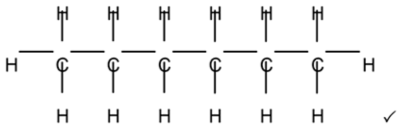
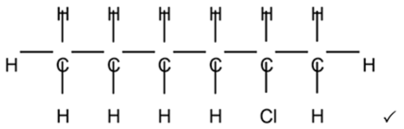
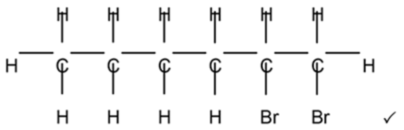
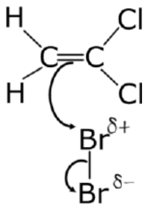
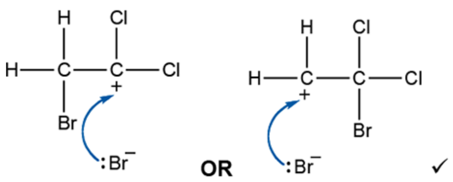
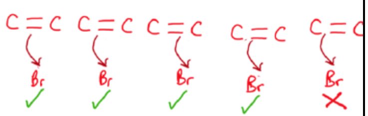
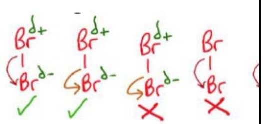
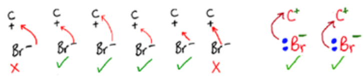
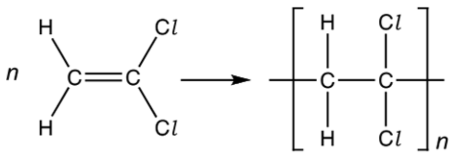
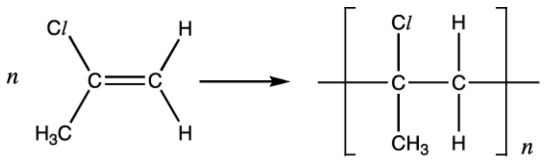
Mark scheme - Alkenes

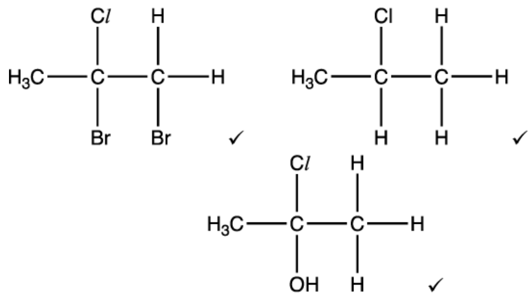
Question			Answer/Indicative content	Marks	Guidance
1		i	**Product with H_2**  **Product with HCl**  **Product with Br_2** 	3(AO 1.2x3)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** part molecular formulae but not full **<u>Examiner's Comments</u>** Most candidates answered this question well and achieved full marks. The most common errors were to put the chlorine on the wrong carbon, or to put both bromines on the same carbon.
		ii	Nickel/Ni ✓	1(AO 1.2)	**ALLOW** Pt **OR** Pd **OR** Rh **<u>Examiner's Comments</u>** Most candidates correctly stated nickel, although it was spelled incorrectly a lot of the time, which was ignored. "Acid" was the most common incorrect answer
		iii	(orange to) colourless **OR** bromine is decolourised ✓	1(AO 1.2)	**ALLOW** 'it decolourises / turns colourless' **IGNORE** colour change **<u>Examiner's Comments</u>** Many candidates wrote the colour change the wrong way around, or thought that a gas would be evolved, or wrote "clear" instead of "colourless". A large proportion merely stated what type of reaction it was, rather than what they would observe.
			Total	**5**	
2	a		steam **AND** Acid/H^+ (catalyst) ✓	1	**<u>Examiner's Comments</u>**

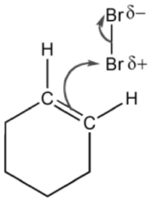
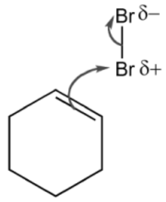
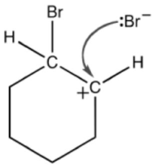
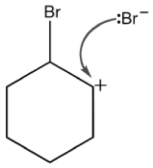
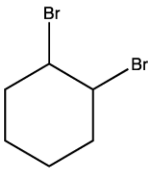
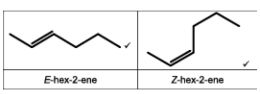
					Many candidates knew the answer to this question but forgot that water must be in the gaseous state. There were numerous responses stating nickel as the catalyst, but most knew that an acid catalyst was required.
	b	i	1,2-dibromo-1,1-dichloroethane✓	1	<u>**Examiner's Comments**</u> This question was generally well answered, although some candidates made careless mistakes such as not writing -di or writing 1,2-dibromo-1-dichloroethane
		ii	 **1st curly arrow (from ANY alkene)** Curly arrow from double bond to Br of Br–Br ✓ **DO NOT ALLOW** partial charge on C=C **2nd curly arrow** Correct dipole on Br Br **AND** curly arrow for breaking of Br–Br bond ✓ **3rd curly arrow** **Correct carbocation** with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation ✓ **DO NOT ALLOW** δ+ on C of carbocation  *i.e. ALLOW carbonium + on either C atom*	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **For curly arrows, ALLOW straight or snake-like arrows and small gaps (see examples):** **1st curly arrow** must • go to a Br atom of Br–Br • **AND** start from, **OR** be traced back • to **any point across width** of C=C  **2nd curly arrow** must • start from, **OR** be traced back to, **any part of** $^{\delta+}$Br–$^{\delta-}$ bond • **AND** go to $^{\delta-}$  **3rd curly arrow** must • go to the C^+ of carbocation • **AND** start from, **OR** be traced back • to **any point across width** of lone pair on :Br^-

