

Past-paper walk-through

Arenes ■ 30.1

eXercise

Questions in this set

- 9701/41 N25 Q8 ■ 13 marks
- 9701/42 N25 Q9 ■ 14 marks
- 9701/44 N25 Q5 ■ 13 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- **//** separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 8

9701/41 N25 ■ Q8 ■ 13 marks

- 8** (a) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.
- (i) Describe the directing effect of the $-\text{NO}_2$ group. Explain your answer.

Question 8

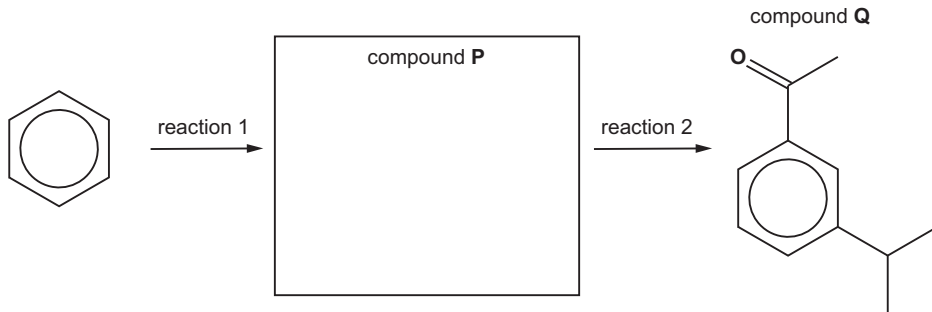
- (ii) The nitration of arenes uses a mixture of concentrated HNO_3 and concentrated H_2SO_4 to generate the NO_2^+ electrophile.

Write an equation for the formation of the NO_2^+ electrophile.

Question 8

(b) Carbon-carbon bond formation is an important reaction in organic synthesis.

Fig. 8.1 shows the synthesis of compound **Q** from benzene in two reaction steps.



Question 8

Fig. 8.1

- (i) Draw the structure of compound **P** in the box in Fig. 8.1. [1]
- (ii) Suggest reagents and conditions for reactions 1 and 2 in Fig. 8.1.

Question 8

Question 8

[2]

(c) Separate samples of $\text{C}_6\text{H}_5\text{Br}$ and $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ are added to warm $\text{AgNO}_3(\text{aq})$.

State the expected observations, if any. Explain your answer.

Question 8

- - - -

Question 8

- - - -

Question 8

[3]

(d) Acyl bromides, RCOBr , react readily with H_2O .

The mechanism of this reaction is similar to that of the reaction of H_2O with acyl chlorides, RCOCl .

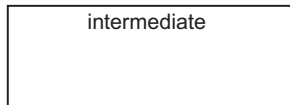
(i) Name the mechanism of this reaction.

Question 8

- (ii) Complete the mechanism in Fig. 8.2 for the reaction of RCOBr with H_2O .

Include all relevant lone pairs of electrons, curly arrows, charges and dipoles.

Draw the structure of the intermediate.



Question 8

R

Br



Question 8



Fig. 8.2

[4]

[Total: 13]

Solution 8

(a)(i)

Mark scheme

- NO₂ group directs to 3 (and 5) / meta position AND due to being an electron-withdrawing / electronegative group
- 1

Solution 8

(a)(ii)

Mark scheme

- $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{NO}_2^+ + \text{HSO}_4^- + \text{H}_2\text{O}$
- OR $\text{HNO}_3 + 2\text{H}_2\text{SO}_4 \rightarrow \text{NO}_2^+ + 2\text{HSO}_4^- + \text{H}_3\text{O}^+$
- 1

Solution 8

(b)(i)

Mark scheme

- 1

(b)(ii)

Mark scheme

- M1: (reaction 1) ethanoyl chloride / CH_3COCl AND AlCl_3
- M2: (reaction 2) 2-bromopropane / $(\text{CH}_3)_2\text{CHBr}$ AND FeBr_3
- 2

Solution 8

(c) Mark scheme

- M1:
 - with $\text{C}_6\text{H}_5\text{Br}$
 - no change / no precipitate AND
 - with $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$
 - cream precipitate
 - in $\text{C}_6\text{H}_5\text{Br}$
- M2: lone pair / p-orbital on Br delocalised / overlaps with ring / π system
- M3: C–Br bond stronger / has partially double bond character

Solution 8

- 3
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Solution 8

(d)(i)

Mark scheme

- (nucleophilic) addition–elimination
- 1

Solution 8

(d)(ii) Mark scheme

- M1 M2:
- ■
- lone pair on O
- ■
- curly arrow from (lone pair) O (in H₂O) to C (of C=O)
- ■
- correct dipole on C=O
- ■

Solution 8

- curly arrow from the C=O bond to O atom
- any two [1], all four [2]
- M3: correct intermediate
- M4: curly arrow from (lone pair on) O(−) to C–O bond AND curly arrow from C–Br to Br
- 4

Question 9

9701/42 N25 ■ Q9 ■ 14 marks

- 9 Compound **X** is made from benzene by the route shown in Fig. 9.1.

