Q1.

Which species can behave as a Brønsted–Lowry acid in aqueous solution?

A SO_4^{2-} ⬭

B HCO_3^- ⬭

C BF_3 ⬭

D NH_3 ⬭

(Total 1 mark)

Q2.

Which can **not** function as a Brønsted-Lowry acid?

A CH_3COO^- ⬭

B HCO_3^- ⬭

C H_3O^+ ⬭

D NH_4^+ ⬭

(Total 1 mark)

Q3.

This question is about sulfuric acid and its salts.

(a) Draw the displayed formula of a molecule of H_2SO_4

(1)

(b) In aqueous solution, sulfuric acid acts as a strong acid. The H_2SO_4 dissociates to form HSO_4^- ions and H^+ ions.

The HSO_4^- ions act as a weak acid and dissociate to form SO_4^{2-} ions and H^+ ions.

Give an equation to show each stage in the dissociation of sulfuric acid in aqueous solution.

Include appropriate arrows in your equations.

Equation 1 _____

Equation 2 _____

(2)

(c) A student is required to make 250 cm^3 of an aqueous solution that contains an accurately measured mass of sodium hydrogensulfate ($NaHSO_4$).

Describe the method that the student should use to make this solution.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

(4)

(d) A solution that contains 605 mg of $NaHSO_4$ in 100 cm^3 of solution has a pH of 1.72

Calculate the value of K_a for the hydrogensulfate ion (HSO_4^-) that is behaving as a weak acid.
Give your answer to three significant figures.

State the units of K_a

K _____ Units _____

(6)

(e) Some sodium sulfate is dissolved in a sample of the solution from part **(d)**.

Explain why this increases the pH of the solution.

_____

_____

_____

_____

_____

_____

(2)

(Total 15 marks)

Q4.

This question is about Brønsted–Lowry acids.

(a) Give the meaning of the term Brønsted–Lowry acid.

_____

_____

(1)

(b) What is meant by the term strong when describing an acid?

_____

_____

(1)

(c) At 298 K, 25.0 cm^3 of a solution of a strong monoprotic acid contained 1.45×10^{-3} mol of hydrogen ions.

Calculate a value for the pH of this solution.
Give your answer to 2 decimal places.

pH _____

(2)

(d) Calculate the pH of the solution formed after the addition of 35.0 cm^3 of 0.150 mol dm^{-3} NaOH to the original 25.0 cm^3 of monoprotic acid.

The ionic product of water $K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6} at 298 K.
Give your answer to two decimal places.

pH _____

(5)

(e) A buffer solution is made when 1.50 g of sodium hydroxide are added to 1.00 dm^3 of a 0.150 mol dm^{-3} solution of a weak acid HA.

For HA, the acid dissociation constant, $K_a = 1.79 \times 10^{-5}$ mol dm^{-3}.

Calculate the pH of this buffer solution.

pH _____

(6)

(Total 15 marks)

Q5.

Nitric acid (HNO_{-3}) is a strong acid. Ethanoic acid (CH_3COOH) is a weak acid.

(a) Write an equation to show how ethanoic acid behaves as a weak acid in its reaction with water.

_____

(1)

(b) When pure ethanoic acid reacts with pure nitric acid, ethanoic acid acts as a base.

Write an equation for this reaction.

_____

(1)

(c) Two beakers, **A** and **B**, each contain 100.0 cm^{-3} of 0.0125 mol dm^{-3} nitric acid.

(i) Calculate the pH of the solution formed after 50.0 cm^{-3} of distilled water are added to beaker **A**.
Give your answer to 2 decimal places.

_____

_____

_____

(2)

(ii) Calculate the pH of the solution formed after 50.0 cm^3 of 0.0108 mol dm^{-3} aqueous sodium hydroxide are added to beaker **B**.
Give your answer to 2 decimal places.

_____

_____

_____

_____

_____

_____

_____

(4)

(d) A third beaker, **C**, contains 100.0 cm^3 of 0.0125 mol dm^{-3} ethanoic acid.
The acid dissociation constant K_a for ethanoic acid has the value 1.74×10^{-5} mol dm^{-3} at 25 °C.

