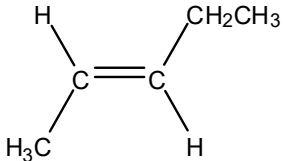
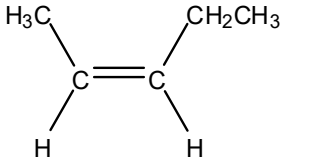
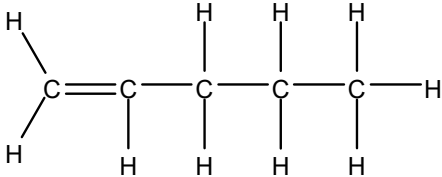
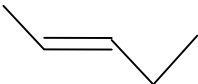
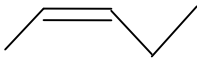
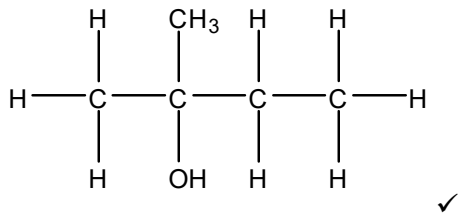


Question		er	Marks	Guidance
1	(a)	Only one (desired) product formed ✓	1	ALLOW no waste products OR no co-product OR all atoms on left hand side are in the desired product OR sulfuric acid is the only product IGNORE it is an addition reaction
	(b)	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 94% award 3 marks Moles of sulfur reacted or theoretical moles of H ₂ SO ₄ = 1.60 × 10 ⁶ ✓ Actual moles of H ₂ SO ₄ = 1.50 × 10 ⁶ ✓ % yield = 94 ✓	3	IF there is an alternative answer, check to see if there is any ECF credit possible using working below ALLOW 1.6 × 10 ⁶ to the calculator value 1.601246106 × 10 ⁶ correctly rounded ALLOW 1.60 up to calculator value 1.601246106 correctly rounded ALLOW 1.5 × 10 ⁶ to the calculator value 1.498470948 × 10 ⁶ correctly rounded ALLOW 1.5 up to calculator value 1.498470948 correctly rounded ALLOW theoretical mass of H ₂ SO ₄ = 157 (tonnes) up to the calculator value of 157.0822430 correctly rounded for two marks ALLOW ECF for a percentage yield from wrong moles above but answer must have two significant figures
	(c) (i)	Position of equilibrium – unchanged ✓ Rate of backward reaction – decreases ✓	2	

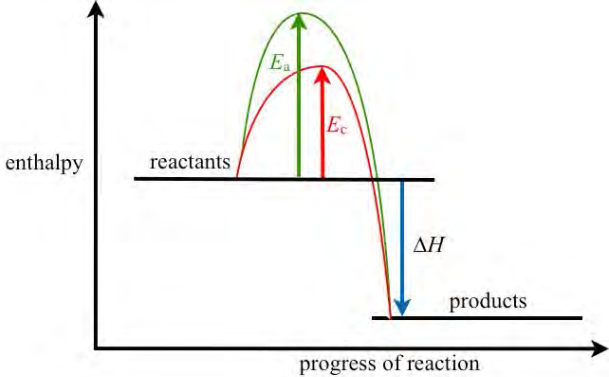
Question		er	Marks	Guidance
(c)	(i)	<p>(equilibrium position shifts) to the left because (forward) reaction is exothermic OR (equilibrium position shifts) to the left because reverse reaction is endothermic ✓</p>	1	<p>Both position of equilibrium AND explanation needed for one mark</p> <p>Note: ALLOW suitable alternatives for 'to left', e.g. towards SO₂ or O₂ / towards reactants OR in backward direction OR in reverse direction OR decreases yield of SO₃/products ALLOW 'favours the left', as alternative for 'shifts equilibrium to left' ALLOW reaction gives out heat for exothermic ALLOW reaction takes in heat for endothermic ALLOW moves to the left in the endothermic direction</p> <p>ALLOW ORA if specified IGNORE responses in terms of rate</p>
	(iii)	<p>(equilibrium position shifts) to the left because there are more moles (of gas) on the reactant side OR (equilibrium position shifts) to the left because there are fewer moles (of gas) on product side ✓</p>	1	<p>Both position of equilibrium AND explanation needed for one mark</p> <p>Note: ALLOW suitable alternatives for 'to left', e.g.: towards SO₂ or O₂ / towards reactants OR in backward direction OR in reverse direction OR decreases yield of SO₃/products ALLOW 'favours the left', as alternative for 'shifts equilibrium to left' ALLOW correct reference to volume of gases e.g. shifts to the left because there is a smaller volume of gas on the product side ALLOW ORA if specified IGNORE responses in terms of rate</p>