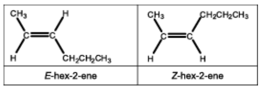
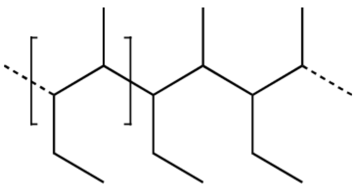
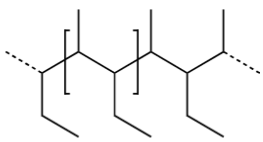
			DO NOT ALLOW half headed or double headed arrows but allow **ECF** if seen more than once		**OR** start from – charge on Br– • ion  *(Lone pair **NOT** needed if curly arrow shown from – charge on Br⁻)* **<u>Examiner's Comments</u>** Many candidates gained all three marks on this question and the diagrams were clear and easy to read. Lower ability candidates had incorrect dipoles or curly arrows that could not be traced back to the correct origin. Candidates should be encouraged to consider what the arrows mean rather than memorising mechanisms with no understanding.
	c	i	 Correct polymer with side links and brackets ✓ Equation balanced with *n* ✓ **TAKE CARE** of '*n*' position on both sides of equation.	2	**For repeat unit,** • displayed formula required • 'side bonds' required on either side of repeat unit from C atoms • **ALLOW** section containing more than one repeat unit **DO NOT ALLOW ECF** from incorrect repeat unit *n* on LHS at any height to the left of the formula *n* on RHS must be subscript **<u>Examiner's Comments</u>** Most candidates correctly drew the repeat unit and were credited with one mark, but many placed the *n* position in the wrong place on the left-hand side of the equation or forgot to write it in at all.
		ii	**Advantage (1 mark)** Energy production / (energy) used to produce electricity ✓	2	

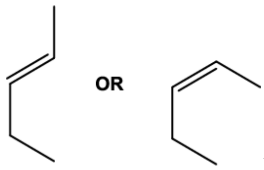
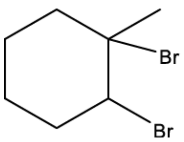
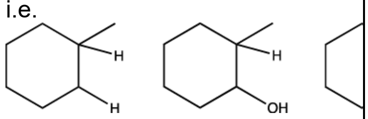
			Disadvantage (1 mark) Formation of HCl/products of combustion cause acid rain **OR** Formation of CO_2/gases that cause global warming / greenhouse gases **OR** Formation of CO✓		**ALLOW** reduced use of fossil fuels **ALLOW** less landfill / less harm to wildlife **ALLOW** chlorine/Cl **OR** Cl_2 **ALLOW** toxic/poisonous waste products **<u>Examiner's Comments</u>** With all the media interest in plastic pollution this question was answered well, although many gave the answer 'quick and efficient' as an advantage which was not credited. Candidates should beware of vague statements such as these. Many wrote 'harmful' instead of toxic, or 'bad for the environment' instead of being specific about the environmental issue.
			Total	**9**	
3			Electron pair acceptor (1) I^+ (1)	2	
			Total	**2**	
4		i	(because) molecule contains only single C–C bonds (1)	1	**allow** no multiple bonds / no double or triple bonds **allow** contains single bonds only
		ii	109.5°	1	
		iii	Combustion for energy production (alternative to fossil fuels) (1) Use as an organic feedstock (1)	2	
			Total	**4**	

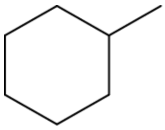
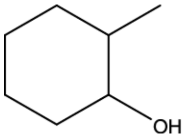
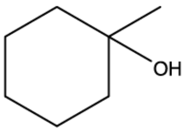
5	a	i	 Correct repeat unit (*n* and brackets not required) ✓ Equation balanced with *n* ✓ **TAKE CARE** of '*n*' position on both sides of equation.	**2**	**For monomer,** **ALLOW** correct molecular **OR** structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **For repeat unit,** **DO NOT ALLOW** molecular formula **NOTE**: 'side bonds' **ARE** required on either side of repeat unit from C atoms **ALLOW** section of polymer containing more than one repeat unit **NO ECF** from incorrect repeat unit **Examiner's Comments** The majority of candidates correctly drew the repeat unit but only afew wrote a full equation, balanced with *n*. The most common error was omission of the '*n*' before the monomer. Candidates are reminded of the importance of balancing equations.
		ii	Formation of HCl/hydrochloric acid/ **OR** chlorine ✓	**1**	**ALLOW** Cl or Cl_2 for chlorine **IGNORE** toxic waste products *Response must reflect chlorine in some way* **Examiner's Comments** Most candidates realised that the combustion would produce toxic/harmful gases, but the majority either incorrectly identified the problem gas as CO_2/CO or did not identify the gas at all. Others referred to ozone damage and global warming. Good responses referred to the formation of chlorine compounds such as hydrogen chloride.

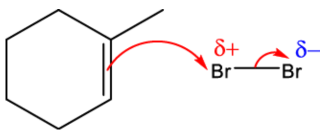
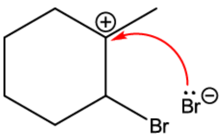
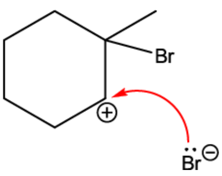
	b	i		3	**ALLOW** structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) For connectivity, **ALLOW** | OH | CH_3 CH_3– C **DO NOT ALLOW** OH— **Examiner's Comments** This part was generally well answered with the majority of candidates scoring two or three marks. The most common errors were the omission of the C*l* atom from each structure, or identifying the minor product instead of the major product from the reaction with steam. For addition products of an alkene, candidates are advised to copy the alkene but with a single rather than a double bond, then to add the reagent across where the double bond was. This might have prevented the omission of the C*l* atom on so many of the structures seen.
		ii	H^+/acid/H_2SO_4/H_3PO_4 ✓	1	**ALLOW** HCl **IGNORE** (aq) **OR** 'dilute' **OR** concentrated **Examiner's Comments** Most candidates correctly identified an acid catalyst, with the most common response being phosphoric acid. Common mistakes were nickel, zinc and acidified dichromate.
			Total	**7**	
6			Curly arrow from double bond to Br of Br–Br ✓ Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Curly arrow **must** start from bond and go to correct atom **DO NOT ALLOW** any other partial charges e.g. shown on double bond

