the lines in the spectrum.*

3 ▪ (CHEMI/22_HL_Summer_2017_Q8) ▪ *Acids & Bases, Stoichiometric Relationship*

a	i	H_2O/water ✔	*Accept "hydroxide ion/OH^-".*
a	ii	Acid / Base: HOCl ***AND*** OCl^- ***OR*** H_2O ***AND*** OH^- ✔	
b	i	«$0.100\ mol\ dm^{-3} \times 0.0250\ dm^3$» = 0.00250 «mol» ✔	
b	ii	«$M = \frac{0.510\,g}{0.00250\,mol}$ =» 204 «$g\ mol^{-1}$» ✔	
b	iii	«$1.00 \times 10^{-14} = [H^+] \times 0.100$» 1.00×10^{-13} «$mol\ dm^{-3}$» ✔	
b	iv	weak ***AND*** pH at equivalence greater than 7 ***OR*** weak acid ***AND*** forms a buffer region ✔	
b	v	calorimetry ***OR*** measurement of heat/temperature ***OR*** conductivity measurement ✔	*Accept "indicator" but not "universal indicator".*
b	vi	«pK_a = pH at half-equivalence =» 5.0	

c		$K_a = 10^{-4.35}$ / 4.46683×10^{-5} ✔ $[H_3O^+] = \sqrt{4.46683 \times 10^{-5} \times 1.60 \times 10^{-3}}$ / $\sqrt{7.1469 \times 10^{-8}}$ / 2.6734×10^{-4} «$mol\ dm^{-3}$» ✔ pH = «$-\log \sqrt{7.1469 \times 10^{-8}}$ =» 3.57 ✔	*Award **[3]** for correct final answer to two decimal places.* *If quadratic equation used, then:* *$[H_3O^+] = 2.459 \times 10^{-4}$ «$mol\ dm^{-3}$»* *and pH = 3.61*

4 - (CHEMI/20_HL_Winter_2017_Q1) - *Stoichiometric Relationship, Energetics / Thermochemistry , Chemical Kinetics*



a		21.4 °C ✓	*Accept values in the range of 21.2 to 21.6 °C.* *Accept two different values for the two solutions from within range.*
b		*HCl:* 30.4 «°C» ✓ *CH_3COOH:* 29.0 «°C» ✓	*Accept range 30.2 to 30.6 °C.* *Accept range 28.8 to 29.2 °C.*
c		***ALTERNATIVE 1*** «volume CH_3COOH =» 26.0 «cm^3» ✓ «[CH_3COOH] = 0.995 mol dm^{-3} × $\frac{50.0 cm^3}{26.0 cm^3}$ =» 1.91 «mol dm^{-3}» ✓ ***ALTERNATIVE 2*** «n(NaOH) = 0.995 mol dm^{-3} × 0.0500 dm^3 =» 0.04975 «mol» ✓ «[CH_3COOH] = $\frac{0.04975}{0.0260} dm^3$ =» 1.91 «mol dm^{-3}» ✓	*Accept values of volume in range 25.5 to 26.5 cm^3.* *Award **[2]** for correct final answer.*
d	i	«total volume = 50.0 + 26.0 =» 76.0 cm^3 ***AND*** «temperature change 29.0 – 21.4 =» 7.6 «°C» ✓ «q = 0.0760 kg × 4.18 kJ kg^{-1} K^{-1} × 7.6 K =» 2.4 «kJ» ✓	*Award **[2]** for correct final answer.*

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d	ii	«n(NaOH) = 0.995 mol dm^{-3} × 0.0500 dm^3 =» 0.04975 «mol» ***OR*** «n(CH_3COOH) = 1.91 mol dm^{-3} × 0.0260 dm^3 =» 0.04966 «mol» ✓ «$\Delta H = -\frac{2.4 kJ}{0.04975 mol}$ =» – 48 / – 49 «kJ mol^{-1}» ✓	*Award **[2]** for correct final answer.* *Negative sign is required for M2.*
e		CH_3COOH is weak acid/partially ionised ✓ energy used to ionize weak acid «before reaction with NaOH can occur» ✓	
f	i	«initially steep because» greatest concentration/number of particles at start ***OR*** «slope decreases because» concentration/number of particles decreases ✓ volume produced per unit time depends on frequency of collisions ***OR*** rate depends on frequency of collisions ✓	
f	ii	mass/amount/concentration of metal carbonate more in X ***OR*** concentration/amount of CH_3COOH more in X ✓	

5 - (CHEMI/20_HL_Winter_2017_Q2) - *Measurement & Data Processing, Stoichiometric Relationship, Chemical Kinetics*

a		«series of» lines ***OR*** only certain frequencies/wavelengths ✓ convergence at high«er» frequency/energy/short«er» wavelength ✓	*M1 and/or M2 may be shown on a diagram.*
b		electron transfer/transition between high«er» energy level to low«er» energy level ***OR*** electron transitions into first energy level causes UV series ***OR*** transition into second energy level causes visible series ***OR*** transition into third energy level causes infrared series ✓	*Accept any of the points shown on a diagram.*
c		24 × 0.786 + 25 × 0.101 + 26 × 0.113 ✓ 24.33 ✓	*Award **[2]** for correct final answer.* *Award **[0]** for 24.31 with no working (data booklet value).*
d	i	carbon: «$\frac{0.4490 g}{44.01 g mol^{-1}}$ =» 0.01020 «mol» / 0.1225 «g» ***OR*** hydrogen: «$\frac{0.1840 g \times 2}{18.02 g mol^{-1}}$ =» 0.02042 «mol» / 0.0206 «g» ✓ oxygen: «0.1595 – (0.1225 + 0.0206) =» 0.0164 «g» / 0.001025 «mol» ✓ empirical formula: $C_{10}H_{20}O$ ✓	*Award **[3]** for correct final answer.* *Do **not** award M3 for a hydrocarbon.*

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