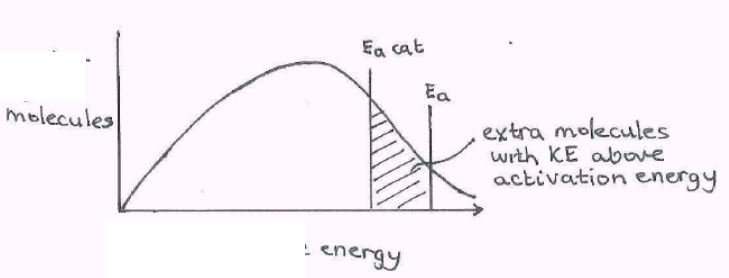
Question	er	Marks	Guidance
(d) (<p>Correct structure ✓</p> $ \begin{array}{cccc} \text{H} & \text{H} & \text{CH}_3 & \text{H} \\ & & & \\ \text{H}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $ <p>OR</p> $ \begin{array}{cccc} \text{H} & \text{CH}_3 & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $ <p>OR</p> $ \begin{array}{ccc} \text{H} & \text{CH}_3 & \text{H} \\ & & \\ \text{H}-\text{C} & -\text{C} & -\text{C}-\text{OH} \\ & & \\ \text{H} & \text{CH}_3 & \text{H} \end{array} $	1	<p>ALLOW correct structural OR displayed OR skeletal formula OR mixture of the above (as long as unambiguous)</p> <p>ALLOW bonds going to any part of the CH₃, CH₂ and CH bonds</p> <p>ALLOW vertical 'bond' to any part of the OH group DO NOT ALLOW horizontal -HO in the formula</p> <p>ALLOW as a slip one stick with no H on in a displayed formula</p> <p>IGNORE name</p>

Question		er	Marks	Guidance
(d)	(ii)	<p>Correct structure for L ✓</p>  <p>Correct structure for M ✓</p>  <p>Correct structure for N ✓</p> 	3	<p>ALLOW correct structural OR displayed OR skeletal formula OR mixture of the above (as long as unambiguous) for L, M and N</p> <p>e.g.</p>  <p>L or M</p>  <p>L or M</p> <p>N – CH₂CHCH₂CH₂CH₃</p> <p>Answers to L and M are interchangeable</p> <p>IGNORE <i>cis/trans</i> OR <i>E/Z</i> labels</p> <p>ALLOW as a slip one stick with no H on in a displayed formula</p> <p>ALLOW 2 marks if three correct structures are drawn but some are in the wrong boxes</p> <p>ALLOW 1 mark if two correct structures are drawn but in the wrong boxes</p>

Question		er	Marks	Guidance
(d)	(ii)		1	<p>ALLOW correct structural OR displayed OR skeletal formula OR mixture of the above (as long as unambiguous)</p> <p>ALLOW vertical 'bond' to any part of the OH group DO NOT ALLOW horizontal –HO in the formula</p> <p>ALLOW as a slip one stick with no H on in a displayed formula</p>
Total			13	

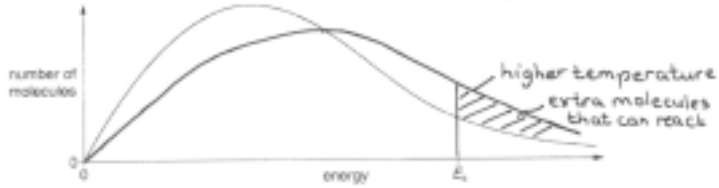
Question			Answer	Mark	Guidance
2	(a)	(i)	$\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2 \checkmark$ $\text{ClO} + \text{O} \rightarrow \text{Cl} + \text{O}_2 \checkmark$	2	ALLOW any correct multiples ALLOW $\text{ClO} + \text{O}_3 \rightarrow 2\text{O}_2 + \text{Cl}$ IGNORE state symbols and dots
		(ii)	$\text{O}_3 + \text{O} \rightarrow 2\text{O}_2 \checkmark$	1	ALLOW any correct multiple ALLOW $2\text{O}_3 \rightarrow 3\text{O}_2$ IGNORE state symbols and dots
	(b)		Adsorption of reactants OR NO and CO attached to surface \checkmark Bonds weaken in reactants \checkmark Chemical reaction OR rearrangement of electrons \checkmark Desorption \checkmark	4	ANNOTATE WITH TICKS AND CROSSES ALLOW CO and NO (weakly) bonded to surface OR reactants bond to surface OR CO and NO form temporary bonds with the catalyst DO NOT ALLOW absorption ALLOW bonds weaken in NO OR bonds weaken in CO OR activation energy is lowered ALLOW bonds break and new bonds made in product OR N_2 and CO_2 made ALLOW products leave the surface OR N_2 and CO_2 no longer bonded to surface ALLOW desorption ALLOW desorption if absorption given at start of answer