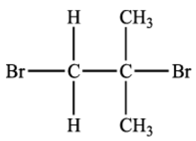
			 **OR**  Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation ✓  **OR**  Correct product:  ✓		**DO NOT ALLOW** missing H on displayed formulae (penalise once only) **DO NOT ALLOW** δ+ on C of carbocation. Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **IGNORE** wording if diagrams are correct Maximum of two marks for mechanism based on incorrect structure of cyclohexene **Examiner's Comment:** The precise setting out of a reaction mechanism was a skill that a good number of candidates have mastered with many accurate mechanisms being drawn. Others need more time to develop these skills; many errors being made with the position of dipoles and curly arrows. Despite making errors in the mechanism, many achieved one mark for drawing a correct final structure.
			Total	**4**	
7	a	i	 	2	**ALLOW** 1 mark if skeletal formulae of both *E* and *Z* hex-2-ene are shown but in the incorrect columns **IF** correct unambiguous structural **OR** displayed **OR** mixture of formulae are shown

					ALLOW 1 mark if both stereoisomers are in the correct columns e.g the following scores 1 mark  **IF** the skeletal formula of *E* hex-3-ene is shown in the first box **ALLOW** 1 mark for the skeletal formula of *Z* hex-3-ene as **ECF** **Examiner's Comments** It was anticipated that most candidates would be able to provide the skeletal formulae for the *E* and *Z* isomers of hex-2-ene but this proved not to be the case. A large number of responses displayed the C=C group and gave structural formulae for the side chains, while others confused *E* and *Z*, placing the isomers in the incorrect columns. A number of candidates opted to use an ambiguous formula and it was not uncommon to see C_3H_7 attached to a C=C group. Candidates should be made aware of the importance of showing each C atom when a question requires structural detail.
		ii	(carbon-carbon) double bond does not rotate **OR** has restricted rotation ✓ Each carbon atom of the double bond attached to (two) different groups / atoms ✓	2	**Examiner's Comments** Most candidates recognised that the C=C group had restricted rotation which resulted in *E/Z* isomerism. However, many struggled to explain that each C atom in the C=C group was bonded to different groups with sufficient clarity.
	b	i		1	**ALLOW** repeat unit at any point along the section provided that it works, e.g. 

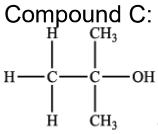
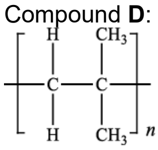
			One repeat unit shown ✓ *(could be any of the three repeat units shown)*		**Examiner's Comments** The majority of candidates were able to use brackets to show the repeat of the polymer shown. A number of candidates placed brackets inaccurately, often intersecting carbon atoms in the backbone.
		ii	Structure of pent-2-ene:  ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **Examiner's Comments** Candidates found this part more difficult than part **(c)(i)**. Many candidates correctly drew the structure of pent-2-ene as hydrocarbon **B** but a wide range of other responses was seen. Two common incorrect responses were the structures of either 2-methylpent-2-ene or 2-methylpentane.
		iii	(50,000/70 =) 714 **OR** 715 ✓	1	**MUST** be a whole number **Examiner's Comments** Many candidates were able to use the repeat unit identified in **(c)(i)** or the monomer in **(c)(ii)** to determine the number of monomer molecules in the polymer.
			Total	**7**	
8		i	**Product from Br_2**  ✓ **Product from H_2/Ni**	4	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **IGNORE** names **WATCH** for missed methyl stick **ALLOW** added H shown, i.e. 

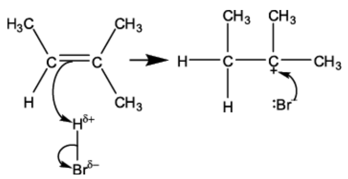
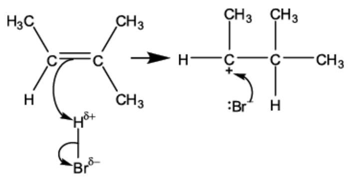
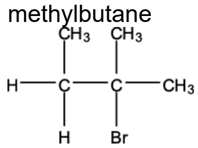
			 ✓ **Mixture of isomers from H_2O**  ✓  ✓		**ALLOW** in either order **Examiner's Comments** Most of the candidates were able to show correct structures for all four organic products. The majority of these candidates used skeletal formulae. A small proportion of responses included incomplete structures. These included a missing Br atom on the product from the reaction of compound **A** with Br_2 or a missing methyl group. Candidates should be advised to check structures carefully, especially when using skeletal formulae.
		ii	Steam **OR** temperature ≥ 100°C ✓ acid (catalyst) ✓	2	**ALLOW** $H_2O(g)$ **IGNORE** pressure **IGNORE** High temperature / reflux **ALLOW** H^+ / named mineral acid / H_2SO_4 / H_3PO_4 **DO NOT ALLOW** 'weak acid' e.g. ethanoic acid **Examiner's Comments** Most candidates were able to state that an acid catalyst was required for the reaction of compound **A** with H_2O. However, although many candidates recognised the need for the reaction to be heated only the strongest responses referred to temperatures above 100 °C. It was not uncommon to see vague responses that simply referred to a high temperature. Candidates should be encouraged to give precise conditions for the hydration reaction of an alkene.

