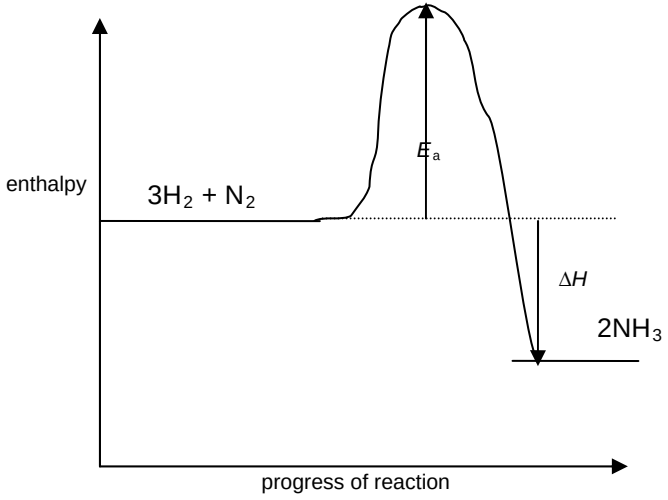
Question			Answer	Marks	Guidance
1	(a)	(i)		3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC**
			$2NH_3$ added as product ✓		**IGNORE** state symbol **ALLOW** product mark even if product line above the reactant line
			Δ*H* labelled with product below reactant **AND** arrow downwards ✓		**ALLOW** –92 as a label for Δ*H* **ALLOW** this line even if it has a small gap at the top and bottom ie does not quite reach reactant or product line
			E_a labelled correctly **AND** above reactants ✓		The curve must be drawn for this marking point
					**IGNORE** arrows at both ends of activation energy line but **DO NOT ALLOW** arrow pointing down The E_a line must go to maximum (or near to the maximum) on the curve **ALLOW** if the line clearly shows an activation energy and is not an enthalpy change **ALLOW** this line even if it has a small gap at the top and bottom ie does not quite reach the maximum or reactant line

Question			er	Marks	Guidance
	(a)	**(ii)**	–46 (kJ mol^{-1}) ✓	1	**DO NOT ALLOW** 46 with no sign
		(iii)	Any value between +1 to +249 (kJ mol^{-1}) ✓	1	+ sign is ot needed
		(iv)	+342 (kJ mol^{-1}) ✓	1	+ sign is ot needed
	(b)	**(i)**	$2CO + 2NO \rightarrow 2CO_2 + N_2$ ✓	1	**ALLOW** correct multiples

Question			er	Marks	Guidance
	(b)	(ii)	CO and NO are adsorbed (onto surface) **OR** reactants are adsorbed (onto surface) ✓	3	**ALLOW** CO and NO stick onto surface **OR** CO and NO form weak attractions to the surface **OR** gases are adsorbed onto surface **OR** gases bond to surface **NOT** absorb but **allow** ecf for deabsorb later on
			weakening of bonds **OR** chemical reaction **OR** new bonds are made **OR** carbon dioxide and nitrogen are made ✓		**ALLOW** lowers activation energy **IGNORE** alternative pathway Requires less energy is not sufficient
			CO_2 and N_2 desorbs (from the surface) **OR** products desorbs (from the surface) ✓		**ALLOW** products leave (the surface) **OR** products diffuse away (from surface) **OR** weak attraction to surface is broken **ALLOW** deadsorb

Question			er	Marks	Guidance
	(c)	(i)	***Any two from:*** IR (spectroscopy) ✓ Mass spectrometry ✓ UV (spectroscopy) ✓ NMR ✓ GC ✓	2	**ALLOW** mass spec / MS / mass spectroscopy **ALLOW** atomic absorption / AAS **IGNORE** satellite imaging or thermal imaging
		(ii)	***Any one from:*** Idea that pollution travels (across country) borders **OR** idea that all countries contribute towards pollution **OR** Cooperation means that scientists can share ideas **OR** scientists can warn governments of risk **OR** world-wide legislation can be introduced **OR** allows monitoring of pollution in different countries **OR** richer countries can help poorer countries introduce pollution controls **OR** One country cannot control pollution unless all countries do ✓	1	**ALLOW** some countries produce more pollution than others **ALLOW** so protocols can be developed
	(d)		**Step 1** $NO + O_3 \rightarrow NO_2 + O_2$ ✓ **Step 2** $NO_2 + O \rightarrow NO + O_2$ ✓ **overall** $O_3 + O \rightarrow 2O_2$ ✓	3	

