Question number	Answer	Notes	Marks
1 (a)	$I_2 + Cl_2 \rightarrow 2ICl$	ACCEPT halves and multiples	1
(b) (i)	M1 rate of forward reaction = rate of backwards reaction	ACCEPT both reactions occur at the same rate IGNORE forward reaction = backwards reaction	2
	M2 concentrations of reactants/ products remain constant	ACCEPT amounts/masses for concentrations ACCEPT don't change/stay for remain IGNORE concentrations/ amounts of reactants and products are the same/are equal ALLOW colour remains constant	
(ii)	M1 equilibrium has shifted to the left / equilibrium has shifted to the ICl side / equilibrium has shifted to the reactants side OR more ICl has been produced / more reactants have been produced	IGNORE references to Le Chatelier's principle e.g. an increase in temperature favours the endothermic reaction	2
	M2 an increase in temperature shifts the equilibrium in the endothermic direction	ACCEPT 'therefore the (backward) reaction is endothermic' for M2 if M1 has been awarded	

Question number	Answer	Accept	Reject	Marks
2 (a)	any two from: ● forward and backward reactions (still) occurring ● concentrations/amounts of reactants/products/components remain constant ● rate of forward reaction = rate of reverse reaction IGNORE concentrations/amounts of reactants and products are the same IGNORE reaction is reversible/goes both ways, OWTTE IGNORE references to le Chatelier	both reactions (still) occurring stay the same in place of remain constant		2
(b) (i)	M1 – (increase in temperature) decrease(s)	less/lower(s)/drop(s)/gets smaller		1
	M2 – (increase in pressure) increase(s)	more/raise(s)/higher/gets bigger		1
(ii)	M1 – (forward) reaction is exothermic/gives out heat OR reverse reaction is endothermic/takes in heat			1
	M2 – fewer (gas) molecules/particles on right hand side OR fewer moles (of gas) on right hand side IGNORE references to volumes IGNORE references to le Chatelier's principle IGNORE references to reverse reaction lowers the temperature IGNORE references to forward reaction reduces the pressure	reverse argument shifts to side with fewer (gas) molecules/fewer moles (of gas)	atoms	1

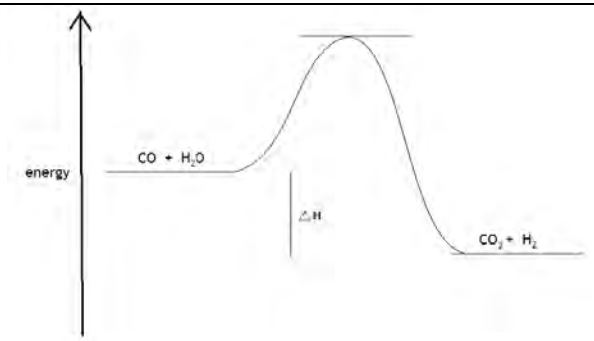
2 (c) (i)	(the position of) equilibrium is not established/reached			1
(ii)	M1 – (the mixture of gases is) cooled M2 – ammonia liquefies / condenses	temperature is decreased		1 1
(iii)	recycled / <u>re</u>used / recirculated	put (back) into the reaction chamber used <u>again</u> (in the process)		1
(d)	<u>heat(ing)</u> / <u>energy</u> costs would be higher	yield (of ammonia) would decrease		1
(e) (i)	M1 M_r (N_2) = 28 M2 112 000 ÷ 28 (= 4 000) / 112 000 ÷ M1 M3 8 000 / M2 x 2	28 anywhere in the calculation 112 ÷ 28) 2 = 8 for 2 marks (112 000 ÷ 14) x 2 = 16 000 for 2 marks Correct final answer without working for 3 marks		1 1 1
(ii)	1 200 / 15% of M3			1
			Total	15