		iii	Curly arrow from double bond to Br of Br–Br ✓ Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br−Br bond ✓  ……………………………………………………… Correct carbocation with + charge on C **AND** curly arrow from Br^- to C^+ of carbocation ✓  **OR**  **Note:** '+' and '–' are fine for charge (circles used for clarity)	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** Curly arrow **must** start from bond and go to correct atom **DO NOT ALLOW** any other partial charges e.g. shown on C=C bond **DO NOT ALLOW** δ+ on C of carbocation. **IF** C atoms are displayed **IGNORE** missing bonds to H atoms Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **Examiner's Comments** The mechanism of the reaction of compound **A** with Br_2 was well known and consequently the majority of candidates scored all three marks. A common reason for scoring only two marks was inaccurate placement of the curly arrow from the bromide ion to the carbocation intermediate. This arrow should start from either a lone pair or the minus sign of the bromide ion.
		iv	electrophilic addition ✓	1	**Examiner's Comments** Most of the candidates were able to name the mechanism

					correctly. However it was not uncommon to see incorrect responses which included electrophilic substitution and nucleophilic addition.
			Total	**10**	
9	a	i	C_2H_5O ✓	1	**ALLOW** elements in any order **DO NOT ALLOW** any other answer **Examiner's Comments** This part was answered well by most candidates. Some candidates however wrote the molecular rather than the empirical formula, or attempted to show the empirical formula as C_2H_4OH instead of C_2H_5O.
		ii	Compound E:  ✓ **Stage 1**: Compound **E**: Bromine/Br_2 ✓ **Stage 2**: NaOH/KOH **OR** OH^- ✓ *Only award if intermediate contains at least **one** halogen atom*	3	**For structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **ALLOW** dichloro/diiodo compound **IGNORE** connectivity of bonds to CH_3 **ALLOW** chlorine/Cl_2 **OR** iodine/I_2 **IGNORE** conditions, e.g. u.v. **DO NOT ALLOW** H_2O **IGNORE** conditions **NOTE:** Max of **2 marks** available for **monobrominated** intermediate **1 mark** Reagent: HBr **AND** Intermediate: $CH_3C(CH_3)_2Br$ **OR** $BrCH_2CH(CH_3)_2$ **1 mark**

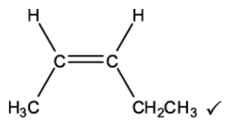
					Intermediate: $CH_3C(CH_3)_2Br$ **OR** $BrCH_2CH(CH_3)_2$ **AND** Reagent: NaOH **Examiner's Comments** This demanding part was answered poorly by weaker candidates and was good for differentiating higher ability candidates. The mark scheme allowed some credit for using a hydrogen halide to obtain a monosubstituted haloalkane for compound E. Surprisingly, reaction mechanism names were often given instead of reagents. Many candidates seemed to guess, sometimes showing the same reagents for both stages in the hope of getting a mark. Many showed an intermediate containing no halogen atom.
	b	i	Alkene **AND** C_nH_{2n} ✓	1	**IGNORE** branched before alkene **Examiner's Comments** This part was answered very well. Most candidates identified Compound B as a member of the alkenes and showed the correct general formula of C_nH_{2n}.
		ii	Hydrogen/H_2 **AND** Ni (catalyst) ✓	1	**ALLOW** Pt **OR** Pd **OR** Rh **ALLOW** hydrogenation for hydrogen **IGNORE** any temperature and pressure stated **Examiner's Comments** A surprisingly large number of candidates answered this part poorly. Many candidates identified either hydrogen or nickel, but not both. Other common errors included steam and H_3PO_4. This was an easy

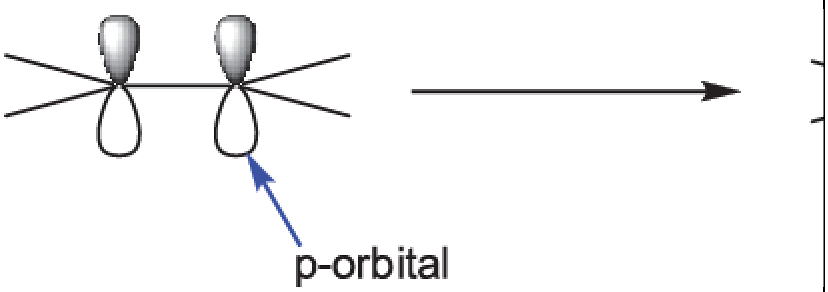
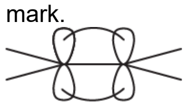
					question and the incorrect answers reflected that many candidates had not learnt organic reagents and conditions for the reactions in the specification.
	c		Compound C:  ✓ **CARE**: Tertiary alcohol Compound **D**: (repeat unit)  ✓	2	**For structures:** **ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above ___________________________________ ***Connectivity*** **IGNORE** connectivity of bonds to CH_3 e.g. **ALLOW** CH_3– **ALLOW any** vertical bond to OH, e.g. **ALLOW** OH **OR** OH | | **DO NOT ALLOW** OH– ___________________________________ **DO NOT ALLOW** more than one repeat unit **REQUIRED:** Side links (dotted lines fine) **NOT REQUIRED:** Brackets and '*n*' **<u>Examiner's Comments</u>** This part was answered well. If a mark was lost, it was almost always due to compound C, especially at the low scoring end of the range. Many struggled with the structure of a tertiary alcohol or omitted H atoms from the structure. Compound D was generally drawn correctly by candidates of all abilities. If the mark was not credited, it was usually due to not removing the double bond, or drawing more than one repeat unit.

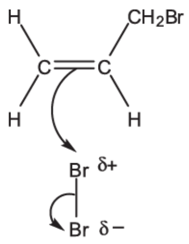
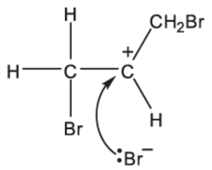
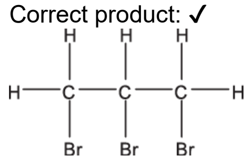
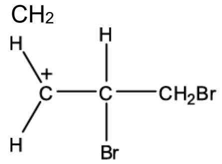
			Total	**8**	
1 0	a		*Please refer to marking instructions on page 4 of mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive description with all three scientific points explained thoroughly. *There is a well-developed and detailed description of the mechanism, including correct structures, accurately drawn curly arrows and using charges and dipoles consistently. Candidates compare tertiary and secondary carbocation stability to justify major product.* **Level 2 (3–4 marks)** Attempts to describe all three scientific points but explanations may be incomplete. **OR** Explains two scientific points thoroughly with no omissions. *The description has some structures with reasonably accurate curly arrows and some charges and dipoles identified.* **Level 1 (1–2 marks)** A simple description based on at least two of the main scientific points **OR** Explains one scientific point thoroughly with few omissions. *The description is communicated in an unstructured way, including some use of curly arrows, charges or dipoles.* **0 marks** No response worthy of credit.	6	Throughout: **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above if unambiguous **Indicative scientific points** **1. Two possible products of reaction** $CH_3C(CH_3)BrCH_2CH_3$ $CH_3CHBrCH(CH_3)CH_3$ **IGNORE** names where correct structures are present **2. Mechanism for formation of either product.** Curly arrow from C=C to attack the H atom of the HBr Correct dipole on H–Br Curly arrow from H–Br bond to Br Carbocation with full positive charge on carbon atom Curly arrow from negative charge on Br^- or lone pair on Br^- to carbon atom with positive charge  **or**  **3. Major organic product** Major product: 2-bromo-2-methylbutane  • Major product is formed from the most stable carbocation intermediate

