3. Increased surface area **(1)**

more collisions **(1)** 2

[9]

(c) (i) $2H_2O_2 \rightarrow 2H_2O + O_2$ 1

(ii) Speeds up (alters the rate of) a chemical reaction 1
Remains unchanged (or not used up) 1

(iii) Remains unchanged (or not used up or not in the overall reaction equation) 1
Offers alternative reaction route (or acts as an intermediate) 1

[10]

5. (a) Graph starts at origin 1

Graph skewed to left and has decreasing gradient to maximum 1

Graph after maximum decreases in steepness, never touches *x* axis, levels out less than 5 mm from *x* axis. 1

(b) Minimum energy 1

To start a reaction (*or for a reaction to occur*) 1

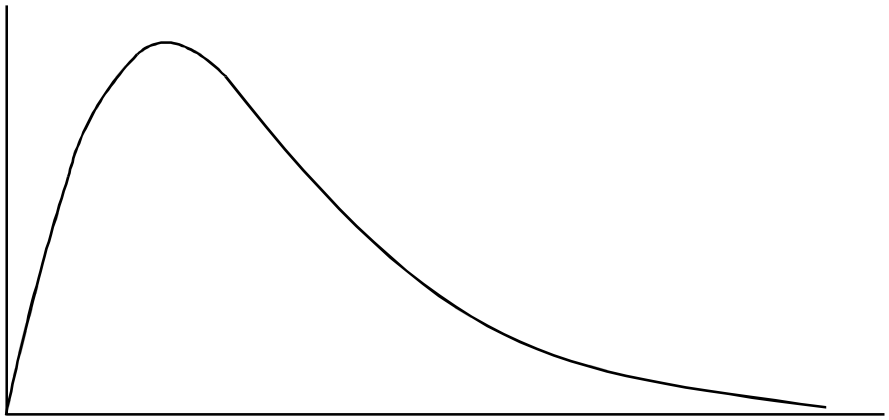
(c) Molecules gain energy (*or always some molecules have* $E > E_a$) 1

Due to collisions 1

(d) Decreases 1
E_a lowered **(1)**
By alternative route **(1)**
So more molecules have energy > E_a **(1)** max 2

[10]

7. (a) (i)



Number of molecules or particle **(1)**
NOT moles or mols or atoms
Not fraction or proportion

(Molecular) Energy **(1)** Not velocity

(ii) The total number of particles (or molecules) in the sample
OR the number of molecules present

(iii) No molecules have no energy
OR all molecules have some energy

Do not allow "if there are no molecules there is no energy" 4

(b) (i) The minimum energy required **(1)**

for a reaction to occur **(1)**
OR to start reaction or for a successful collision

(ii) Changes: Catalyst **(1)**

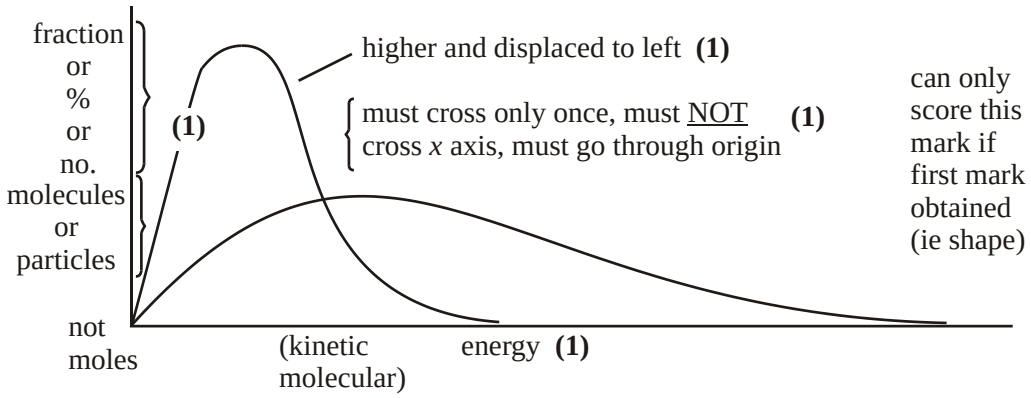
Explanation: Alternative route **(1),** with a lower activation energy **(1)**
OR a lower activation energy (1)
so more molecules can react (1)/more molecules have this energy