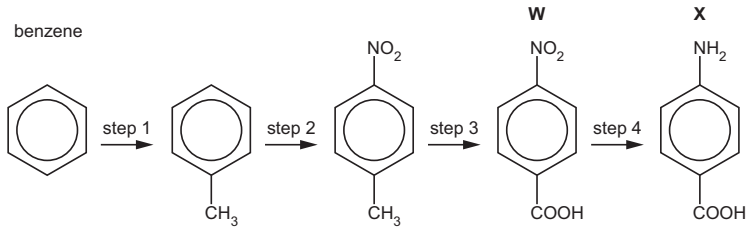


Fig. 9.1

- (a) Describe the bonding in benzene, C_6H_6 .

Question 9

Your answer should include:

- the hybridisation of the six carbon atoms
- the types of bond between the carbon atoms
- the orbitals that overlap to produce the bonds between the carbon atoms
- the type of bond between the carbon atoms and the hydrogen atoms
- the orbitals that overlap to produce the bonds between the carbon atoms and the hydrogen atoms.

Question 9

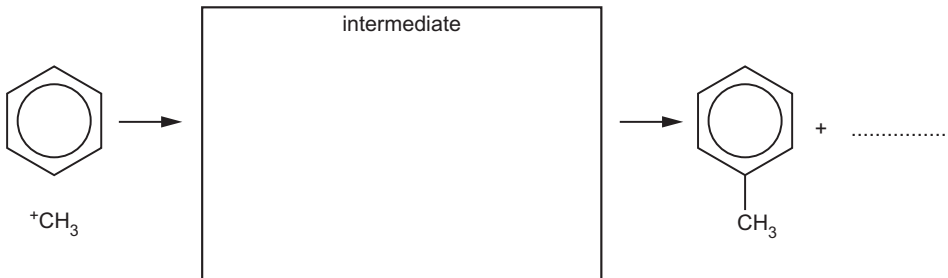
(b) Describe the reagents and conditions required for step 1 in Fig. 9.1.

Question 9

(c) In step 1 of Fig. 9.1 benzene reacts with $^+\text{CH}_3$.

Complete Fig. 9.2 to show the mechanism for this reaction, including:

- the movement of electron pairs using curly arrows
- the structure of the intermediate involved.



Question 9

|

|

Question 9



Fig. 9.2

[3]

- (d) Describe the reagents and conditions required for step 2 of Fig. 9.1.

Question 9

- (e) Identify the reagents required for step 3 of Fig. 9.1. Compound **W** is the product of this step.

Question 9

(f) Name compound **W**.

Question 9

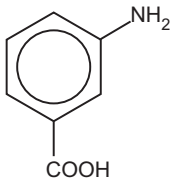
(g) The reagents commonly used for step 4 will **not** reduce the -COOH group.

Identify the reagents and conditions required for step 4 of Fig. 9.1.

Question 9

(h) Benzene can also be used as a starting material to make compound **Y**.

compound **Y**



Describe how the route described in Fig. 9.1 (repeated below) can be changed to give compound **Y** instead of compound **X**.

Explain your answer.

Question 9

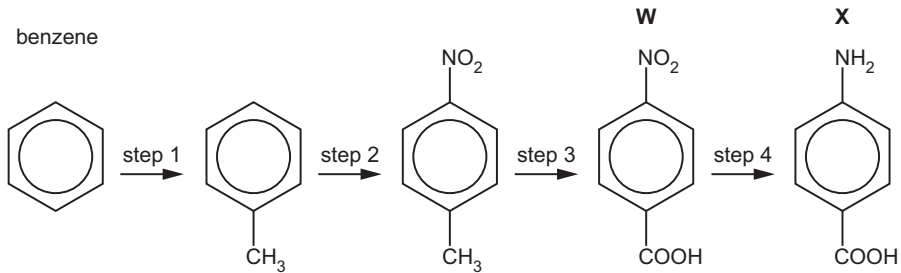


Fig. 9.1

[Total: 14]