					OR −Br is attached to carbon atom with the least hydrogens attached **OR** the carbon with the most $-CH_3$ groups attached **OR** the −H is attached to the carbon atom with most hydrogens attached **Examiner's Comments** The first of the six mark level of response questions required candidates to draw the mechanism of electrophilic addition, outline the two possible products and explain which one of these products would be the most likely to be formed. The most common mark for this question was five marks mainly due to candidates not being able to explain the formation of the major product in terms of the formation of the more stable tertiary carbocation in the intermediate stage of the mechanism. Candidate scoring five marks frequently quoted Markownikoff's rule as an explanation. Varying degrees of competence was displayed in the production of the mechanism. The correct positioning of curly arrows was a skill that the most candidates had clearly mastered with many accurate mechanisms being submitted. Weaker candidates clearly need more time to develop these skills.
	b	i	Any **one** from: • σ bond is between bonding atoms/nuclei **AND** π bond is above and below the bonding atoms / nuclei • σ bond has direct/head-on overlap of orbitals **AND** π bond has sideways overlap • π bond has a lower bond enthalpy / is weaker than a σ bond	1	**IGNORE** the length of the σ bond and π bond **IGNORE** the type of orbital for σ bond

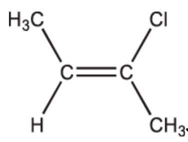
			• σ bond has electron density between bonding atoms **AND** π bond has electron density above and below bonding atoms ✓		**Examiner's Comments** The vast majority of candidates were unable to describe the difference between a σ and a π bond. The simplest answer was that the π bond was the weaker bond or the σ bond was the stronger. Many candidates attempted to describe how the two different bonds were formed. It was clear that candidates understood the concept of the sideways overlap of the p orbitals to form theπ bond but were unable to describe the formation of the σ bond. A common misconception was that the σ bond could only be formed by the overlapping of the s orbitals. The best candidates were able to articulate that the σ bond results from the head on overlap of orbitals resulting in the bond forming directly between two atoms whereas the π bond results in the electron density being located above and below the plane of the bonding atoms.
		ii	One carbon atom (in double bond) is attached to two groups which are identical / the same ✓	1	**ALLOW** • One carbon atom in (double bond) is not attached to (two) different groups/groups of atoms • Right-hand carbon is attached to two groups that are the same/two methyl groups. • Two groups are the same on **right-hand side** • Three groups are the same (on the double bond) **DO NOT ALLOW** • Two groups on the same side of the double bond

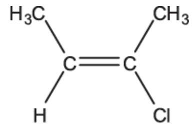
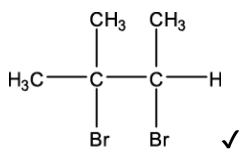
					• *Must be right-hand side; Same side could be top or bottom)* • Functional groups **OR** molecules for groups **Examiner's Comments** This question required candidates to apply their knowledge of *E/Z* isomerism to suggest why compound A did not have *E/Z* isomers. Whilst it was clear that many candidates understood the concept of *E/Z* isomerism many found it difficult to apply this concept and articulate an explanation.
		iii		1	**Mark Independently** **ALLOW** correct structural **OR** displayed **OR** skeletal formulae **OR** a combination of above as long as unambiguous **ALLOW** C_2H_5 for CH_2CH_3 **IGNORE** connectivity of alkyl groups **BUT** ....**DO NOT ALLOW** $-CH_3CH_2$
		iii	(Z-)pent-2-ene ✓	1	**DO NOT ALLOW** trans-pent-2-ene **Examiner's Comments** Most candidates were able to draw the structural isomer of compound A and provide a suitable name.
			Total	**10**	
11			Acid ✓	1	**ALLOW** H^+ / named mineral acid / H_2SO_4 / H_3PO_4 **DO NOT ALLOW** 'weak acid' e.g. ethanoic acid **IGNORE** pressure **IGNORE** temperature **Examiner's Comments**

					This question was answered well and the majority of candidates identified a suitable catalyst for the hydration of an alkene. A common incorrect response was nickel.
			Total	**1**	
12	a		 **First mark** diagram on left with p-orbitals labelled **OR** unlabelled diagram **AND** the statement: (sideways) overlap of p orbitals ✓ **Second mark** (labelled) diagram on right showing π-bond ✓	2	**Note**: A diagram is required for **each** mark **DO NOT ALLOW** C=C in one diagram but **ALLOW ECF** for subsequent use in another diagram. The bonds shown in the diagram are **required** **ALLOW ECF** for missing bonds in second diagram **IGNORE** any atoms joined to the bonds **ALLOW** a diagram where the p-orbitals are linked for second mark.  e.g. **Examiner's Comments** Most candidates produced reasonable diagrams to illustrate the formation of a π-bond. A common mistake was showing a C=C group rather a C—C bond in the centre of each structure. Omission of the peripheral bonds was also frequently seen. Although over half of the cohort received some credit in this part it was clear that many candidates found this question difficult. Only the most able scored both marks.
	b	i	Curly arrow from double bond to Br of Br–Br ✓	4	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** Curly arrow **must** start from bond and go to correct atom

			Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond ✓  -- Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation ✓  -- Correct product: ✓  		**DO NOT ALLOW** any other partial charges e.g. shown on double bond **ALLOW** carbocation on terminal CH_2  **DO NOT ALLOW** δ+ on C of carbocation. Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **Examiner's Comments** There were many excellent attempts at this mechanism and it is clearly well understood by candidates at this level. Consequently the majority of candidates scored three or four marks. In some cases the placement of the curly arrow from the C=C group was the cause for a candidate to only score three marks. Curly arrows should be drawn accurately. Where an arrow is expected to come from a bond, candidates are encouraged to start the arrow touching the bond.
		ii	Electrophilic addition ✓	1	<u>**Examiner's Comments**</u> The name of this mechanism was also well known by most candidates.
	c	i	H_2 **AND** Ni (catalyst) ✓	1	**ALLOW** name or formula for each **IGNORE** any stated

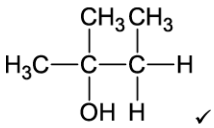
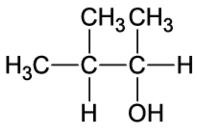
					temperature and pressure **Examiner's Comments** To score the mark in this question candidates had to state that both hydrogen and nickel were required for step 1. It was often the case that only one of these was stated. Although hydrogen was often seen as a reagent it was common to see an incorrect catalyst, such as H_2SO_4.
		ii	(Initiation) $Cl_2 \rightarrow 2Cl$ **AND** UV ✓ (Propagation) $C_3H_7Br + Cl \rightarrow C_3H_6Br + HCl$ ✓ $C_3H_6Br + Cl_2 \rightarrow C_3H_6BrCl + Cl$ ✓ (Termination) Two from the three termination equations below ✓ $2Cl \rightarrow Cl_2$ $C_3H_6Br + Cl \rightarrow C_3H_6BrCl$ $2C_3H_6Br \rightarrow C_6H_{12}Br_2$ names of steps initiation, propagation and termination linked to one correct equation for each step in this mechanism✓	5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** any ECF in this question **IGNORE** references to temperature **THROUGHOUT, ALLOW** correct molecular formulae **OR** structural **OR** displayed **OR** skeletal **OR** mixture of the above **IGNORE** dots **IGNORE** state symbols **IGNORE** one incorrect termination equation **Examiner's Comments** This question required candidates to apply their knowledge of the radical substitution mechanism to form a bromochloroalkane. Examiners were encouraged by the number of excellent attempts and it is clear that candidates had prepared well for this type of question. Consequently most candidates scored four or five marks. A common reason for a candidate only scoring four marks was the omission of UV radiation as an essential condition.

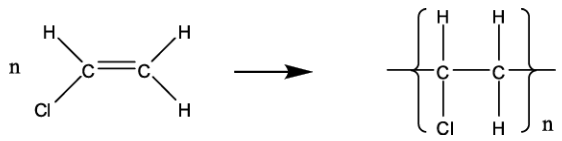
		iii	further substitution **OR** produces different termination products **OR** More than one termination step✓ substitution at different positions along chain ✓	2	**IGNORE** mixture of organic products (*in question*) **ALLOW** dichloro / multichloro / dibromo / multibromo compounds formed **OR** an example of a further substitution product **OR** an example of a different termination product **ALLOW** more than one hydrogen (atom) can be replaced **ALLOW** radicals react with each other to form other products **ALLOW** forms different structural isomers **ALLOW** a hydrogen (atom) on a different carbon (atom) can be replaced **Examiner's Comments** Candidates often found it difficult to provide clearly written explanations for this question. The majorly of responses focused on further substitution or the idea of different termination steps. Only the best candidates recognised that chlorination of 1-bromopropane would produce a mixture of structural isomers.
			Total	**15**	
13	a		**B** ✓	1	**ALLOW** CF_2CF_2 **OR** C_2F_4 **OR** tetrafluoroethene **Examiner's Comments** The majority of candidates were able to identify **B** as the monomer required to make PTFE.
	b	i	 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal **OR** mixture of the above **ALLOW** *E* isomer

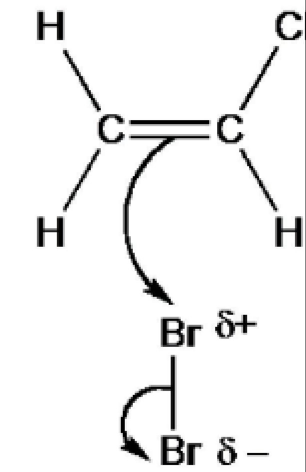
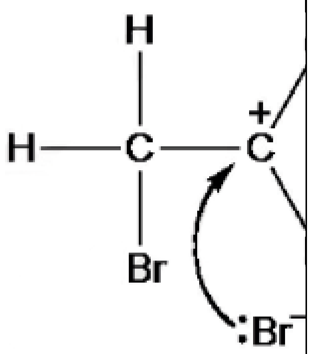
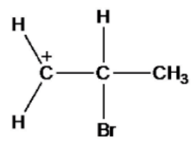
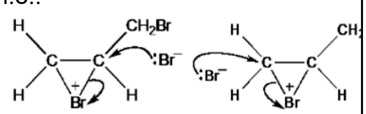
					 **Examiner's Comments** The monomer of polymer **H** was correctly identified by the majority of the cohort. However, a small proportion of candidates simply drew the repeat unit of **H**.
		ii	HCL ✓	1	**DO NOT ALLOW** Cl_2 **IGNORE** names **IGNORE** nitrogen oxides / NO_x **Examiner's Comments** Most candidate were able to provide the formula of HC*l*. Common incorrect answers included C*l*O and C*l*$_2$.
			Total	**3**	
14	a		 ✓	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **DO NOT ALLOW** molecular formula **ALLOW** dichloro or diiodo compound instead of the dibromo compound as the **only** alternatives. **Examiner's Comments** This question required candidates to interpret the reaction scheme and suggest an intermediate compound that could be formed from 2-methylbut-2-ene that could be also hydrolysed to give the diol shown. The most able candidates demonstrated their understanding of this scheme and often suggested the correct dihalo compound. Most candidate favoured the dibromo compound however some chose to show the dichloro or diiodo compound. All of these responses received credit.