(i) Write an expression for K_a for ethanoic acid and use it to calculate the pH of the ethanoic acid solution in beaker **C**.
Show your working. Give your answer to 2 decimal places.

K_a _____

_____

Calculation _____

_____

_____

_____

(4)

(ii) Aqueous sodium hydroxide is added to beaker **C** until the pH of the solution becomes 4.84.

Name the salt formed in the reaction of ethanoic acid with sodium hydroxide.

_____

(1)

(iii) Calculate the value of $\frac{[\text{salt}]}{[\text{ethanoic acid}]}$ in the solution with the pH of 4.84.

_____

_____

_____

_____

_____

_____

(3)

(e) Explain why chloroethanoic acid is a stronger acid than ethanoic acid.

_____

_____

_____

_____

(2)

(f) Explain why data books do not usually contain values of K_a for strong acids.

_____

_____

_____

_____

(2)

(Total 20 marks)

Q6.

This question is about several Brønsted–Lowry acids and bases.

(a) Define the term *Brønsted–Lowry* acid.

_____

_____

(1)

(b) Three equilibria are shown below. For each reaction, indicate whether the substance immediately **above** the box is acting as a Brønsted–Lowry acid (**A**) or a Brønsted–Lowry base (**B**) by writing **A** or **B** in each of the six boxes.

(i) $CH_3COOH + \underset{\square}{H_2O} \rightleftharpoons \underset{\square}{CH_3COO^-} + H_3O^+$

(1)

(ii) $CH_3NH_2 + \underset{\square}{H_2O} \rightleftharpoons \underset{\square}{CH_3NH_3^+} + OH^-$

(1)

(iii) $\underset{\square}{HNO_3} + H_2SO_4 \rightleftharpoons \underset{\square}{H_2NO_3^+} + HSO_4^-$

(1)

(c) A 25.0 cm^3 sample of 0.0850 mol dm^{-3} hydrochloric acid was placed in a beaker. Distilled water was added until the pH of the solution was 1.25.

Calculate the total volume of the solution formed. State the units.

(3)

(d) At 298 K, the value of the acid dissociation constant (K_a) for the weak acid HX in aqueous solution is 3.01×10^{-5} mol dm^{-3}.

(i) Calculate the value of pK_a for HX at this temperature.
Give your answer to 2 decimal places.

(1)

(ii) Write an expression for the acid dissociation constant (K_a) for the weak acid HX.

(1)

(iii) Calculate the pH of a 0.174 mol dm^{-3} solution of HX at this temperature.
Give your answer to 2 decimal places.

(3)

(e) An acidic buffer solution is formed when 10.0 cm^3 of 0.125 mol dm^{-3} aqueous sodium hydroxide are added to 15.0 cm^3 of 0.174 mol dm^{-3} aqueous HX.
The value of K_a for the weak acid HX is 3.01×10^{-5} mol dm^{-3}.

Calculate the pH of this buffer solution at 298 K.
Give your answer to 2 decimal places.

(6)
(Total 18 marks)

Q7.

Ammonia and ethylamine are examples of weak Brønsted–Lowry bases.

(a) State the meaning of the term *Brønsted–Lowry base*.

(1)

(b) (i) Write an equation for the reaction of ethylamine ($CH_3CH_2NH_2$) with water to form a weakly alkaline solution.

(1)

(ii) In terms of this reaction, state why the solution formed is **weakly** alkaline.

_____

_____

(1)

(c) State which is the stronger base, ammonia or ethylamine. Explain your answer.

Stronger base _____

Explanation _____

_____

_____

_____

(3)

(d) Give the formula of an organic compound that forms an alkaline buffer solution when added to a solution of ethylamine.

_____

(1)

(e) Explain qualitatively how the buffer solution in part (d) maintains an almost constant pH when a small amount of hydrochloric acid is added to it.

_____

_____

_____

_____

(2)

(Total 9 marks)

Q8.

When iron(II) sulfate is used for killing weeds in lawns, it is often mixed with the fertiliser ammonium sulfate. Ammonium sulfate also makes the soil acidic.

(a) Write an equation to show how the ammonium ion behaves as a Brønsted–Lowry acid in water.