Question			er	Marks	Guidance
	(e)	(i)	Reaction gives NO **OR** reaction gives NO_2 **OR** reaction gives a mixture of oxides **OR** activation energy too high **OR** rate of reaction is too slow ✓	1	**ALLOW** makes a mixture of oxides/products **ALLOW** reaction cannot be carried out experimentally **ALLOW** reaction does not take place nitrogen and oxygen do not react together is **not** sufficient **IGNORE** heat loss to surroundings **IGNORE** reference to bond enthalpy being a mean value
		(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = +82 (kJ mol^{-1}) award 2 marks** **IF answer = –82 (kJ mol^{-1}) award 1 mark** ΔH = 193 – 111 ✓ = +82 ✓	2	 **ALLOW** 82 **ALLOW** one mark for –82 **ALLOW** one mark for +304 / –304
			Total	**19**	

Question			Answer	Marks	Guidance
2	(a)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = –162 (kJ mol^{-1}) award 3 marks** Energy associated with bond breaking = 3354 **OR** (2 × 805) + (4 × 436) ✓ Energy associated with bond making = 3516 **OR** (4 × 415) + (4 × 464) ✓ Enthalpy change = –162 ✓	3	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. IF ECF, **ANNOTATE WITH TICKS AND CROSSES, etc** **IGNORE** sign **IGNORE** sign **ALLOW** ECF from wrong additions of energy associated with bond breaking and/or from bond making **ALLOW** two marks for (+)162, (+)6870, –6870 or (+)766 **ALLOW** one mark for –766
	(b)	(i)	Absorbs IR radiation ✓ Bonds vibrate ✓	2	**IGNORE absorbs heat** **ALLOW** IR re-radiated **DO NOT ALLOW** absorbs UV radiation **DO NOT ALLOW** blocks IR radiation **ALLOW** bonds stretch **OR** bonds bend **IGNORE** molecule vibrates/rotates **DO NOT ALLOW** bonds break

Question			er	Marks	Guidance
	(b)	(ii)	***Any two from:***	2	
					DO NOT ALLOW reference to carbon being stored – the answer must either refer to carbon dioxide or not mention the name of the stored substance
			(liquid) injected deep into the oceans ✓		**ALLOW store deep** in the oceans **OR** on the **sea-bed** ✓ **ALLOW** stored deep under the sea **DO NOT ALLOW** dissolve CO_2 in the sea **OR** stored in ocean
			Stored in (old) geological formations **OR** stored underground in rocks **OR** stored in (old) mines **OR** stored in (old) oil wells ✓		**ALLOW** stored under the sea bed **ALLOW** pumped into oil wells to force last bit of oil out
			Stored by reaction with metal <u>oxides</u> **OR** reaction to form (solid) <u>carbonates</u> **OR** stored as a <u>carbonate</u> **OR** equation to show formation of metal carbonate ✓		**IGNORE** mineral storage

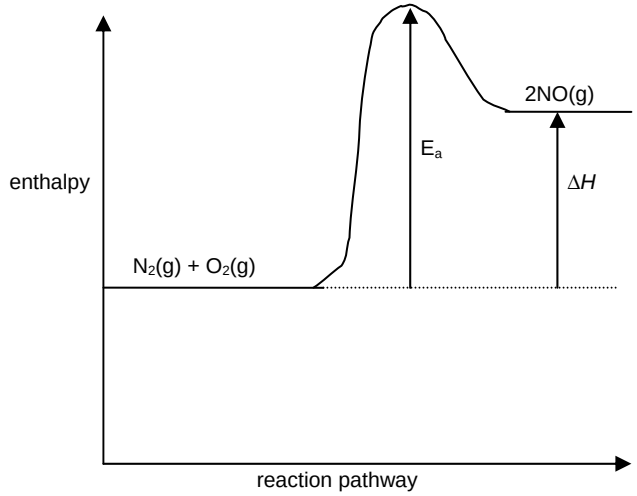
Question			er	Marks	Guidance
	(c)	(i)		7	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** dot for radical and any state symbols for all equations
			Homolytic ✓		
			$Br_2 \longrightarrow 2Br$ ✓		
			$Br + C_2H_6 \longrightarrow HBr + C_2H_5$ ✓ $C_2H_5 + Br_2 \longrightarrow C_2H_5Br + Br$ ✓		If more than one termination step is written they must all be correct to be awarded the mark **DO NOT ALLOW** termination steps with H
			$Br + C_2H_5 \longrightarrow C_2H_5Br$ **OR** $Br + Br \longrightarrow Br_2$ **OR** $C_2H_5 + C_2H_5 \longrightarrow C_4H_{10}$ ✓		
			Two names of steps linked to appropriate equations ✓ **OR** **three** names of steps linked to appropriate equations ✓✓		initiation step linked to correct equation propagation step linked to one equation in which there is a radical on the left and a radical on the right termination step linked to equation involving two radicals: If no equations are given to link the names of the step then award one mark for mention of all three steps If halogen other than bromine do not give equation mark for initiation and only give one mark for all three terms linked to appropriate equations If hydrocarbons other than ethane are used **DO NOT ALLOW** any marks for the equations in the propagation steps