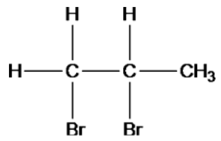
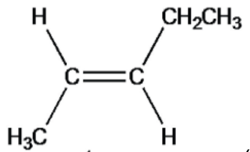
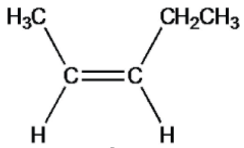
					A large proportion of structures suggested were obtainable from 2-methylbut-2-ene but could not be hydrolysed. These included the products of hydrogenation e.g. 2-methylbutane, or hydration e.g. 2-methylbutan-2-ol. Consequently only the most able candidates achieved a mark in part (b), as this was essentially dependant on part (a).
	b		Reagent **A**: correct halogen✓ e.g. Br_2 / bromine	1	**ALLOW** Cl_2 if dichloro compound drawn **ALLOW** I_2 if diiodo compound drawn **IGNORE** state symbols Answer must match box from **(a)** to score **Examiner's Comments** This question required candidates to interpret the reaction scheme and suggest an intermediate compound that could be formed from 2-methylbut-2-ene that could be also hydrolysed to give the diol shown. The most able candidates demonstrated their understanding of this scheme and often suggested the correct dihalo compound. Most candidate favoured the dibromo compound however some chose to show the dichloro or diiodo compound. All of these responses received credit. A large proportion of structures suggested were obtainable from 2-methylbut-2-ene but could not be hydrolysed. These included the products of hydrogenation e.g. 2-methylbutane, or hydration e.g. 2-methylbutan-2-ol. Consequently only the most able candidates achieved a

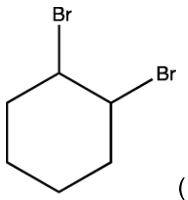
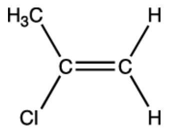
					mark in part (b), as this was essentially dependant on part (a).
	c	i	Steam **AND** acid catalyst ✓	1	**ALLOW** H^+ / named acid / H_2SO_4 / H_3PO_4 **ALLOW** $H_2O(g)$ **ALLOW** water only if a temperature of 100 °C or above is quoted. **IGNORE** any temperature given with steam **IGNORE** pressure **Examiner's Comments** One would expect the majority of candidates to do well in a question which required them to state the reagents and conditions required for the hydration of alkenes; however this was not the case. The most able candidates provided accurate responses which referred to both steam and the acid catalyst, which was often shown to be H_3PO_4. Other candidates stated only one of the two required responses and it was common to see the acid catalyst stated alongside a temperature and pressure but with no reference to steam. Some candidates stated the reagent as H_2O instead of steam and this was allowed if accompanied by a temperature of over 100 °C. Candidates should be encouraged to learn reagents and conditions required for organic reactions.
		ii	(compounds or molecules) having the same molecular formula but different structural formulae ✓	1	**ALLOW** different structure **OR** different displayed formula **OR** different skeletal formula for structure Same formula is **not** sufficient Different arrangement of atoms is **not** sufficient **Examiner's Comments**

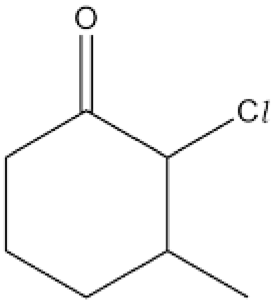
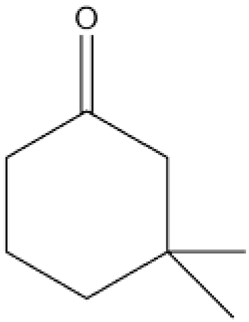
					The majority of candidates were able to explain the term structural isomers.
		iii	 ✓  ✓	2	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above **ALLOW** any vertical bond to OH **DO NOT ALLOW** OH− **Examiner's Comments** Many candidates found this question difficult and a large number of candidates showed structures of alcohols with the molecular formula $C_5H_{12}O$, but that could not be formed from 2-methylbut-2-ene. Examples of these incorrect responses included 2-methylbutan-1-ol, pentan-1- ol, pentan-2-ol and pentan-3-ol. Only the most able could show the structures of both alcohols produced by the hydration of 2-methlybut-2-ene. Candidates should be reminded to check that any structures they suggest are consistent with the context of the question.
		iv	Does not contain OH group(s) **OR** does not contain hydroxyl group(s) **OR** is not an alcohol ✓ Does not form hydrogen bonds with water ✓	2	**ALLOW ORA** throughout **DO NOT ALLOW** OH^- (ions) / hydroxide (ions) 'Does not form hydrogen bonds' is **not** sufficient **Examiner's Comments** The majority of candidates were able to recognise that the key to the solubility of the isomers in water is that they contain the OH group whereas 2-methylbut-2-ene does not. Most candidates scored the second mark by accurately explaining that the OH group could form hydrogen bonds with water.
			Total	**8**	

15	a		 Correct polymer with side links ✓ Balanced equation for formation of correct polymer - correct use of *n* in the equation and brackets ✓	2	**Displayed formulae MUST be used to award each mark** *n* on LHS can be at any height to the left of formula **AND** *n* on the RHS must be a subscript (essentially below the side link) **Examiner's Comments** The majority of candidates were able to show the displayed formula for the correct polymer. Surprisingly, many candidates failed to score the second mark because they did not consider balancing the equation on the left-hand side by inserting an *n* before the chloroethene monomer.
	b	i	$CH_2CHCl + 2O_2 \rightarrow CO + CO_2 + HCl + H_2O$ ✓	1	**ALLOW** any other correctly balanced equation with the same reactants and products **ALLOW** C_2H_3Cl for CH_2CHCl **Examiner's Comments** The stronger candidates were able identify that the other non-toxic product was water and therefore could to provide a suitable equation for this unfamiliar question. A significant number of candidates found this question difficult and it was common to see equations where hydrogen had been stated as the other product. A smaller proportion of candidates attempted to balance the equation using only the three products stated in the question.
		ii	Sodium hydrogencarbonate neutralises HCl ✓	1	**Assume that 'it' refers to sodium hydrogencarbonate but** **DO NOT ALLOW** other chemicals e.g. sodium **ALLOW** $NaHCO_3$ is a base **ALLOW** forms a salt or sodium