_____

(1)

(b) Compounds such as ammonium sulfate react on warming with sodium hydroxide solution as shown in the equation below.

$$(NH_4)_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2NH_3 + 2H_2O$$

Use this information to describe a simple test, other than smell, to show that ammonia is evolved. State what you would observe.

Test _____

_____

Observation _____

(2)

(Total 3 marks)

Q9.

Summarised directions for recording responses to multiple completion questions			
A (i), (ii) and (iii) correct only	**B** (i) and (iii) correct only	**C** (ii) and (iv) correct only	**D** (iv) alone correct

Brønsted-Lowry acid-base reactions include

(i) $OH^- + CH_3Cl \rightarrow CH_3OH + Cl^-$

(ii) $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$

(iii) $KF + PF_5 \rightarrow K^+ + PF_6^-$

(iv) $H_2O + H_2O \rightarrow H_3O^+ + OH^-$

(Total 1 mark)

Q10.

In which one of the following reactions is the role of the reagent stated correctly?

	Reaction	**Role of reagent**
A	$TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO$	TiO_2 is an oxidising agent
B	$HNO_3 + H_2SO_4 \rightarrow H_2NO_3^+ + HSO_4^-$	HNO_3 is a Brønsted-Lowry acid
C	$CH_3COCl + AlCl_3 \rightarrow CH_3CO^+ + AlCl_4^-$	$AlCl_3$ is a Lewis base
D	$2CO + 2NO \rightarrow 2CO_2 + N_2$	CO is a reducing agent

(Total 1 mark)

Mark schemes

Q1.

B

HCO_3^-

[1]

Q2.

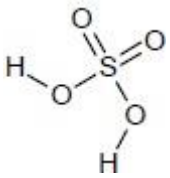
A

CH_3COO^-

[1]

Q3.

(a)



Ignore shape / bond angles
Ignore lone pair(s) on O atoms
NOT lone pair(s) on S atom

1

(b) Equation 1: $H_2SO_4 \rightarrow HSO_4^- + H^+$ / $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$

Equation 1: NOT $\rightleftharpoons$

1

Equation 2: $HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$ / $HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$

Equation 2: NOT $\rightarrow$ *or* $\leftrightarrow$
Allow $\leftrightharpoons$ *or* $\rightleftarrows$ *or* $\leftrightarrows$

1

Ignore state symbols in both equations
Allow multiples in both equations

(c) **M1** weigh solid and transfer using a method that Allows exact mass to be known (there should be two weighings, one of which could be zeroing, and method could be by difference or with washings or directly weighed into container)

M1 *Ignore any mass quoted*
NOT if any other solid added

1

M2 <u>dissolve</u> in water in suitable container (NOT in 250 cm^3 of water)

M2 *NOT if any other solution added*

1

M3 transfer with washings into 250 cm^3 volumetric/graduated flask

M3 *Reference to 250 cm^3 can appear anywhere*

1

M4 make up to mark / 250 cm^3 AND THEN shake / invert / mix

M4 *Allow if conical flask used*

NOT if beaker used

1

Alternative method (M2-4)

M2 *in 250 cm^3 volumetric/graduated flask*

M3 *dissolve (NOT in 250 cm^3 of water)*

M4 *make up to mark / 250 cm^3 AND THEN shake/invert/mix*

(d) **M1** $[H^+] = 10^{-1.72}$ (= 0.0191 (mol dm^{-3}))

1

M2 amount $NaHSO_4$ = 0.605/120.1 (= 5.04×10^{-3} (mol))

1

M3 initial $[NaHSO_4] = [HSO_4^-]$ = **M2** x 10 (= 5.04×10^{-2} (mol dm^{-3}))

$$K_a = \frac{[H^+][SO_4^{2-}]}{[HSO_4^-]} \quad \text{or} \quad K_a = \frac{[H^+]^2}{[HSO_4^-]}$$

