Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	Any one from: Catalyst / speeds up reaction / increases rate / increases rate of attainment of equilibrium / lowers activation energy	Ignore any mention of protonation or mechanism for catalysis Do not award additional incorrect types of reaction	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	• calculation of moles of H^+ in 25.0 cm^3 **(1)** • calculation of moles of H^+ in 250 cm^3 flask **(1)**	Ignore SF throughout 8(b)(i) to 8(c)(ii) except 1 SF, which should be penalised once only Example of calculation: (moles NaOH = $0.200 \times \frac{23.60}{1000}$) = 0.00472 (mol) (= mol H^+ in 25.0 cm^3) (= 10 x 0.00472) = 0.0472 (mol) (in 250 cm^3) Allow TE for M2 on moles of NaOH Correct answer with or without working scores 2 marks	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	• subtracts moles of H^+ in HCl from answer to (b)(i)	Example of calculation: 0.0472 – 0.00400 = 0.0432 (mol) Allow TE on answer to part (b)(i)	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)(i)	• calculation of moles of CH_3COOH that have reacted	Example of calculation: (0.105 — 0.0432) = 0.0618 Allow TE on part (b)(ii) unless negative value	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)(ii)	• calculation of equilibrium moles of $CH_3CH_2CH_2OH$ **(1)** • calculation of equilibrium moles of $CH_3COOCH_2CH_2CH_3$ **(1)** • calculation of equilibrium moles of H_2O **(1)**	Example of calculation: 0.0800 — 0.0618 = 0.0182 0.0618 0.111 + 0.0618 = 0.1728 Allow TE on answer to part (c)(i) unless negative value	(3)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(i)	(K_c =) $\frac{[CH_3COOCH_2CH_2CH_3][H_2O]}{[CH_3COOH][CH_3CH_2CH_2OH]}$	IGNORE state symbols even if incorrect Do not award round brackets	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(ii)	An explanation that makes reference to the following points: • Same number of moles/molecules on both sides of the equation (1) • (so) volume / V cancels in K_c expression (1)	2 marks could be scored by a correct mathematical expression showing V or dm^3 cancel Allow same number of terms on top and bottom of K_c expression Allow units cancel out Allow "**all** divided by the same volume"	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(iii)	• calculates value of K_c (1) • final value of K_c quoted to 2 or 3 SF (1)	Example of calculation $K_c = \frac{(0.0618) \times (0.1728)}{(0.0432) \times (0.0182)} =$ 13.58241758 = 14 / 13.6 (no units) Correct answer with no working gains full marks Ignore units No TE on wrong K_c expression	2

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)	An explanation that makes reference to the following points: • the equilibrium shifts to the left **or** the mixture absorbs carbon dioxide from the atmosphere (1) • so the mixture is (becoming more) acidic / the acid reforms (1)	Mark independently Allow no longer alkaline Do not award just "pH decreases"	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(f)	An explanation that makes reference to the following points: • carry out / repeat experiment **and** leave for longer than a week (1) • the titre value / K_c value will remain unchanged (if equilibrium has been established) (1)	Ignore pH probes / checking pH Allow repeat experiment **and** check titres within first week Allow moles / concentration are unchanged Ignore just "results unchanged"	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(g)	An answer that makes reference to the following points: • K_c value will be greater than that calculated in (d)(iii) **(1)** • because the (forward) reaction is endothermic **or** backward / reverse reaction is exothermic **(1)**	M2 depends on M1 Ignore References to the equilibrium position shifting to the right (with increasing temperature)	**(2)**

Q2.

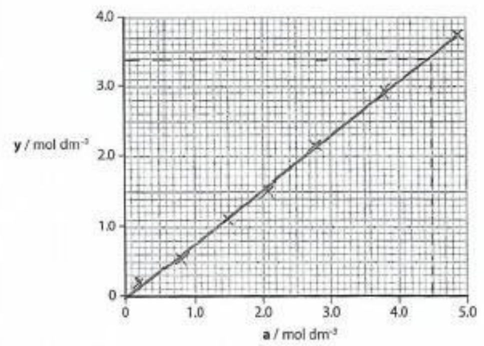
Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(i)	$(K_c =) \dfrac{[HI(g)]^2}{[H_2(g)][I_2(g)]}$	Ignore missing state symbols or units Do not award round brackets	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(ii)	$(K_c =) \dfrac{4y^2}{(a-y)^2}$ • Numerator term correct **(1)** • Denominator term correct **(1)**	Allow square brackets Allow $(2y)^2$ Allow $(a^2 - 2ay + y^2)$ or $(a-y)(a-y)$	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	• both values correct to 2 DP	1.13 2.93	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	• All 7 points plotted correctly **(1)** • Appropriate straight line of best fit, drawn through the origin **(1)**	Allow TE for incorrect values from 9(b)(i) Do not allow all points above or below the line of best fit Allow line of best fit to intersect one square either side of the origin	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iii)	• co-ordinates correctly read off the line on graph **(1)**	At least 1 line must be shown on the graph to indicate selection of co-ordinates	**(2)**



