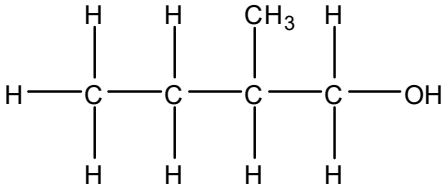
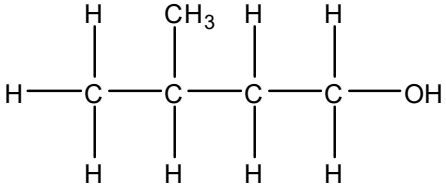
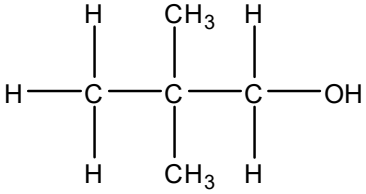
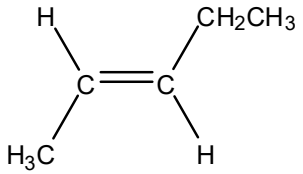
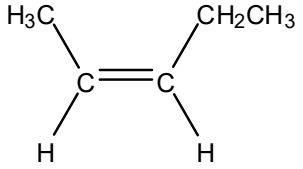
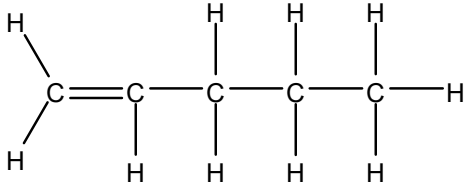
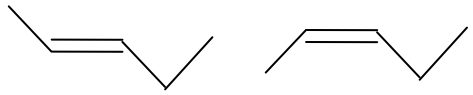
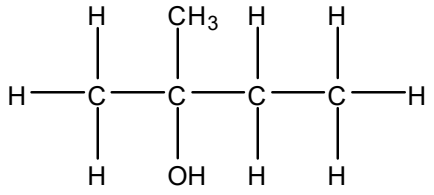
Question			er	Marks	Guidance
1	(a)		Only one (desired) product formed ✓	1	**ALLOW** no waste products **OR** no co-product **OR** all atoms on left hand side are in the desired product **OR** sulfuric acid is the only product **IGNORE** it is an addition reaction
	(b)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = 94% award 3 marks** Moles of sulfur reacted or theoretical moles of H_2SO_4 = 1.60×10^6 ✓ Actual moles of H_2SO_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_2SO_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	

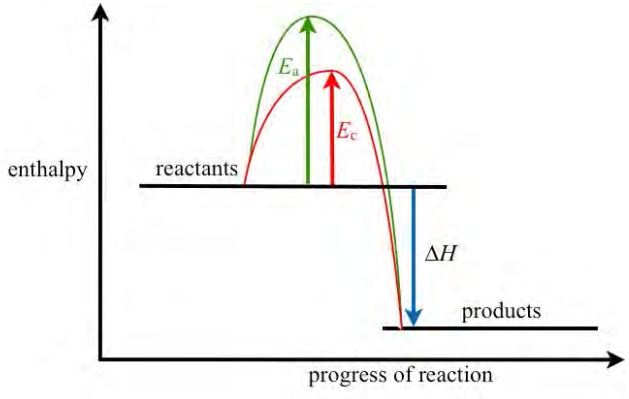
Question			er	Marks	Guidance
	(c)	(i	(equilibrium position shifts) to the left **because** (forward) reaction is exothermic **OR** equilibrium position shifts) to the left **because reverse** reaction is endothermic ✓	1	Both position of equilibrium **AND** explanation needed for one mark **Note: ALLOW** suitable alternatives for 'to left', e.g. towards SO_2 or O_2 / towards reactants **OR** in backward direction **OR** in reverse direction **OR** decreases yield of SO_3/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 **ALLOW ORA** if specified **IGNORE** responses in terms of rate
		(iii)	(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 ✓	1	Both position of equilibrium **AND** explanation needed for one mark **Note: ALLOW** suitable alternatives for 'to left', e.g.: towards SO_2 or O_2 / towards reactants **OR** in backward direction **OR** in reverse direction **OR** decreases yield of SO_3/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