If change incorrect CE = 0

Allow answers anywhere in b (ii) 5

[9]

10. (a) 2



(b) See above 2

(c) Energy < E_a or must have enough energy (to react) **(1)** 1

(d) Increase concentration (or pressure) **(1)** 1

(e) Many **(1)** more molecules have E > E_a / enough energy **(1)** 2

NOT KE increases with T

(f) Lowers E_a **(1)**
alternative route **(1)** 2

[10]

12. (a) Activation energy;-
The minimum energy needed for a reaction to occur / start **(1)** 1

(b) Catalyst effect:-
Alternative route (or more molecules have Ea) **(1)**
Lower activation energy **(1)** 2

(c) Increase in moles of gas:-

Position of E_{mp} unchanged **(1)**
More molecules with E_{mp} **(1)**
Area under curve increases **(1)**
Molecules with $E \geq E_a$ increased **(1)**

Temperature decreased:-

Position of E_{mp} moves to the left **(1)**
More molecules with E_{mp} **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ decreased **(1)**

Catalyst introduced:-

Position of E_{mp} unchanged **(1)**
Molecules with E_{mp} unchanged **(1)**
Area under curve unchanged **(1)**
Molecules with $E \geq E_a$ increased **(1)** 12

[15]

13. (a) the minimum energy; 1
Energy required for a reaction to occur; 1
(or to start a reaction or for successful collisions)

(b) axes labelled:- y: number *(or fraction or %)* of molecules *(or particles)*
x: energy *(or KE);* 1
curve starts at origin; 1
skewed to right; 1
approaches x axis as an asymptote; 1
(penalise a curve that levels off > 10% of max peak height or a curve that crosses the energy axis)

second curve displaced to the left (*and does not cross T_1 curve for a second time*) 1
and peak higher; 1

many fewer molecules; 1

fewer molecules have $E > E_a$ *;* 1
(can score this mark from suitably marked curves)

(b) molecules *(or particles or collisions)* do not have enough energy; 1
(or orientation may be wrong)

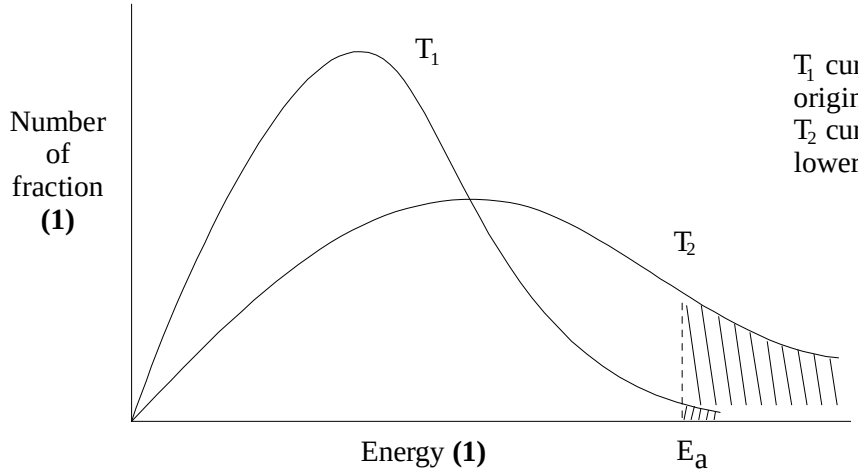
increase the pressure; 1
(or increase the concentration or reduce the volume)
increases the collision frequency; 1
(or more collisions)
(do not allow if stated to be due to increase in energy implied by temperature increase)

add a catalyst; 1

lowers <u>activation energy</u> (or E_a) *(Q of L mark);* 1

[15]

14.