Question Number	Acceptable Answers	Additional Guidance	Mark
	• gradient correctly calculated **(1)**	<u>Example of calculation</u> $\frac{3.40 - 0.00}{4.50 - 0.00}$ = gradient of graph Gradient = 0.76 Ignore SF except 1SF Do not allow units for the gradient Allow a value from 0.71 to 0.81 inclusive	

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iv)	• $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}}$ = gradient / $\frac{\mathbf{y}}{\mathbf{a}}$ **(1)** • re-arrangement of expression and calculation of K_c **(1)**	<u>Example of calculation</u> $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = 0.76$ K_c = 40.1 /40 (no units) Allow TE on gradient from part (iii) $K_c = [(2 \times \text{grad})/(1\text{-grad})]^2$ Correct answer with no working scores (2)	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	• hydrogen is flammable / explosive	Allow iodine vapour damages eyes /toxic Allow hydrogen iodide is corrosive / acidic / irritant (if qualified) / lachrymator Ignore references to high pressure Ignore references to safety precautions	**(1)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)	• Faster rate of reaction / increased rate (1) • K_c unchanged (1)	Ignore references to shifting position of equilibrium	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(i)	An explanation that makes reference to the following points: • (K_c is) smaller / decreases / gets less (1) • (forward) reaction is exothermic (1)	Allow reverse/backwards reaction is endothermic MP2 dependent on MP1	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(ii)	• straight line drawn on the graph with a less steep gradient (and goes through the origin)	Do not allow if lines cross	(1)

Q3.

Question Number	Answer	Additional Guidance	Mark
	• calculation of eqm moles (1) • expressions for 3 partial pressures (1) • substitution of values into K_p expression (1) • rearrangement of K_p expression (1) • calculation of total pressure **and** answer to 1 / 2 SF (1)	Example of calculation Initial mol: N_2 1.0; H_2 3.0; NH_3 - Eqm mol: N_2 1.0 − 0.15 = 0.85; H_2 3.0 − (3 x 0.15) = 2.55; NH_3 0.30 Total mol at eqm: 0.85 + 2.55 + 0.30 = 3.7 Partial pressure: N_2 $\frac{0.85}{3.7} \times P$; H_2 $\frac{2.55}{3.7} \times P$; NH_3 $\frac{0.30}{3.7} \times P$ $K_p = 7.76 \times 10^{-5} = \frac{\left(\frac{0.30 \times P}{3.7}\right)^2}{\left(\frac{0.85 \times P}{3.7}\right)\left(\frac{2.55 \times P}{3.7}\right)^3}$ $7.76 \times 10^{-5} = \frac{0.087419}{P^2}$ $P^2 = 1126.5$ (atm^2) $P = 33.564$ $= 34 / 30$ (atm) Allow any symbol for total pressure Allow TE throughout Correct answer to 1 or 2 SF with some working scores (5) Correct answer to 1 or 2 SF with no working scores (4)	(5)

Q4.

Question Number	Answer	Additional Guidance	Mark
	• the quotient / Q: $\frac{[CO_2][H_2]}{[CO][H_2O]} = \frac{2 \times 2}{1 \times 1} = 4$, which is larger than K_c **or** (since $K_c = 1$) the concentrations of the products must be equal to the concentrations of the reactants at equilibrium **(1)**	Allow amounts / moles / (partial) pressures for concentrations Allow calculated K_c / the quotient / Q will be greater than 1	**(3)**
	• the concentrations of CO_2 and H_2 / products need to decrease **and** those of CO and H_2O / reactants need to increase **(1)**	Allow shift so that there is 1.5 mol of each substance	
	• so reaction shifts to the left **(1)**	M3 conditional on some explanation	

Q5.

Question Number	Answer	Additional Guidance	Mark
	• calculation of initial mol I^- **(1)**	Example of calculation initial mol I^- = (25.0 x 0.100) ÷1000 = 2.5 x 10^{-3} / 0.0025 (mol)	**(7)**
	• calculation of eqm mol I^- **(1)**	eqm mol I^- (= mol Ag^+) = (12.20 x 0.0500) ÷1000 = 6.1 x 10^{-4} / 0.00061 (mol)	
	• calculation of mol I^- reacted **(1)**	mol I^- reacted = 2.5 x 10^{-3} – 6.1 x 10^{-4} = 1.89 x 10^{-3} / 0.00189 (mol)	
	• calculation of eqm mol-1 SO_4^{2-} **(1)**	eqm mol SO_4^{2-}= mol I^- reacted / 2 =1.89 x 10^{-3} ÷ 2 = 9.45 x 10^{-4} / 0.000945	
	• calculation of eqm [SO_4^{2-}(aq)] **and** calculation of eqm [I^-(aq)] **(1)**	eqm [SO_4^{2-}] = (9.45 x 10^{-4} x 1000) ÷ 25 = 0.0378 (mol dm^{-3}) **and** eqm [I^-] = (6.1 x 10^{-4} x 1000) ÷ 25.0 = 2.44 x 10^{-2} / 0.0244 (mol dm^{-3})	
	• calculation of K_c **and** answer to 2 / 3 SF **(1)**	K_c = 0.0378 ÷ 0.0244^2 = (63.49) = 63 / 63.5 Do not award unless their numbers are correct or are TE. Allow TE throughout. Correct answer with working gains 7 marks	
	• units **(1)**	dm^3 mol^{-1} (standalone mark) Allow dm^3 mol^- / mol^{-1} dm^3 / mol^- dm^3	

Q6.