1

M4 $K_a = \frac{0.0191^2}{0.0504 - 0.0191}$

1

M5 K_a = 1.17×10^{-2} ($1.15 - 1.18 \times 10^{-2}$) must be 3sf

1

M6 mol dm^{-3}

1

*Correct answer scores **M1-5** (must be 3sf)*

***Alternative method** that does not subtract 0.0191:*

*7.21×10^{-3} ($7.15 - 7.26 \times 10^{-3}$) scores **M1-5***

(where **M4** $K_a = \frac{0.0191^2}{0.0504}$)

If not correct answer:

*For **M1-3**, if answer is shown, it must be correct (Ignore sf)*

*Allow ECF from **M1/2/3** to **M4**/5 (but not from **M3** to **M5** if omission of **M3** gives negative **M5**)*

*NOT ECF from incorrect K_a expression in **M4** to **M5***

M6** If not mol dm^{-3}, Allow ECF for units from incorrect K_a expression in **M4

*7.21×10^{-2} ($7.15 - 7.26 \times 10^{-2}$) gives **M1,2,4,5** (by alternative method omitting **M3**)*

(e) **M1** ($HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$) equilibrium moves/shifts left (to counteract / remove increased $[SO_4^{2-}]$)

***M1** Allow H^+ reacts with SO_4^{2-}/sulfate*

Ignore favours the reverse / left / backwards reaction

NOT base / A^- / sodium sulfate in place of SO_4^{2-}/sulfate

M2 so $[H^+]$ decreases

1

M2 *Allow fewer H^+ (ions) or amount of H^+ lower or removes H^+*
M2 *independent of* ***M1***

1

[15]

Q4.

(a) Proton donor

1

(b) Completely ionises to give H^+ ions in water

1

(c) 0.058 mol dm^{-3}

1

1.24

1

(d) Amount of NaOH = 5.25×10^{-3}

1

Since 1:1 reaction amount of OH− ions in excess

= $5.25 \times 10^{-3} - 1.45 \times 10^{-3}$ mol

= 3.80×10^{-3} moles OH^-

1

$[OH^-] = 3.80 \times 10^{-3} \times 1000/60 = 0.0633$

1

$K_w = [H^+][OH^-$ so $H^+ = \frac{10^{-14}}{0.0633} = 1.58 \times 10^{-13}$

1

pH = 12.80

1

(e) Amount of OH^- added 1.5 / 40 = 0.0375 mol

1

Use of 1:1 ratio to calculate amount of A^- formed = 0.0375 mol

1

Amount of weak acid initially = 1 × 0.15 = 0.150 mol so amount of weak acid after addition of NaOH = 0.150 − 0.0375 = 0.1125

If M3 incorrect can only score max of 3 marks

1

$[H^+] = K_a [HA]/[A^-]$ or $[H^+] = 1.79 \times 10^{-5} \times 0.1125/0.0375$

1

$= 5.37 \times 10^{-5}$

1

pH = 4.27

1

[15]

Q5.

(a) $CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$

OR

$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

Must show $\rightleftharpoons$

Allow CH_3CO_2H, $CH_3CO_2^-$

Ignore state symbols

1

(b) ($CH_3COOH + \underline{HNO_3} \longrightarrow CH_3COOH_2^+ + NO_3^-$)

IGNORE $\rightleftharpoons$

Allow CH_3CO_2H, $CH_3CO_2H_2^+$, $CH_3C^+(OH)_2$

1

(c) (i) (new $[HNO_3] = [H^+] = \frac{100}{150} \times 0.0125$)

M1 $[H^+] = 8.3(3) \times 10^{-3}$ (mol dm^{-3})

OR

new$[HNO_3]$ = $\frac{\text{mol } HNO_3}{\text{total vol}} = \frac{1.25 \times 10^{-3}}{150 \times 10^{-3}}$

1

M2 pH = − log M1 OR 2.08

Must be 2dp

Allow correct pH conseq to their $[H^+]$ *concentration*

1

(ii) M1 mol NaOH (= $50 \times 10^{-3} \times 0.0108$) = 5.40×10^{-4}

1

M2 Subtraction of M1 from moles of HNO_3 (1.25×10^{-3} or conseq from 1c(i))

Excess mol $H^+ = 7.10 \times 10^{-4}$

M2 allow ecf for subtraction of mol

If no subtraction, no further marks

1

M3 $[H^+] = \frac{M2}{150 \times 10^{-3}}$ OR $\frac{7.10 \times 10^{-4}}{150 \times 10^{-3}} = 4.73 \times 10^{-3}$