Question	Answer	Mark	Guidance
(c)	<p>one activation energy labelled on enthalpy profile diagram ✓</p> <p>idea that activation energy is lowered ✓</p> <p>catalyst has a different reaction pathway OR different reaction mechanism OR two curves drawn on profile ✓</p> <p>QWC – correct diagram of reaction profile for endothermic or exothermic reaction with products and reactants at different heights – y axis labelled as energy or enthalpy ✓</p>		<p>ANNOTATE WITH TICKS AND CROSSES</p> <p>ALLOW double headed arrows on the activation energy label ALLOW vertical line with no arrows DO NOT ALLOW arrow just pointing downwards Be generous with respect to the position of the line and the maximum of the curve</p> <p>marks can be awarded via, reaction profile, in words or from Boltzmann</p> <p>IGNORE any enthalpy change label drawn</p>  <p>IGNORE missing progress of reaction</p>

Question	Answer	Mark	Guidance
(c)	<p>Drawing of Boltzmann distribution AND axes labelled (number of) molecules and energy ✓</p> <p>More molecules with energy above activation energy with a catalyst OR More molecules that overcome the activation energy ✓</p> <p>More effective collisions OR more successful collisions ✓</p>	7	<p>Boltzmann distribution - must start at origin and must not end up at 0 on y-axis ie must not touch x-axis. DO NOT ALLOW Boltzmann mark if two distributions are drawn one for non-catalysed and one for catalysed</p> <p>ALLOW particles instead of molecules</p> <p>DO NOT ALLOW atoms instead of particles</p>  <p>DO NOT ALLOW more molecules have sufficient energy to react</p>

Question	Answer	Mark	Guidance
(d)	<p>ANY FOUR FROM Enable reactions to occur with less waste OR enable reactions to take place with higher atom economy OR fewer undesired products ✓</p> <p>Enable reactions to happen with less toxic solvents/reactants OR enable reactions to produce less toxic waste/side products ✓</p> <p>Reactions can happen at room temperature OR reactions can happen at atmospheric pressure OR reactions can happen at a lower pressure OR reactions can happen at a lower temperature ✓</p> <p>Saves energy (costs) ✓</p> <p>Reduce carbon dioxide emissions OR reduces amount of fuel burnt OR reduces greenhouse gas emissions ✓</p> <p>Enable reactions to occur with more specificity OR enable reactions to produce correct stereoisomer ✓</p>	4	<p>ANNOTATE WITH TICKS AND CROSSES</p> <p>ALLOW make less hazardous waste ALLOW corrosive, poisonous, harmful, hazardous as alternative to toxic DO NOT ALLOW does not harm the environment IGNORE dangerous</p> <p>IGNORE less expensive IGNORE reduces activation energy</p> <p>IGNORE less pollution</p>
Total		18	

Question			Expected Answers	Marks	Additional Guidance
3	(a)	(i)	$2\text{H}_2\text{O}_2 \longrightarrow 2\text{H}_2\text{O} + \text{O}_2$ ✓	1	ALLOW any correct multiple including fractions IGNORE state symbols
		(ii)	More crowded particles OR more particles per (unit) volume ✓ more collisions per second OR more frequent collisions ✓	2	ALLOW particles are closer together DO NOT ALLOW 'area' instead of 'volume' IGNORE 'more concentrated particles' ALLOW collisions more often OR increased rate of collision OR collisions are more likely OR there is a greater chance of collisions 'More collisions' is not sufficient
		(iii)	Any two from the following: Reaction takes alternative route ✓ Activation energy is lowered ✓ More molecules have energy above activation energy OR more molecules have enough energy to react ✓	2	ALLOW catalyst changes reaction mechanism ALLOW an alternative approach using adsorption particles adsorbed onto surface ✓ so bonds weakened as a result of the adsorption ✓