T_1 curve:
origin and shape **(1)**
T_2 curve:
lower and to right **(1)**

At T2: more molecules **(1)**

have sufficient energy **(1)**

plus reference to E_a or shaded area on graph **(1)**

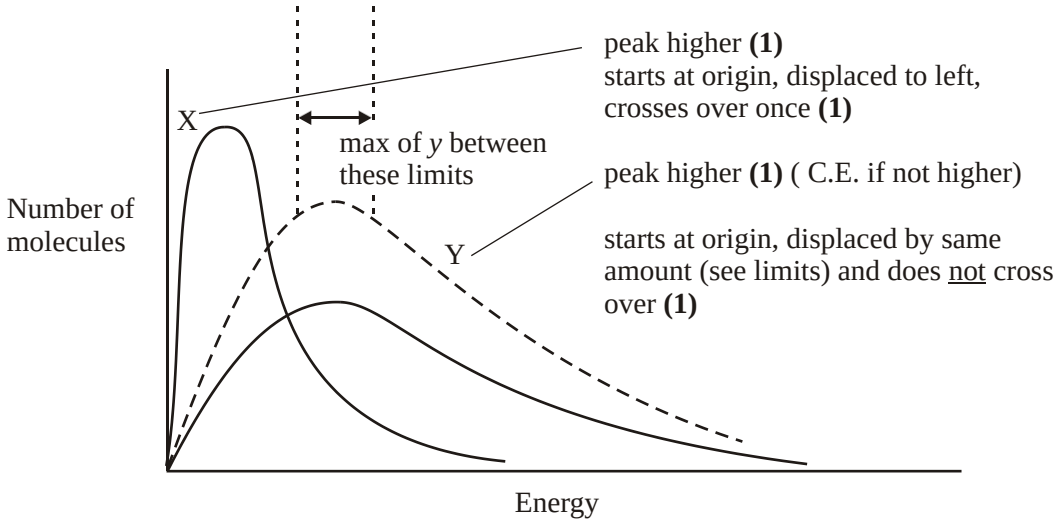
Larger mass: more particles **(1)**

higher curve **(1)**

most probable energy is same **(1)**

[10]

15. (a) (i) (ii) 4



(b) (i) collide **(1)**
with sufficient energy (or $E \geq E_a$) **(1)** (*or with correct orientation*)

(ii) molecules (or particles) have more energy (or move faster) **(1)**
more molecules (or collisions) have $E \geq E_a$ (or sufficient energy) **(1)** 4

(c) (i) equilibrium reached **(1)**
(or rate forward reaction = rate backward)

(ii) Reaction is endothermic **(1)**
or ΔH +ve
or reverse reaction is exothermic

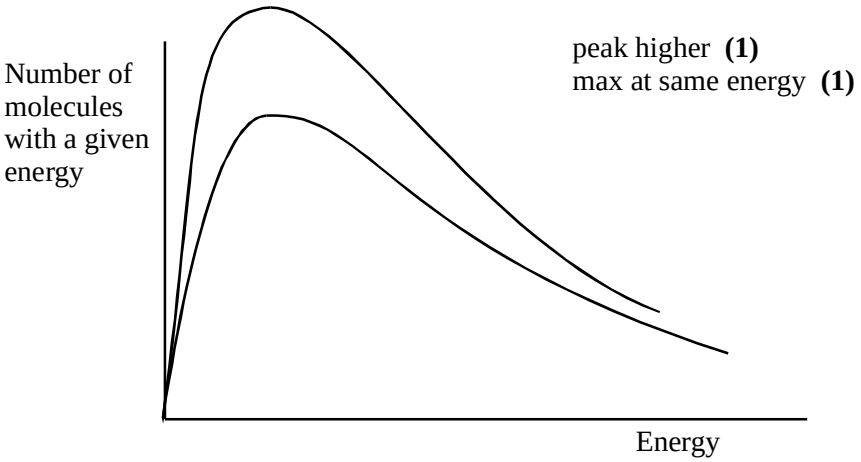
endothermic reaction favoured **(1)** 3
(or reaction shifts to R
or moves forward
or more products formed)

[11]

20. (a) (i) *Point* infinity or never **(1)**

Explanation no maximum energy for molecules **(1)**

(ii)



peak higher **(1)**
max at same energy **(1)**

(iii) no difference **(1)** 5

(b) *Requirement 1* Collision **(1)**

Requirement 2 With sufficient energy or correct orientation **(1)** 2

[7]

21. (a) Same 1

(b) (i) Decreases 1

More moles on left hand side 1

Equilibrium moves to increase the pressure 1
(Or to oppose the change or to compensate for low pressure)

(ii) Cost of producing high pressure **(1)**
Cost of plant to resist high pressure **(1)**
Correct safety factor with reason **(1)** max 2