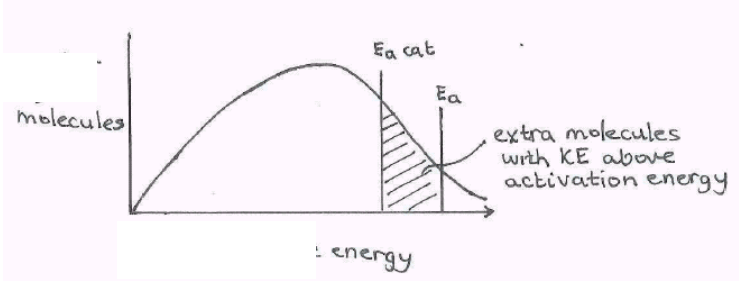
Question			er	Marks	Guidance
	(d)	(	Correct structure ✓  **OR**  **OR** 	1	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **ALLOW** bonds going to any part of the CH_3, CH_2 and CH bonds **ALLOW** vertical 'bond' to any part of the OH group **DO NOT ALLOW** horizontal –HO in the formula **ALLOW** as a slip one stick with no H on in a displayed formula **IGNORE** name

Question			er	Marks	Guidance
	(d)	(ii)	Correct structure for **L** ✓  Correct structure for **M** ✓  Correct structure for **N** ✓  	3	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) for **L**, **M** and **N** **e.g.**  **L or M** ***L or M*** **N –** $CH_2CHCH_2CH_2CH_3$ Answers to **L** and M are interchangeable **IGNORE** *cis*/*trans* **OR** *E*/*Z* labels **ALLOW** as a slip one stick with no H on in a displayed formula **ALLOW** 2 marks if three correct structures are drawn but some are in the wrong boxes **ALLOW** 1 mark if two correct structures are drawn but in the wrong boxes

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

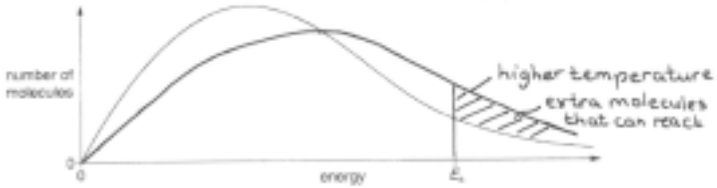
Question			Answer	Mark	Guidance
2	(a)	(i)	$Cl + O_3 \rightarrow ClO + O_2$ ✓ $ClO + O \rightarrow Cl + O_2$ ✓	2	**ALLOW** any correct multiples **ALLOW** $ClO + O_3 \rightarrow 2O_2 + Cl$ **IGNORE** state symbols and dots
		(ii)	$O_3 + O \rightarrow 2O_2$ ✓	1	**ALLOW** any correct multiple **ALLOW** $2O_3 \rightarrow 3O_2$ **IGNORE** state symbols and dots
	(b)		Adsorption of reactants **OR** NO and CO attached to surface ✓ Bonds weaken in reactants ✓ Chemical reaction **OR** rearrangement of electrons ✓ Desorption ✓	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** deadsorption **ALLOW** deabsorption if absorption given at start of answer

Question	Answer	Mark	Guidance
(c)	one activation energy labelled on enthalpy profile diagram ✓ idea that activation energy is lowered ✓ catalyst has a different reaction pathway **OR** different reaction mechanism **OR** two curves drawn on profile ✓ **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 ✓		**ANNOTATE WITH TICKS AND CROSSES** **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 marks can be awarded via, reaction profile, in words or from Boltzmann **IGNORE** any enthalpy change label drawn  **IGNORE** missing progress of reaction

Question			Answer	Mark	Guidance
	(c)		Drawing of Boltzmann distribution **AND** axes labelled (number of) molecules and energy ✓		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 **ALLOW** particles instead of molecules **DO NOT ALLOW** atoms instead of particles 
			More molecules with energy above activation energy with a catalyst **OR** More molecules that overcome the activation energy ✓ More effective collisions **OR** more successful collisions ✓	7	**DO NOT ALLOW** more molecules have sufficient energy to react

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

Question			Expected Answers	Marks	Additional Guidance
3	(a)	(i)	$2H_2O_2 \longrightarrow 2H_2O + O_2$ ✓	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 ✓

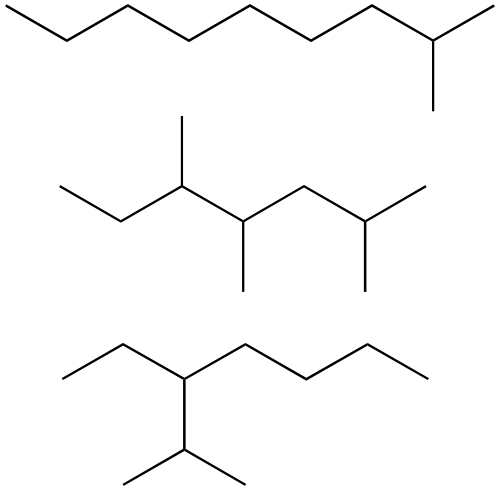
Question			Expected Answers	Marks	Additional Guidance
		(iv)	Correct curve for higher temperature ✓ Activation energy does not change **OR** clearly labelled on diagram, e.g. E_a **OR** E ✓ More molecules have energy above activation energy **OR** more molecules have enough energy to react ✓	**3**	maximum of curve to right **AND** lower than maximum of original curve **AND** above dotted line at higher energy as shown in diagram below **IGNORE** minor point of inflexion of curve  Note that the diagram above would score all 3 marks More successful collisions is **not** sufficient
	(b)	**(i)**	$\frac{34.0}{}$ × 100 **267.4** ✓ 12.7% ✓	**2**	First mark for 267.4 **OR** (34.0 + 233.4) **OR** (169.3 + 98.1) at **bottom** of fraction with or without × 100 **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