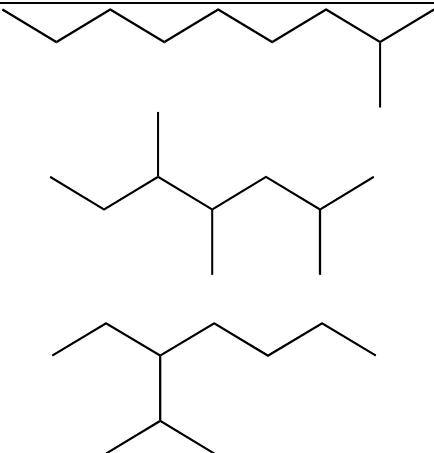
Question		Expected Answers	Marks	Additional Guidance
	(iv)	<p>Correct curve for higher temperature ✓</p> <p>Activation energy does not change OR clearly labelled on diagram, e.g. E_a OR E ✓</p> <p>More molecules have energy above activation energy OR more molecules have enough energy to react ✓</p>	3	<p>maximum of curve to right AND lower than maximum of original curve AND above dotted line at higher energy as shown in diagram below</p> <p>IGNORE minor point of inflexion of curve</p>  <p>Note that the diagram above would score all 3 marks</p> <p>More successful collisions is not sufficient</p>
(b)	(i)	<p>$\frac{34.0}{267.4} \times 100$ 267.4 ✓</p> <p>12.7% ✓</p>	2	<p>First mark for 267.4 OR (34.0 + 233.4) OR (169.3 + 98.1) at bottom of fraction with or without $\times 100$</p> <p>ALLOW from 2 sig figs up to calculator value ALLOW full marks for 13 OR 12.7 OR 12.72 OR 12.715 up to calculator value with no working out 12.71 scores one mark only NO ECF for this part from incorrect numbers in first expression</p>

Question		Expected Answers	Marks	Additional Guidance
	(ii)	<p>Any three from the following:</p> <p>Oxygen comes from air ✓</p> <p>No poisonous materials formed OR no poisonous materials involved ✓</p> <p>No waste products formed OR atom economy is 100% ✓</p> <p>Anthraquinone is regenerated OR recycled OR used again OR Anthraquinone acts as a catalyst ✓</p>	3	<p>IGNORE hydrogen comes from the air</p> <p>IGNORE harmful</p> <p>ALLOW higher atom economy</p>
	(c)	<p>Bond breaking absorbs energy AND bond making releases energy ✓</p> <p>More energy released than absorbed ✓</p>	2	<p>ALLOW bond breaking is endothermic AND bond making is exothermic</p> <p>ALLOW exothermic change transfers more energy than endothermic change OR bond making transfers more energy than bond breaking OR '(the sum of the) bond enthalpies in the products is greater than the (sum of the) bond enthalpies in the reactants' OR '(the sum of the) bond enthalpies of the bonds made is greater than (the sum of) the bond enthalpies of the bonds broken'</p> <p>IGNORE reference to strong and weak bonds</p> <p>IGNORE enthalpy of products is less than enthalpy of reactants</p>
Total			15	

Question		Expected Answers	Marks	Additional Guidance
4	(a)	Cracking ✓	1	ALLOW catalytic or thermal cracking ✓
	(b)	(i)	1	ALLOW correct formula if no name given: e.g. H ₃ PO ₄ OR H ₂ SO ₄ OR H ⁺ ✓ ALLOW correct name of acid even if an incorrect formula is used IGNORE heterogeneous OR homogeneous
		(ii)	1	DO NOT ALLOW 'reaction shifts' The idea of a shift in equilibrium is essential
		(iii)	3	One mark for conditions. This mark is independent of the reasons for conditions One mark for reason for the chosen temperature One mark for reason for the chosen pressure ALLOW fewer moles of products
		(iv)	3	
	(c)	Propene ✓	1	ALLOW prop-1-ene ✓ DO NOT ALLOW prop-2-ene
	(d)	(i)	1	
		(ii)	1	ALLOW correct formula of or named carbonate OR alkali OR base Correct name and wrong formula does not score