(c) No change 1

Catalyst has no effect on equilibrium position 1
(Or catalyst affects rate of forward and backwards reactions equally)

(d) Negative 1

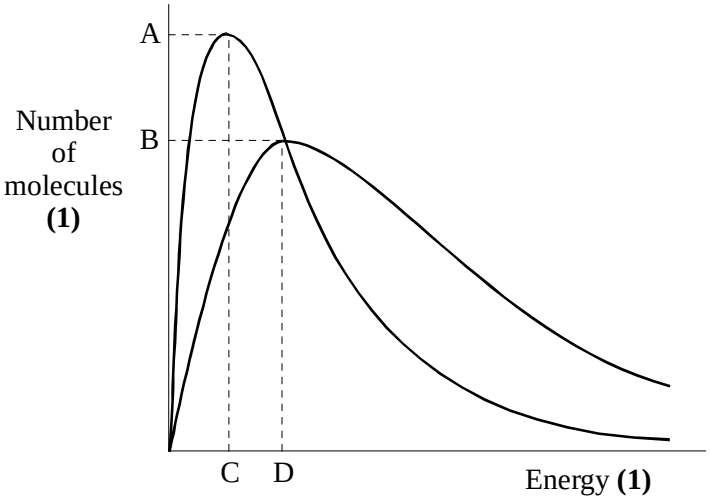
Reaction *(or equilibrium)* moves in the exothermic direction *(or to the right)* 1

In order to oppose the change *(or to raise the temperature)* 1

(e) Recycled (*or re-used or 'put back in'*) 1

[12]

22. (a) (i)



(ii) C **(1)** 3

(b) *Requirement 1* collisions **(1)**

Requirement 2 with sufficient energy **(1)** 2

(c) *Greater effect* Temperature **(1)**

Explanation For small ΔT, more molecules **(1)** have energy $\geq E_a$ **(1)** 3

[8]

23. (a) removal/loss of electrons 1

(b) no change 1
equal number of gaseous moles on either side 1
both sides affected equally 1
increases 1
equilibrium moves to lower the temperature/oppose the change 1
endothermic reaction favoured /forward reaction is endothermic 1

(c) (i) +2 1
+5 1

(ii) $NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$ 1

(iii) $Ag \rightarrow Ag^+ + e^-$ 1

(iv) $NO_3^- + 4H^+ + 3Ag \rightarrow NO + 2H_2O + 3\ Ag^+$ 1

[12]

24. (a) 12 (kPa) 1

pp = mole fraction × total pressure **or** mole fraction = 12/104 1

= 0.115 1

(allow 0.12)

(b) 68 (kPa) 1

(c) $K_p = \dfrac{(pSO_3)^2}{(pSO_2)^2 \times (pO_2)}$ 1

(If K_p wrong, allow consequential units only)

(penalise square brackets in expression but then mark on)

$= \dfrac{68^2}{24^2 \times 12}$ 1

= 0.669 1

(Allow 0.67)

(Allow full marks in calculation consequential on their values in (a) and (b))

kPa^{-1} 1

(d) T_2 1

(Must be correct to score any marks in this section)

<u>Exothermic</u> 1

Reduce T to shift equilibrium to the right
or forward reaction favoured by low T
or K_p increases for low T
or low T favours exothermic reaction 1

(e) Increase 1

None 1

[13]

Notes

(a) If K_p has [ ] lose mark in (a) but allow full marks in (d)

If K_p wrong/upside down etc, allow max 2 in (d) for substitution of numbers **(1)** and consequential units **(1)**

(b) Mark for moles of SO_2Cl_2 can be scored in part (c) (ii) if not gained in (b)

1.75 get **(2)**

If moles of SO_2Cl_2 = 1, this is a Chemical Error, hence a 2 mark penalty

- If total moles given in (b) = 1.75, this scores [2] in (b); but if the no moles of SO_2Cl_2 = 1 in (c)(ii), lose both marks in (c)(ii) for pp of SO_2Cl_2 = (1/1.75) × 125, i.e. the 2 mark penalty is in (c)(ii).
- If total moles given in (b) = 2.5, score zero in (b), but can gain full marks in (c)(ii) consequentially, i.e. the 2 mark penalty is in (b).
- If moles of SO_2Cl_2 = 1 and total in (b) does not equal 2.5, still lose both in (b) but can get all 4 conseq in (c)(ii) for 1/x etc and 0.75/x etc

(c) (i) Allow "Total pressure = sum of partial pressures" for **(1)** or $p_A = x_A \times p_{tot}$

(ii) First mark is for mole fraction.
If either number in either mole fraction is not consequential on (b), then lose both marks for that partial p.