Question			er	Marks	Guidance
	(c)	(ii)	***Any two from:***	2	
			More than one C–H bond can be substituted **OR** multi-substitution can occur **OR** more than one substitution can happen ✓		**ALLOW** equations or examples of multi substitution
			Lots of termination steps ✓		**ALLOW** an equation to illustrate formation of other products eg butane **ALLOW** examples of other products that can be formed in termination steps eg bromobutane
			termination steps can give products that will also react with (bromine) radicals ✓		**ALLOW** examples of products eg butane reacting with bromine radicals to give bromobutane
			Total	**16**	

Question			Answer	Mark	Guidance
3	(a)	(i)	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ ✓	1	**IGNORE** state symbols
		(ii)	Bond breaking absorbs energy **AND** bond forming releases energy ✓ More energy released than absorbed ✓	2	**ALLOW** bond breaking is endothermic **AND** bond forming is exothermic **DO NOT ALLOW** bond forming requires energy The second marking point is **dependent** on the correct identification of the energy changes during bond breaking and bond making **ALLOW** exothermic change transfers more energy than endothermic change **OR** bond forming 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** reference to number of bonds broken or made **IGNORE** enthalpy of products is less than enthalpy of reactants
	(b)	(i)	(Enthalpy change) when one mole of a substance ✓ is completely combusted **OR** burns in excess oxygen ✓	2	**ALLOW** energy released **DO NOT ALLOW** energy required **ALLOW** element **OR** compound **OR** molecule **DO NOT ALLOW** one mole of atoms **ALLOW** reacts fully with oxygen
		(ii)	Would make carbon dioxide and water instead **OR** activation energy (too) high **OR** rate is (too) slow **OR** do not react together ✓	1	**ALLOW** will make other compounds (containing carbon and hydrogen or carbon, oxygen and hydrogen) **ALLOW** reaction cannot be carried out experimentally **IGNORE** heat is lost to the surroundings

Question			Answer	Mark	Guidance
3	(b)	(iii)	(+)2801 ✓ + −)394 × 6 + (−)286 × 6 **OR** (–)4080 ✓ −1279 ✓	3	**IGNORE** sign **IGNORE** sign **ALLOW** full marks for −1279 with no working out ✓✓✓ Unit **not** needed **ALLOW** ECF enthalpy change of combustion of carbon dioxide and water – enthalpy of combustion of glucose **ALLOW for 2 marks:** +1279 cycle wrong way around **OR** +151 **OR** +691 one value not × 6 **OR** –6881 **OR** +6881 wrong sign for 2801 or 4080 **OR** +2121 ✓✓correct cycle but not × 6 **ALLOW for 1 mark:** –151 **OR** –691 cycle wrong way around and one value not × 6 **OR** –2121 cycle wrong way around and not × 6 **OR** –3481 **OR** +3481 ✓ wrong sign and not × 6 **Note:** There may be other possibilities
			Total	**9**	

Question			Answer	Mark	Guidance
4	(a)	(i)	Reaction in which energy enters the system (from the surroundings) ✓	1	**ALLOW** reaction that absorbs energy **ALLOW** takes energy in (from the surroundings) **ALLOW** enthalpy of products have higher enthalpy than enthalpy of reactants **ALLOW** heat instead of energy **ALLOW** correct reference in terms of bond breaking and bond making **IGNORE** incorrect reference to bond breaking or bond making
		(ii)	+33 ✓	1	+ sig is **not** required **DO NOT ALLOW** –33