Question number	Answer	Notes	Marks
3 (a)	M1 (goes darker because) more NO_2 is formed M2 as equilibrium/reaction shifts to left M3 because there are more moles/molecules (of gas) on the left hand side	 allow 'moves backwards/in reverse direction' accept 'fewer moles/molecules on the right hand side' ignore references to Le Chatelier's principle	3
(b) (i)	M1 the equilibrium/reaction has shifted to the right / more N_2O_4 has been formed M2 a decrease in temperature shifts the equilibrium in the exothermic direction	 accept 'therefore the (forward) reaction is exothermic' for M2 if M1 has been awarded	2
(ii)	(yes: because) bond making is exothermic/releases (thermal/heat) energy		1

Question number	Answer	Accept	Reject	Marks
4 (a)	Any two from: M1 both forward and backwards reactions are occurring M2 amounts/concentrations of reactants and products stay the same/pressure (of gas mixture) stays the same M3 rate of forward reaction = rate of backwards reaction	masses for amounts	are the same	2
(b) (i)	M1 increase M2 (forward) reaction is exothermic/gives out heat M2 dep on M1 IGNORE references to le Chatelier's principle and to reaction tries to decrease the temperature/equilibrium shifts to right	<u>reverse</u> reaction is endothermic	equilibrium shifts to left	1 1
(b) ii)	M1 increase M2 fewer moles/molecules (of gas) on right (hand side) M2 dep on M1 IGNORE references to le Chatelier's principle and to reaction tries to decrease the pressure/equilibrium shifts to right	more molecules on left (hand side)	equilibrium shifts to left	1 1

(c)	(i)	$2CH_3OH + O_2 \rightarrow 2H_2CO + 2H_2O$ M1 formulae M2 balancing M2 dep on M1 IGNORE catalyst if on <u>both</u> sides or above arrow IGNORE state symbols	multiples and halves		2
	(ii)	M1 – a substance that increases the rate of a reaction IGNORE alters the rate and any reference to enzymes M2 and is chemically unchanged (at the end of the reaction) IGNORE references to takes no part in the reaction	mass does not change without being used up		1 1
	(iii)	M1 provides an alternative reaction path(way)/route/mechanism M2 (alternative path has a) lower activation energy [Activation energy can be described, e.g. the minimum energy needed (by colliding particles) for reaction to occur] MAX 1 if any mention of particles gaining energy	M1 molecules adsorb on/stick to the catalyst M2 weakens the bonds in the reactant molecules		1 1
(d)		$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$ M1 all formulae correct M2 balanced M2 dep on M1 IGNORE state symbols	multiples and halves correct equation for methanal for one mark		2
				Total	14

Question number	Answer	Notes	Marks
5 a	$CH_4 + H_2O \rightarrow CO + 3H_2$	Accept fractions and multiples	1
b i	M1 (increased pressure) has no effect (on yield) M2 because equal numbers of (gas) moles/molecules on each side	Ignore no effect on other factors eg equilibrium (position) Do not award M2 if M1 is incorrect	2
ii	M1 (at higher temperature equilibrium position shifts to left so yield of hydrogen) decreases M2 because (forward) reaction is exothermic	Accept because backward reaction is endothermic Accept because reaction moves in the endothermic direction Ignore references to Le Chatelier's principle eg increase in temperature favours the endothermic reaction Do not award M2 if M1 is incorrect	2

c	i		M1 for CO_2 + H_2 / products below CO + H_2O M2 for approximately vertical line/arrow with Δ*H* symbol/enthalpy change/-41kJ/mol between reactants and products M2 CQ on M1 unless if products above the activation energy	2
	ii	no effect / OWTTE		1
	iii	M1 provides alternative pathway / route / OWTTE M2 with lower activation energy	Accept words such as another / different in place of alternative, but not just route Accept lowers the activation energy Accept less energy needed to start the reaction Reject (catalyst) provides energy for M1 and M2 Ignore references to providing surface for reaction	2