(d) If pCl_2 is not equal to pSO_2 or any number used in K_p is not conseq on (c)(ii), allow units only

SIG FIGS; must be 3 sig figs in (b) but then allow 2 sig figs in (c) and (d); (ignore extra figs) but penalise incorrect rounding

(e) If effect wrong, no marks for explanation.
If effect missing, e.g. answer states "equm shifts to right", mark on.
In the explanation, the word "endothermic" (or its equivalent) is essential.

26. (a) An <u>equilibrium</u> opposes change **(1)** 1

(b) (i) *Effect on yield of hydrogen:* decreases **(1)**
Note C.E. if not decrease, but mark on if no answer

Explanation: pressure lowered (or increase opposed) **(1)**
by favouring fewer moles (of gas) **(1)**

(ii) *Effect on yield of hydrogen*: increase **(1)** 6
CE if wrong as above

Explanation: pressure / concentration / reactants / steam reduced **(1)**
by shifting to right **(1)**
or steam removed or forward reaction favoured

(c) *Reason 1*: cost of high temperature / energy **(1)**

Reason 2: cost of plant (to resist high T) too high **(1)** 2
OR plant could not contain high T

[9]

27. (a) rate forward reaction = rate backward reaction **(1)**
concentration remains constant **(1)**
NOT 'Equal',
Allow 'The same' if clear that means constant

2

(b) fewer moles (of gas) on R.H.S **(1) (or converse)**
(methanol favoured) by reducing applied pressure **(1)**
Or removing constraint

2

(c) Power / energy required to provide high pressure / pumping **(1)**
Strong pressure vessel / or equipment **(1)**
High maintenance costs
Any two

2

(d) Effect: decreases **(1)**
Explanation: reaction exothermic **(1)**
system tries to lower T or remove constraint or oppose the change
or endothermic reaction favoured 3

(e) to speed up reaction **(1)**
or otherwise to slow
or takes too long
or to give more molecules $E > E_A$

1

[10]

28. (a) mark labelled **X** on curve **A** where curve **C** joins **A**; 1

(b) equilibrium opposes a change; 1
(Q of L mark)

(c) **B** 1

more ammonia is produced (or yield increases); 1
fewer moles (of gas) on right (or 4 mol goes to 2 mol); 1
equilibrium moves to oppose increase in pressure (or oppose change); 1

(d) **C** 1

amount of ammonia (or yield or equilibrium) unchanged; 1
reaction is faster; 1

[9]

29. (a) (i) All (reagents) (reagents) are in the same phase/state/are gases **(1)**

(ii) The forward and backward reations are occurring **(1)**

at the same/equal rate **(1)**

or concentrations of reactants (and products) are constant **(1)**

and reaction is continuous **(1)**
Note: "concentrations of reactants and products are the same" is incorrect

3

(b) (i) (Concentration of hydrogen /products) increased **(1)**
NB if a product stated this must be H_2

Equilibrium moves to right / forward reaction favoured **(1)**

to remove added water / system reacts to oppose change **(1)**
Mark CE if effect wrong. Do not allow "rate" answers

(ii) (concentration of hydrogen / products) increased **(1)**

Equilibrium moves to right / forward reaction favoured **(1)**

Reaction exothermic / gives out heat / moves to oppose change **(1)**

*Allow max **(1)** for exothermic if other answers incorrect* 6

(c) None **(1)**

Rates of both forward and backward reactions increased / changed **(1)**

by same amount **(1)**

Allow; Activation energy of forward and backward reactions lowered by the same amount (1)

CE if effect wrong

3

[12]