M3 <u>if no use of volume, no further marks</u> (pH=3.15)

If incorrect volume used, can score M4

1

M4 pH = -log M3 OR 2.32

M4 Allow 2.33 Must be 2 dp

1

(d) (i) M1 $K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$

Penalise ( ) once here Not [H+][A-] / [HA]

If K_a expression wrong – Allow correct pH conseq to their [H+] concentration M4 only

1

M2 $K_a = \frac{[H^+]^2}{[CH_3COOH]}$ or with numbers or with HA

1

M3 $[H^+] = [\sqrt{(1.74 \times 10^{-5} \times 0.0125)}] = 4.66 \times 10^{-4}$

Mark for answer

1

M4 pH = 3.33

Must be 2dp

Allow correct pH conseq to their [H+] concentration

(pH = 3.83 can score M1, M2 and M4)

1

(ii) Sodium ethanoate

Ignore formula

Allow sodium acetate

1

(iii) M1 $[H^+] = 1.45 \times 10^{-5}$

Accept 1.445×10^{-5} or 1.4×10^{-5}

1

M2 $\frac{[salt]}{[acid]}$ (OR $\frac{[CH_3COO^-]}{[CH_3COOH]} = \frac{Ka}{[H^+]}$)= $\frac{1.74 \times 10^{-5}}{1.45 \times 10^{-5}}$

If M1 incorrect CE=0

Inclusion of 0.0125 in calculation can only score M1

1

M3 1.2(0)

Ignore units

1.4×10^{-5} gives 1.24

1

(e) M1 (Electronegative) chlorine withdraws electrons

Allow Cl has negative inductive effect

1

M2 Stabilises/reduces charge on COO-

OR weakens O-H bond

OR makes O-H more polar

Ignore chloroethanoic acid dissociates more readily
Mark independently

1

(f) M1 Strong acids (almost) completely dissociated/ionised

OR not an equilibrium

OR equilibrium lies far to the right

Cannot have K_a value for a reaction not in equilibrium scores both marks

1

M2 K_a value for strong acids tends to infinity/is very large
OR can't divide by zero in K_a

1

[20]

Q6.

(a) Proton donor or H^+ donor

Allow donator

1

(b) (i) B B

Both need to be correct to score the mark

1

(ii) A A

Both need to be correct to score the mark

1

(iii) B A

Both need to be correct to score the mark

1

(c) **M1** $[H^+] = 10^{-1.25}$ OR 0.05623

1

M2 mol HCl = $(25 \times 10^{-3}) \times 0.0850$ $(= 2.125 \times 10^{-3})$

Mark for Working

1

M3 vol $\left(= \frac{2.125 \times 10^{-3}}{0.05623}\right)$ = 0.0378 dm^3 or 37.8 cm^3

allow 0.0375 – 0.038 dm^3 or 37.5 – 38 cm^3

Units and answer tied
Lose M3 if total given as (25 + 37.8) = 62.8 cm^3
Ignore "vol added = 12.8 cm^3 " after correct answer

1

(d) (i) 4.52

Must be 2dp

1

(ii) $K_a = \frac{[H^+][H^-]}{[HX]}$ ignore = $\frac{[H^+]^2}{[HX]}$ but this may score M1 in (d)(iii)

Must have all brackets but allow ( ) Allow HA etc

***NO** mark for 10^{-pKa}*

1

(iii) **M1** $K_a = \frac{[H^+]^2}{[HX]}$ or with numbers

Allow $[H^+] = \sqrt{(Ka \times [HA])}$ for M1

1

M2 $[H^+] = (\sqrt{(3.01 \times 10^{-5} \times 0.174)} = \sqrt{(5.24 \times 10^{-6})})$
$= 2.29 \times 10^{-3}$ - 2.3×10^{-3}

Mark for answer

1

M3 pH = 2.64 (allow more than 2dp but not fewer)