Question	Expected Answers	Marks	Additional Guidance
(e)	<p>Any two marks from the following:</p> <p>Develop photodegradable polymers ✓</p> <p>Develop biodegradable polymers OR develop compostable polymers ✓</p> <p>Develop techniques for cracking polymers OR develop use as a chemical feedstock ✓</p> <p>Develop ways of making polymers from plant-based substances OR reduce the need to use finite raw materials such as crude oil ✓</p> <p>Designing processes with high atom economy OR reduce waste products during manufacture ✓</p> <p>Develop ways of sorting AND recycling polymers ✓</p>	2	
	Total	14	

Question		Expected Answers	Marks	Additional Guidance
5	(a)	Fractional distillation ✓ Because fractions have different boiling points ✓	2	DO NOT ALLOW just 'distillation' For fractions, ALLOW components OR hydrocarbons OR compounds ALLOW condense at different temperatures ALLOW because van der Waals' forces differ between molecules IGNORE reference to melting points IGNORE 'crude oil' OR 'mixture' has different boiling points' but ALLOW 'separates crude oil by boiling points
	(b) (i)	Decane ✓	1	DO NOT ALLOW deceane
	(ii)	Skeletal formula of branched C ₁₀ H ₂₂ ✓	1	Formula must be skeletal AND must not include any symbol, e.g. CH ₃ Any possible skeletal formulae e.g.

Question			Expected Answers	Marks	Additional Guidance
					
		(iii)	<p>Decane has more surface contact OR branched chains have less surface contact ✓</p> <p>Decane has more van der Waals' forces OR branched chains have fewer van der Waals' forces ✓</p>	2	<p>Both answers need to be comparisons Assume 'it' refers to decane IGNORE surface area ALLOW straight chains can get closer together OR branched chains cannot get as close to one another IGNORE branched chain are more compact</p> <p>ALLOW Decane has stronger van der Waals' forces OR branched chains have weaker van der Waals' forces</p> <p>More intermolecular forces is not sufficient</p>
		(iv)	<p>Branched chains have more efficient combustion OR decane has less efficient combustion ✓</p>	1	<p>ALLOW branched chains are easier to burn OR easier to combust OR burn better OR more efficient fuel OR less likely to produce pre-ignition or knocking OR increases octane rating</p> <p>ALLOW ORA for decane</p>

Question			Expected Answers	Marks	Additional Guidance
					Better fuel is NOT sufficient Burns more cleanly is NOT sufficient
	(c)	(i)	$\text{C}_{10}\text{H}_{22} + 15\frac{1}{2}\text{O}_2 \longrightarrow 10\text{CO}_2 + 11\text{H}_2\text{O}$ <p>All four species correct ✓</p> <p>balancing of four correct species ✓</p>	2	ALLOW any correct multiple IGNORE state symbols
		(ii)	$\text{N}_2 + \text{O}_2 \longrightarrow 2\text{NO} \quad \checkmark$	1	ALLOW any correct multiple including fractions IGNORE state symbols The mark is for the equation IGNORE writing

	(d)	(i)	Species with an unpaired electron ✓	1	<p>ALLOW atom, molecule or particle with an unpaired electron ALLOW 'has an unpaired electron' ALLOW particle formed by homolytic fission</p> <p>DO NOT ALLOW particle with a single electron OR particle with a free electron</p>
		(ii)	catalyst ✓	1	
		(iii)	<p>$O + O_2 \longrightarrow O_3$ OR O reacts with O_2 to make ozone OR the reaction is reversible ✓</p> <p>Rate of formation of ozone is the same as rate of decomposition ✓</p>	2	<p>ALLOW $O_2 + O \rightleftharpoons O_3$ OR $O_3 \rightleftharpoons O_2 + O$ ✓✓</p> <p>ALLOW is in equilibrium OR \rightleftharpoons in correct equation OR has steady state condition ✓</p> <p>IGNORE other equations involving ozone</p>
		(iv)	absorbs (harmful) UV ✓	1	<p>ALLOW 'keeps out UV' OR 'filters UV'</p> <p>ALLOW increased UV could cause skin cancer OR increased UV could cause cataracts OR increased UV could cause mutation of crops ✓</p> <p>IGNORE gamma</p>
			Total	15	