30. (a) (i) *Temperature* change decrease **(1)**

Explanation exothermic reaction **(1)**

(ii) *Pressure change* decrease **(1)**

Explanation fewer moles of gas on l.h.s **(1)** 4

(b) (i) *Temperature* to increase reaction rate **(1)**

Pressure to increase reaction rate **(1)**

(ii) *Reason 1* large surface area **(1)**

Reason 2 lower cost in expensive Pt **(1)** 4

(c) (i) enthalpy of formation **(1)**

(ii) <u>standard</u> conditions **(1)**

1 bar pressure and stated (fixed) temperature **(1)**

reactants and products in <u>standard states</u> **(1)**

(iii) Pollutants (acid rain) – NO_x

produced by combustion engines

(iv) decomposition is exothermic **(1)**

Low T reduces effect of heat evolved **(1)** 7

(d) NO produced in Stage 3 **(1)**

can be recycled to Stage 2 **(1)** 2

[17]

32. (a) (i) *Rates:* Rates are equal, forward and backward **(1)**
Concentrations: Concentrations are constant **(1)**
Q of L mark

(ii) *Equilibrium yield:* Decreases **(1)**
if wrong allow max 1 for a correct moles statement

Explanation: More moles / molecules of product (or 2 → 4) **(1)**
Reaction / equilibrium moves to left / reduce constraint **(1)**
NOT "volume" answers
Allow one for "Reaction favours fewer molecules"

(iii) Enthalpy of reaction is positive / endothermic **(1)**

(iv) Both forward and backward rates changed / increased **(1)**
by equal amount (same proportion) **(1)**
allow one for "Ea of forward and backward reactions reduced by an equal amount"

8

(b) (i) The reaction is exothermic **(1)**
High temperature gives a low equilibrium yield **(1)**
Rate of reaction higher at higher temperature **(1)**
An "equilibrium statement" needed e.g. low temp favours the reaction
Do not allow answers based on cost of higher temperature etc

(ii) Higher pressure gives a higher yield **(1)**
4 moles of gaseous reactant form 2 moles of gaseous product **(1)**
Higher pressure generation or equipment is expensive to produce **(1)**
Equilibrium statement required
Cost factor
N.B. NOT a safety answer

6

[14]

33. (a) (i) <u>enthalpy change</u> when 1 mol of a substance (or compound) (QL mark) 1
is (completely) burned in oxygen (or reacted in <u>excess</u> oxygen) 1
at 298 K and 100 kPa (or under standard conditions) 1

(ii) heat produced = mass of water × Sp heat capacity $x\Delta T$ (or $mc\Delta T$) 1
= 150×4.18×64 (note if mass = 2.12 lose first 2 marks then conseq)
= 40100 J or = 40.1 kJ (allow 39.9-40.2 must have correct units) 1
moles methanol = mass/M_r = 2.12/32 (1) 1
= 0.0663

ΔH = – 40.1/0.0663 = – 605 kJ (mol^{-1}) 1
(allow –602 to –608 or answer in J)
(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks

(b) (i) equilibrium shifts to left at high pressure 1
because position of equilibrium moves to favour fewer moles (of gas) 1

(ii) at high <u>temperature</u> reaction yield is low (or at low <u>*T*</u> yield is high) 1
at low <u>temperature</u> reaction is slow (or at high <u>*T*</u> reaction is fast) 1
therefore use a balance (or compromise) between <u>rate</u> and <u>yield</u> 1

(c) $\Delta H = \Sigma \Delta H_c^{\ominus}$(reactants) – $\Sigma \Delta H_c^{\ominus}$(products) (or correct cycle) 1

$\Delta H_c^{\ominus}(CH_3OH) = \Delta H_c^{\ominus}(CO) + 2 \times \Delta H_c^{\ominus}(H_2) - \Delta H$ 1
$= (-283) + (2 \times -286) - (-91)$ (mark for previous equation or this)
$= -764$ (kJ mol^{-1}) (*units not essential but lose mark if units wrong)* 1
(note + 764 scores 1/3)

[15]

34. (a) Homogeneous; All reactants in the same phase or state **(1)**

Dynamic; Continuous or 'on-going' **(1)**

Equilibrium: Concentrations of reactants and products constant or rates of forward and backward reactions equal **(1)**