Allow 1 for correct pH from their wrong $[H^+]$

If square root forgotten, pH = 5.28 scores 2 for M1 and M3

1

(e) **M1** mol OH^- = $(10.0 \times 10^{-3}) \times 0.125 = 1.25 \times 10^{-3}$

Mark for answer

1

M2 orig mol HX = $(15.0 \times 10^{-3}) \times 0.174 = 2.61 \times 10^{\times 3}$

Mark for answer

1

M3 mol HX in buffer = orig mol HX – mol OH^-

Mark for answer

$= 2.61 \times 10^{-3} - 1.25 \times 10^{-3} = 1.36 \times 10^{-3}$

Allow conseq on their (M2 – M1)

($[HX] = 1.36 \times 10^{-3}/25 \times 10^{-3} = 0.0544$)

If no subtraction, max 3 for M1, M2 & M4 (pH = 4.20)

If $[H^+] = [X^-]$ & √used, max 3 for M1, M2 & M3 (pH = 2.89)

1

M4 mol X^- in buffer = mol OH^- = 1.25×10^{-3}

($[X^-] = 1.25 \times 10^{-3}/25 \times 10^{-3} = 0.05$)

May be scored in M5 expression

1

M5 $[H^+]$ $\left(= \frac{Ka \times [HX]}{[X^-]}\right)$

If use $K_a = \frac{[H^+]^2}{[HX]}$ *no further marks*

$= \frac{3.01\times10^{-5}\times1.36\times10^{-3}}{1.25\times10^{-3}}$ *OR* $\frac{3.01\times10^{-5}\times0.0544}{0.05}$

(= 3.27 × 10⁻⁵)

If either value of HX or X⁻ used wrongly or expression upside down, no further marks

1

M6 pH = 4.48 or 4.49 (allow more than 2dp but not fewer)

*Do **not** allow M6 for correct calculation of pH using their [H⁺] - this only applies in (d)(iii) - apart from earlier AE*

1

[18]

Q7.

(a) Proton acceptor

1

(b) (i) $CH_3CH_2NH_2 + H_2O \longrightarrow CH_3CH_2NH_3^+ + OH^-$

allow eq with or without $\rightleftharpoons$

allow $C_2H_5NH_2$ and $C_2H_5NH_3^+$ (plus can be on N or H or 3)

allow RHS as $C_2H_5NH_3OH$

1

(ii) Mark independently of (b)(i)

Allow

Ethylamine is only partly/slightly dissociated

OR

Ethylamine is only partly/slightly ionized

reaction/equilibrium lies to left or low [OH^-] ***OR*** little OH^- formed

OR little ethylamine has reacted

Ignore "not fully dissociated" or "not fully ionized"

Ignore reference to ionisation or dissociation of water

1

(c) **M1** Ethylamine

If wrong no marks in (c)

1

M2 alkyl group is electron releasing/donating

OR alkyl group has (positive) inductive effect

1

M3 increases electron density on N(H_2)

OR increased availability of lp

OR increases ability of lp (to accept H(+))

Mark M3 is independent of M2

1

(d) $CH_3CH_2NH_3Cl$

Or any amine hydrochloride

allow name (ethylammonium chloride or ethylamine hydrochloride) or other halide for Cl

*or a strong **organic** acid*

NOT *NH_4Cl*

1

(e) Mark independently of (d)

Extra H^+ reacts with ethylamine or OH^-

Or makes reference to Equilibrium (in (b)(i)) with amine on LHS

1

OR $CH_3CH_2NH_2 + H^+ \longrightarrow CH_3CH_2NH_3^+$

OR $H^+ + OH^- \longrightarrow H_2O$

Equilibrium shifts to RHS

OR ratio $[CH_3CH_2NH_3^+]/[CH_3CH_2NH_2]$ remains almost constant

1

[9]

Q8.

(a) $NH_4^+ \rightarrow NH_3 + H^+$

Accept multiples.

Accept $NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$

Ignore state symbols, even if incorrect.

1

(b) Test indicator / conc HCl

Do not accept 'smell'.

Do not accept precipitation reactions of aqueous ammonia.

1

Observation colour for an alkali / white fumes

If wrong test then lose second mark.

1

[3]

Q9.

C

[1]

Q10.

D

[1]