Question			Answer	Mark	Guidance
	(b)	(i)	2NO added for product ✓ Δ*H* labelled with product above reactant **AND** arrow upwards ✓ E_a labelled correctly **AND** above products ✓  	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **IGNORE** State symbol **ALLOW** product line above or below reactants line **ALLOW** (+)66 **ALLOW** line that has a small gap at the top and bottom **IGNORE** arrows at both ends of activation energy line The E_a line must go to maximum (or near to the maximum) on the curve **ALLOW** if the line clearly shows an activation energy and is not an enthalpy change **ALLOW** line that has a small gap at the top and bottom
		(ii)	Activation energy is the **minimum** amount of energy needed for the reactants to react ✓	1	**ALLOW** compounds **OR** elements **OR** molecules **OR** chemicals instead of reactants **ALLOW** minimum energy needed to start a reaction

Question			Answer	Mark	Guidance
	(c)	**(i)**	Rate of forward reaction slows down and rate of backward reaction speeds up ✓ (Until) rate of forward reaction is the same as the rate of the backward reaction ✓	**2**	**ALLOW** at start rate of forward reaction is fast but rate of backward reaction is slow **DO NOT ALLOW** forward reaction is the same as backward reaction
		(ii)	Reaction is faster ✓ Increasing pressure mean more particles per unit volume **OR** increasing pressure gives more crowded particles **OR** increasing pressure gives more concentrated (particles) ✓ So more collisions per second **OR** higher collision frequency **OR** collisions more often ✓ (Changes of pressure) do not change the (position of) equilibrium ✓ Both sides of equation have same number of moles (of gas) ✓	**5**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** particles are closer together **DO NOT ALLOW** 'area' instead of 'volume' **ALLOW** increased rate of collision **OR** collisions are more likely **OR** there is a greater chance of collisions 'More collisions' or 'more successful collision' are **not** sufficient **DO NOT ALLOW** composition of equilibrium is the same (in question) **ALLOW** both sides of equation have same number of molecules (of gas)
		(iii)	Not a closed system ✓	**1**	**ALLOW** gases can escape **OR** gases are continuously entering **OR** it is an open system
	(d)		has an unpaired electron ✓	**1**	**ALLOW** plural: unpaired electrons has a lone electron is **not** sufficient
	(e)	**(i)**	$2NO + O_2 \rightarrow 2NO_2$ ✓	**1**	**ALLOW** any correct multiple including fractions **IGNORE** state symbols

Question			Answer	Mark	Guidance
	(e)	(ii)	NO is not consumed **OR** overall reaction is $O_3 + O \rightarrow 2O_2$ ✓ $NO + O_3 \rightarrow NO_2 + O_2$ ✓ $NO_2 + O \rightarrow NO + O_2$ ✓	**3**	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** $2O_3 \rightarrow 3O_2$ **OR** It is a chain reaction **OR** NO is reformed **OR** mechanism of ozone depletion is changed **OR** NO made can react with more ozone **IGNORE dots** **ALLOW** $NO_2 + O_3 \rightarrow NO + 2O_2$
		(iii)	**ANY TWO FROM:** To identify the functional groups (in pollutants) **OR** to identify the bonds (in pollutants) ✓ Match spectrum to known pollutants **OR** each pollutant will have a different spectrum ✓ Idea that you can measure the concentration or abundance of pollutant ✓	**2**	 **ALLOW** a named bond **IGNORE** any specific wavenumber or range of wavenumbers **ALLOW** match spectrum to database or datasheet
			Total	**21**	

Question			Expected Answers	Marks	Additional Guidance
5	a		Low pressure because more (gas) molecules on right hand side of equation **OR** low pressure because ΔV = positive ✓ Low temperature because the (forward) reaction is exothermic ✓	2	**ALLOW** low pressure because more (gas) moles on right hand side of equation
	b		Increased pressure speeds up reaction / ora ✓ 900 ^{o}C increases the rate **OR** increased temperature speeds up reaction / ora ✓ Idea that high enough temperature without compromising yield **OR** idea that high enough pressure without compromising yield ✓	3	**ANNOTATE WITH TICKS AND CROSSES** **ALLOW** 'pushes gases through system'
	c	i	5.68×10^7 / 5.7×10^7 ✓	1	**ALLOW** two or more significant figures Calculator answer is 5.6812500×10^7
		ii	Used to heat the incoming gases ✓	1	**ALLOW** used to heat rest of factory **OR** sold to the national grid Provide energy to create conditions is not sufficient because one condition is pressure
			Total	**7**	