Question number	Answer	Notes	Marks
5 d	M1 identifying reaction 3 or reaction 4 M2 a correct explanation for either eg in reaction 3, there is gain of hydrogen in reaction 4, there is gain of oxygen	Ignore reactions 5 and 6 Accept increase in oxidation number of H / changes from 0 to (+)1 Accept decrease in oxidation number of N / changes from 0 to -3 Ignore references to gain/loss of electrons Accept decrease in oxidation number of O/ changes from 0 to -2 Accept increase in oxidation number of N / changes from -3 to (+)2 Ignore references to gain/loss of electrons Ignore other explanations Allow: Identifying both Reaction 3 and 4 <u>only</u> for 2 marks Ignore any explanations	2

e	M1 $n(NH_3) = \frac{34 \times 1000}{17} = 2000$ (mol) M2 M_r (NH_4NO_3) = 80 M3 mass (NH_4NO_3) = 80 × 2000 = 160 000 g / 160 kg **OR** M1 M_r (NH_4NO_3) = 80 M2 (so) 17 (kg NH_3) gives 80 (kg NH_4NO_3) M3 (so) 34 (kg NH_3) gives $\frac{80}{17}$ x 34 = 160 kg / 160 000 g	Correct final answer with or without working scores 3 marks Do not award M3 if unit missing or incorrect Mark CQ throughout	3

Question number				Answer	Notes	Marks
6	a	i	M1	air / atmosphere		1
			M2	water / natural gas / hydrocarbons	Allow methane	1
		ii	M1	iron / Fe	Ignore iron oxide Accept phonetic spellings Do not penalise other included numbers - eg Fe(II) / Fe(III) / Fe^{2+} / Fe^{3+}	1
		iii	M1	450 ºC	Accept temperature of 350ºC to 550ºC or temperatures in K If range given, both values must be within acceptable range	1
			M2	200 atm(ospheres)	Accept pressure of 150 atm to 250 atm or pressures in Pa Unit needed for mark If two conditions given, both must be correct	
		iv	M1	cooled / temperature lowered		1
			M2	ammonia liquefies / condenses	M1 and M2 are independent Do not award M2 if implication that other gases condense	1

Question number				Answer	Notes	Marks
6	b		M1	$n(N_2) = (56 \times 10^6) \div 28 \quad / \quad 2 \times 10^6$	No penalty for missing or incorrect power of 10	1
			M2	$n(NH_3) = M1 \times 2 \; / \; 4 \times 10^6$	Conseq on M1	1
			M3	$m(NH_3) = M2 \times 17 \; / \; 68$ t(onnes)	Conseq on M2 Correct final answer with units scores 3 Accept answers in grams and kilograms 34 t scores 2 marks Final answer of 68 with missing or incorrect units scores 2	1
				OR $\frac{34 \times 56}{28}$ = 68 t(onnes)	M1 for 28 and 34 (need not be in this expression) M2 is for expression shown M3 is for answer with units	
	c	(i)	M1	increased		1
			M2	shift to left	Allow less ammonia / products Allow moves in reverse direction Ignore reference to favouring	1
		(ii)	M1	shift to right	Allow more ammonia / products Allow moves in forward direction Ignore reference to favouring	1
			M2	fewer moles/molecules (of gas) on the right	Allow more moles/molecules on the left Do not penalise incorrect numbers, eg 3 moles on the left and 2 moles on the right Ignore references to rate M2 dependent on M1	1

Question number				Answer	Notes	Marks
6	d	i	M1	60		1
		ii	M1	setting out correct division of each % by A_r OR 2.5, 5 and 3.75	Award 0 for whole question if division by atomic numbers / wrong way up / multiplication used If molecular masses used for all three elements, no M1, but can award M2 and M3	1
			M2	division by smallest (gives 1 : 2 : 1.5)	No penalty for subsequently rounding 1.5 to 2 if clear they have divided by smallest	1
			M3	$N_2H_4O_3$	Accept elements in any order Allow NH_4NO_3 If % O wrong or missing, only M1 and M2 can score	1
		iii	M1	ammonium nitrate	Accept phonetic spellings Do not accept ammonia in place of ammonium Do not accept nitrite or nitride in place of nitrate Ignore all formulae	1

Total 18 marks