Important values, constants and standards

Question 9



Question 9

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

	17	18
		2 He helium 4.0
1	9 F fluorine 19.0	10 Ne neon 20.2
	17 Cl chlorine 35.5	18 Ar argon 39.9
2	35 Br bromine 79.9	36 Kr krypton 83.8
3	53 I iodine 126.9	54 Xe xenon 131.3
4	85 At astatine —	86 Rn radon —
5	117 Ts tennessine —	118 Og oganesson —

71 Lu lutetium 175.0	103 Lr lawrencium —
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Question 9

Table of Elements

roup	13	14	15	16
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5	6	7	8
B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0
13	14	15	16
Al aluminum 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1
31	32	33	34
Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0
49	50	51	52
In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6
81	82	83	84
Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —
113	114	115	116
Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —

64	Gd	gadolinium	157.3	65	Tb	terbium	158.9	66	Dy	dysprosium	162.5	67	Ho	holmium	164.9	68	Er	erbium	167.3	69	Tm	thulium	168.9	70	Yb	ytterbium	173.1
96	Cm	curium	—	97	Bk	berkelium	—	98	Cf	californium	—	99	Es	einsteinium	—	100	Fm	fermium	—	101	Md	mendelevium	—	102	No	nobelium	—

Question 9

The Periodic T.

6

Key	
atomic number	1
atomic symbol	H
name	hydrogen
relative atomic mass	1.0

3	4	5	6	7	8	9
21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9
39 Y	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9
57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2
89–103 actinoids	104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —

57	La	lanthanum	138,9	58	Ce	cerium	140,1	59	Pr	praseodymium	140,9	60	Nd	neodymium	144,2	61	Pm	promethium	—	62	Sm	samarium	150,4	63	Eu	europlum	152,0
89	Ac	actinium	—	90	Th	thorium	232,0	91	Pa	protactinium	231,0	92	U	uranium	238,0	93	Np	neptunium	—	94	Pu	plutonium	—	95	Am	americium	—

Question 9

1	2	
3	4	
Li lithium 6.9	Be beryllium 9.0	
11	12	
Na sodium 23.0	Mg magnesium 24.3	
19	20	
K potassium 39.1	Ca calcium 40.1	
37	38	
Rb rubidium 85.5	Sr strontium 87.6	
55	56	
Cs caesium 132.9	Ba barium 137.3	
87	88	
Fr francium -	Ra radium -	

lanthanoids

actinoids

Solution 9

(a) Mark scheme

- ■
- all C atoms are sp^2 hybridised
- ■
- bonds between C atoms are σ and π
- ■
- C–C σ bonds are formed by overlap of sp^2 hybrid orbitals
- ■
- C–C π bonds are formed by overlap of p orbitals

Solution 9

- ■
- bonds between C and H atoms are σ
- ■
- C–H bonds are formed by overlap of sp^2 hybrid orbitals and s orbitals
- Any two [1], any four [2], all six [3]
- 3
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Solution 9

(b)

Mark scheme

- CH_3Cl and AlCl_3 3/1

Solution 9

(c)

Mark scheme

- M1: curly arrow from within hexagon towards $+C$
- M2: intermediate, usual rules for horseshoe and $+$ charge
- M3: curly arrow from C-H bond into ring AND H^+ product
- 3

Solution 9

(d)

Mark scheme

- M1: HNO_3 AND H_2SO_4
- M2: concentrated AND 25°C T 60°C
- 2

Solution 9

(e)

Mark scheme

- alkaline KMnO_4
- 1

Solution 9

(f)

Mark scheme

- 4-nitrobenzoic acid
- 1

Solution 9

(g)

Mark scheme

- (hot) concentrated HCl and Sn
- 1

Solution 9

(h)

Mark scheme

- M1: perform step 3 before step 2 OR perform step 2 before step 1
- M2: COOH is 3-directing OR NO₂ is 3-directing
- 2

Question 5

9701/44 N25 ■ Q5 ■ 13 marks

5 (a) Describe and explain the shape of benzene.

In your answer, include:

- the shape and bond angle in the ring
- the hybridisation of the carbon atoms
- how orbital overlap forms σ and π bonds between the carbon atoms in the ring.

Question 5

(b) Fig. 5.1 shows two reactions of benzoic acid.