Equation; $2NH_3 \rightleftharpoons N_2 + 3H_2$ (Must be decomposition) **(1)**

*K*c; $[N_2][H_2]^3/[NH_3]^2$ **(1)**

5

(b) Conditions:

decomposition favoured by high temp **(1)**

since the reaction endothermic or logical statement with application of Le Chatelier's principle **(1)**

decomposition favoured by low pressure **(1)**

2 mole gas giving 4 moles gas or more gas moles on right **(1)**

4

(c) In practise

low pressure means low production **(1)**
low pressure means low rate **(1)**

high temperature means high rate **(1)**
high temperature expensive **(1)**

Catalyst

equilibrium yield unaffected **(1)**
rates of forward and backwards reactions increased by an equal amount **(1)**
more hydrogen produced in a given time **(1)**

Max 6

[15]

35. (a) **Increase in temperature:**

Yield is increased **(Allow if for H_2 (g) or products) (1)**
Reaction endothermic **(1)**
Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to oppose change **OR** to absorb heat **(1)**

If "Yield statement" incorrect allow max one if reaction stated to be endothermic

Increase in pressure:

Yield is decreased **(Allow if for H_2 (g) or products) (1)**
Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles on right **(1)**
Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to oppose change **OR** to reduce pressure **(1)**

If "Yield statement" incorrect allow max one if number of moles change is correct.

6

(b) **Equilibrium yield:**
Unaffected **or** equilibrium unchanged **(1)**
Rate or speed increased **(1)**
Forward and backwards reactions equally or by the same amount **(1)**

Amount of hydrogen produced:
More hydrogen produced **(1)**

4

[10]

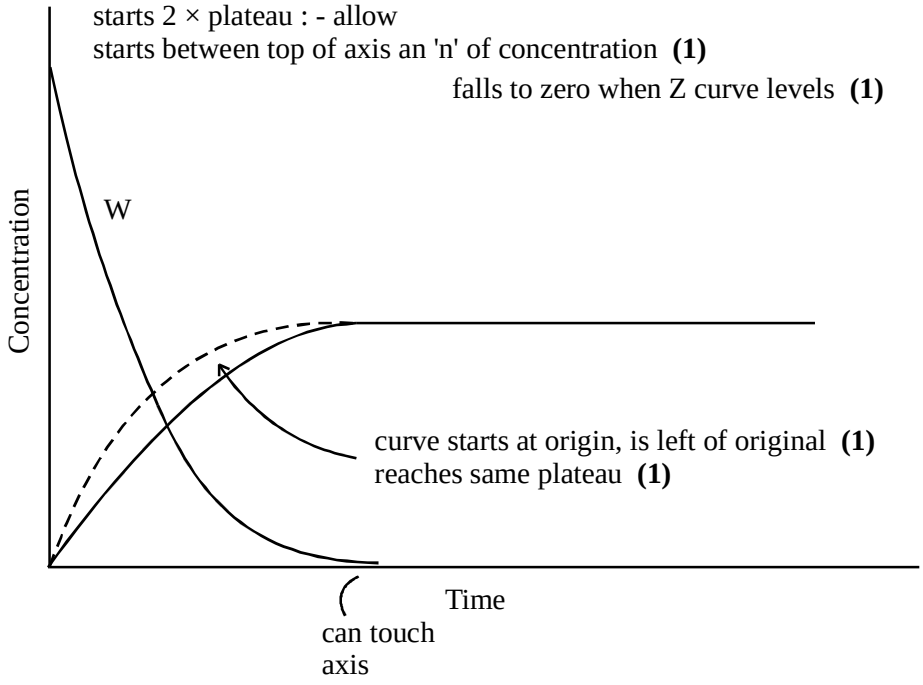
36. (a) <u>minimum</u> energy **(1)**
required before a reaction can occur or go or start **(1)** 2

(b) speeds up (changes) reaction rate **(1)**
without being (chemically) changed **(used up) (1)** 2

(c) provides alternative reaction route **(1)**
with a lower activation energy **(1)**

in (b) and (c) reward 4 marks for 4 points wherever found 2

(d) (i)



starts 2 × plateau : - allow
starts between top of axis an 'n' of concentration **(1)**

falls to zero when Z curve levels **(1)**

curve starts at origin, is left of original **(1)**
reaches same plateau **(1)**

(ii)

can touch axis

(iii) fewer collisions **(1)**
W used up **(1)**
or reactants
or reagents
or fewer particles

6

[12]