					chloride or NaCl **ALLOW** equation to show formation of NaCl from $NaHCO_3$ and HCl even if not balanced. **IGNORE** reacts **Examiner's Comments** The examiners expected candidates to recognise that sodium hydrogencarbonate would neutralise the acidic gas and most candidates communicated this well. Responses such as 'sodium hydrogencarbonate is a base' and '$NaHCO_3$ forms a salt' were accepted. Weaker candidates often used less precise language and responses such as '$NaHCO_3$ reacts with the HCl' did not receive credit.
			Total	**4**	
16	a	i	Curly arrow from double bond to Br of Br–Br (1) Correct dipole shown on Br–Br **AND** curly arrow showing breaking of Br–Br bond (1)  Correct carbocation with + charge on C with 3 bonds **AND** curly arrow from Br^- to C^+ of carbocation (1)  Correct product: (1)	4	Curly arrow must start from bond and go to correct atom **do not allow** partial charges on C=C bond **allow** carbocation on terminal CH_2  **do not allow** δ+ on C of carbocation Curly arrow must come from a lone pair on Br^- **OR** from the negative sign of Br^- ion (then lone pair on Br^- ion does not need to be shown) **allow** formation of bromonium intermediate and curly arrows, i.e.: 

					
		ii	Movement of a pair of electrons	1	**allow** movement of a lone pair
	b	i	One of the carbons of the C=C has two of the same groups attached / has two hydrogen atoms attached (so it can't show 2 different stereoisomers)	1	**allow** a stereoisomer must have 2 different groups attached to each carbon of the C=C double bond
		ii	1 mark each correct DIAGRAM  *trans* (1)  *cis* (1)	2	**allow** correct skeletal **OR** displayed formula **OR** mixture **but** must clearly show arrangement around C=C
	c		*E* isomer **AND** F takes priority over the carbon on the left hand side (as it has a higher atomic number) **AND** CH_2OH takes priority over the CH_3 group on the right hand side	1	*E* with no explanation is insufficient
			Total	**9**	
17	a		Aliphatic = E, H, I, J (1) Alicyclic = E, H, J (1) Aromatic = F, G (1)	3	
	b		C_nH_{2n+1}	1	**do not allow** C_nH_{2n}+ 1
	c	i	*Equation:* $C_6H_{12}O \rightarrow C_6H_{10} + H_2O$ (1) *Calculation:* **FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 32.7 (%) award 3 marks theoretical yield = 7.65 / 100 = 0.0765 (mol) (1) actual yield = 2.05 / 82 = 0.025 (mol) (1) % yield = (0.025 / 0.0765) × 100% = 32.7(%) (1)	4	**ignore** state symbols **allow** $C_6H_{11}OH$ for $C_6H_{12}O$ **If there is an alternative answer, check to see if there is any ECF credit possible using working below** % yield **must** be to 1 dp **allow** theoretical and actual yield calculated in mass theoretical yield = 0.0765 × 82 = 6.273 g % yield = (2.05 / 6.273) = 32.7(%)

					allow ecf from calculated actual and theoretical yields
		ii	bromine water is decolourised (1)  (1)	2	**allow** bromine water turns colourless **ignore** 'goes clear' **allow** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above
			Total	**10**	
18		i	Structure of 2-chloropropene 	1	**allow** any unambiguous structure **allow** $CH_3CCl = CH_2$ (Double bond must be shown)
		ii	HC*l* gas is passed through alkali / carbonate	1	
		iii	Reduces the dependency on finite resources **OR** Biodegradable **OR** Photodegradable	1	**allow** crude oil **OR** petroleum **OR** fossil fuels for 'finite resources' **allow** 'rots naturally'
			Total	**3**	
19		i	phosphoric acid / H_3PO_4	1	if both name and formula are given, the formula must be correct, but **allow** minor errors in an attempt at the name
		ii	(allows the reaction to proceed via a route with) lower activation energy … (1) … so that a greater proportion of molecules exceed the activation energy (1)	2	**allow** a sketch of an energy profile diagram as long as the catalysed and uncatalysed E_a are both labelled **allow** 'more molecules exceed the activation energy' **allow** a sketch of a Boltzmann distribution as long as both axes and both E_a values are labelled
			Total	**3**	
20		i		2	**allow** any unambiguous structure or formula. **allow ecf** on the second structure for hydrogen atom errors if candidate tries to convert to a displayed / structural formula, but the

			 (1)  (1)		carbon skeleton must be correct.
		ii	correct structure of either possible carbocation intermediate shown (1) the tertiary halogenoalkane (which will be labelled as either product 1 or product 2) is identified as the one formed in greater amounts … because the carbocation more stable on C3 than C2 *owtte* (1)	2	If both carbocations are drawn, only one needs to be correct to score the mark. **allow ecf** from **(i)** for correct justification of product formed in greater amount based on incorrect structures.
		iii	*Amount of **D** that reacts* M(**D**: $C_7H_{16}O$) = 110 (g mol^{-1}) **AND** $n(C_7H_{16}O) = \frac{4.125}{110} = 0.0375$ (mol) (1) *Masses of two products formed* M(product: $C_7H_{17}OCl$) = 146.5 (g mol^{-1}) **AND** Mass of 95% product = $0.0375 \times \frac{95}{100} \times 146.5 = 5.22$ g **AND** Mass of 5% product = $0.0375 \times \frac{5}{100} \times 146.5 = 0.27$ g (1)	2	**allow** mass of both products = 0.0375 × 146.5 = 5.49 g Mass of 95% product = $\frac{95}{100} \times 5.49 =$ Mass of 5% product = $\frac{5}{100} \times 5.49 =$ **allow** 'product 1' and 'product 2' if linked to **correct** mass given labelling in **(i)** and reasoning in **(ii)** (**allow ecf** from **(ii)**).
			Total	**6**	