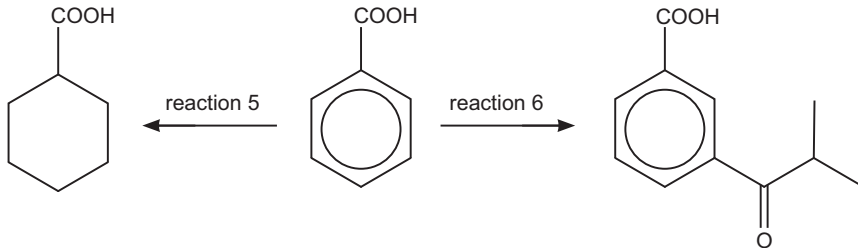


Fig. 5.1

(i) Suggest reagents and conditions for reaction 5 and for reaction 6 in Fig. 5.1.

Question 5

Question 5

[2]

- (ii) State the type of reaction for reaction 5 in Fig. 5.1.

Question 5

(c) In the electrophilic substitution of arenes, different substituents can direct to different ring positions.

(i) Describe the directing effect of the $-\text{CH}_2\text{CH}_3$ group.

Explain your answer.

Question 5

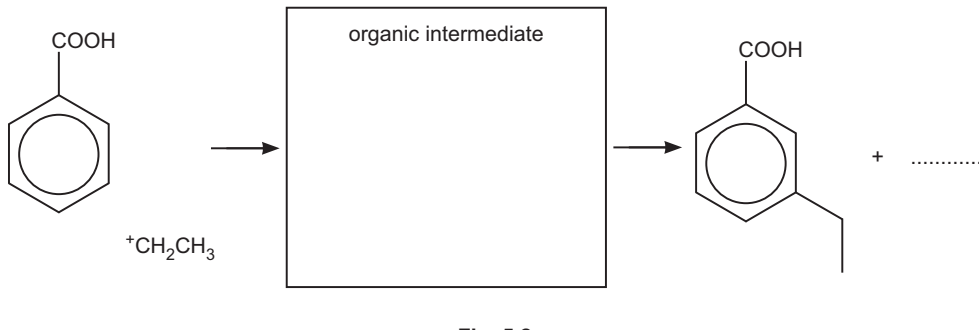
- (ii) The alkylation of arenes uses a mixture of $\text{CH}_3\text{CH}_2\text{Br}$ and FeBr_3 to generate the CH_3CH_2^+ electrophile.

Write an equation for the formation of the CH_3CH_2^+ electrophile.

Question 5

(iii) Complete the mechanism in Fig. 5.2.

Include all relevant curly arrows and charges. Draw the structure of the organic intermediate.



Question 5

Fig. 5.2

Question 5

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[3]

- (iv) Write an equation to show how FeBr_3 is regenerated after the reaction in Fig. 5.2.

Question 5

[Total: 13]

Solution 5

(a) Mark scheme

- M1 and M2: any two [1], all three [2]
- ■
- (hexagonal ring) planar / (trigonal) planar
- ■
- 120°
- ■
- sp² hybridised

Solution 5

- M3: p orbitals overlap sideways / laterally (with each other above and below the ring) forming π bonds
- M4: σ bonds form when sp^2 / hybridised orbitals overlap end-on-end / head on
- 4

Solution 5

(b)(i)

Mark scheme

- M1: (reaction 5)
- Pt / Ni + H₂ (+ heat)
- M2: (reaction 6)
- (CH₃)₂CHCOCl + AlCl₃ (+ heat)
- 2

Solution 5

(b)(ii)

Mark scheme

- reduction / hydrogenation
- 1

Solution 5

(c)(i)

Mark scheme

- (CH₂CH₃ group) directs to 2-, 4- (and 6-) positions AND due to being an electron donating group
- 1

(c)(ii)

Mark scheme

- $\text{CH}_3\text{CH}_2\text{Br} + \text{FeBr}_3 \rightarrow \text{CH}_3\text{CH}_2^+ + \text{FeBr}_4^-$
- 1

Solution 5

(c)(iii)

Mark scheme

- M1: curly arrow from inside / touching the hexagon to (CH₂) group / C⁺ charge
- M2: structure of the intermediate
- M3: curly arrow from C-H bond into / onto the ring AND formation / loss of H⁺
- 3

Solution 5

(c)(iv)

Mark scheme

- $\text{H}^+ + \text{FeBr}_4^- \rightarrow \text{HBr} + \text{FeBr}_3$
- 1
- organic intermediate
- 9701/44
- October/November 2025