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

Question			Expected Answers	Marks	Additional Guidance
4	(a)		Cracking ✓	1	**ALLOW** catalytic or thermal cracking ✓
	(b)	(i)	Acid ✓	1	**ALLOW** correct formula if no name given: e.g. H_3PO_4 **OR** H_2SO_4 **OR** H^+ ✓ **ALLOW** correct name of acid even if an incorrect formula is used **IGNORE** heterogeneous **OR** homogeneous
		(ii)	The position of equilibrium will shift so as to minimise the effect of any change in conditions ✓	1	**DO NOT ALLOW** 'reaction shifts' The idea of a shift in equilibrium is essential
		(iii)	Low temperature **AND** high pressure ✓ Low temperature because the (forward) reaction is exothermic ✓ High pressure because there are fewer moles (of gas) on the right hand side ✓	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)	(60 atmosphere pressure is a) high pressure may be too expensive **OR** may cause safety problems ✓ (300 ºC is sufficiently high) to give a fast rate of reaction ✓ without shifting equilibrium to the left **OR** compromising equilibrium yield ✓	3	
	(c)		Propene ✓	1	**ALLOW** prop-1-ene ✓ **DO NOT ALLOW** prop-2-ene
	(d)	(i)	—CH_2CHCl— + $2\frac{1}{2}O_2 \longrightarrow 2CO_2 + H_2O + HCl$ ✓	1	
		(ii)	Alkali **OR** base **OR** carbonate ✓	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)		**Any two marks from the following**: Develop photodegradable polymers ✓ Develop biodegradable polymers **OR** develop compostable polymers ✓ Develop techniques for cracking polymers **OR** develop use as a chemical feedstock ✓ Develop ways of making polymers from plant-based substances **OR** reduce the need to use finite raw materials such as crude oil ✓ Designing processes with high atom economy **OR** reduce waste products during manufacture ✓ Develop ways of sorting **AND** recycling polymers ✓	**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)	Decane has more surface contact **OR** branched chains have less surface contact ✓ Decane has more van der Waals' forces **OR** branched chains have fewer van der Waals' forces ✓	**2**	**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 **ALLOW** Decane has stronger van der Waals' forces **OR** branched chains have weaker van der Waals' forces More intermolecular forces is **not** sufficient
		(iv)	Branched chains have more efficient combustion **OR** decane has less efficient combustion ✓	**1**	**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 **ALLOW** ORA for decane

Question			Expected Answers	Marks	Additional Guidance
					Better fuel is **NOT** sufficient Burns more cleanly is **NOT** sufficient
	(c)	**(i)**	$C_{10}H_{22} + 15½O_2 \longrightarrow 10CO_2 + 11H_2O$ All **four** species correct ✓ balancing of four correct species ✓	**2**	**ALLOW** any correct multiple **IGNORE** state symbols
		(ii)	$N_2 + O_2 \longrightarrow 2NO$ ✓	**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**	**ALLOW** atom, molecule or particle with an unpaired electron **ALLOW** 'has an unpaired electron' **ALLOW** particle formed by homolytic fission **DO NOT ALLOW** particle with a single electron **OR** particle with a free electron
		(ii)	catalyst ✓	**1**	
		(iii)	$O + O_2 \longrightarrow O_3$ **OR** O reacts with O_2 to make ozone **OR** the reaction is reversible ✓ Rate of formation of ozone is the same as rate of decomposition ✓	**2**	**ALLOW** $O_2 + O \rightleftharpoons O_3$ **OR** $O_3 \rightleftharpoons O_2 + O$ ✓✓ **ALLOW** is in equilibrium **OR** $\rightleftharpoons$ in **correct** equation **OR** has steady state condition ✓ **IGNORE** other equations involving ozone
		(iv)	absorbs (harmful) UV ✓	**1**	**ALLOW** 'keeps out UV' **OR** 'filters UV' **ALLOW** increased UV could cause skin cancer **OR** increased UV could cause cataracts **OR** increased UV could cause mutation of crops ✓ **IGNORE** gamma
			Total	**15**	