Question Number	Answer	Additional Guidance	Mark
	• rearrangement of formula (1) • substitution of correct values (1) • calculation of K_c (1) • units (1)	Example of calculation $K_c = K_p \times (RT)^{\Delta n}$ $K_c = 3.55 \times 10^{-2} \times (0.0821 \times 500)^2$ $K_c = 59.821$ TE on Δn Stand alone mark $dm^6\ mol^{-2}$ or $mol^{-2}\ dm^6$ Correct value with units and no working scores (4) Ignore SF except 1 SF M1 and M2 can be in reverse order	(4)

Q7.

Question Number	Answer	Additional Guidance	Mark
	• substitution of numbers into expression (1) • evaluation of $\Delta H/R$ and $1/T_1 - 1/T_2$ (1) • rearrangement of expression (1) • evaluation of expression (1)	Example of calculation $\ln\left(\frac{K_2}{6.76 \times 10^5}\right) = \left(\frac{-92400}{8.31}\right)\left(\frac{1}{298} - \frac{1}{310}\right)$ $\ln\left(\frac{K_2}{6.76 \times 10^5}\right) = -11119.1 \times 1.299 \times 10^{-4}$ $= -1.4444$ $K_2 = 6.76 \times 10^5 \times e^{-1.4444}$ TE on M2 $K_2 = 1.59467 \times 10^5$ / 159467(atm^{-2}) TE on M3 Allow answer from earlier correct rounding to 2 or more SF Ignore SF except 1 SF Correct answer with no / some working scores (4)	(4)

Q8.

Question Number	Answer	Additional Guidance	Mark
(i)	• (M1) calculation of mole fractions (1) • (M2) calculation of partial pressures (1) • (M3) expression of K_p (1) • (M4) calculation of value of K_p (1) • (M5) units (1)	Example of calculation X_{SO_2} = 0.0160 ÷ 0.8 = 0.02(0) X_{O_2} = 0.0120 ÷ 0.8 =0.015 X_{SO_3} = 0.772 ÷ 0.8 =0.965 P_{SO_2} = 0.02(0) x 2.40 = 0.048 P_{O_2} = 0.015 x 2.40 = 0.036 P_{SO_3} = 0.965 x 2.40 =2.316 $K_p = \frac{(P_{SO_3})^2}{(P_{SO_2})^2 \times P_{O_2}}$ Do not award square brackets $K_p = \frac{2.316^2}{0.048^2 \times 0.036}$ = K_p= 64668.4…./6.46684.. x 10^4 K_p= 65000/6.5 x 10^4/64700/6.47 x 10^4 Ignore SF except 1 atm^{-1} Correct final answer without working scores	(5) (5)

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of the number of molecules	Example of calculation N=(n x L = 0.0160 x 6.02 x 10^{23}) = 9.632 x 10^{21} Ignore SF except 1SF Do not award if any units are given	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to the following points: • to ensure that K_p stays the same/ quotient stays the same **or** only temperature changes the value of K_p **(1)** • the number of (sulfur dioxide) molecules decreases **Either** because the equilibrium shifts to the right or because one of the denominators (oxygen) has increased so the other denominator (sulfur dioxide) has to decrease **(1)**	Standalone marks Allow concentration changes have no effect on the value of K_p Allow 'moles' for molecules	(2)

Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following point: • the concentration of a solid / $Mg(OH)_2$ is constant / unchanged / changes very little	Allow magnesium hydroxide is in a different phase / state (from the aqueous ions) Ignore solids do not appear in K_c expressions / just 'it is solid' Ignore solid does not affect the concentration of the solution Ignore it is a heterogeneous equilibrium Ignore it is difficult to measure the concentration of a solid Do not award the solid does not have a concentration	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(ii)	• $mol^3\ dm^{-9}$	Allow $dm^{-9}\ mol^3$ mol^3/dm^9 Ignore any working before the answer	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	• use of $\Delta_{sol}H = \Delta_{hyd}H[Mg^{2+}(aq)] + 2\Delta_{hyd}H[OH^-(aq)] - \Delta_{latt}H[Mg(OH)_2(s)]$ **(1)** • calculation of $\Delta_{sol}H$ **(1)**	Example of calculation $\Delta_{sol}H = -1920 + 2(-460) - (-2842)$ Allow this shown on a Hess cycle $\Delta_{sol}H = (+)2$ (kJ mol^{-1}) Allow 2000 J mol^{-1} Correct answer with no working scores 2	**(2)**

Question Number	Answer	Mark
(iv)	**The only correct answer is D** ***A*** *is not correct because it should not be linear and should level off* ***B*** *is not correct because it should not increase in that way and should level off* ***C*** *is not correct because it should not be horizontal*	**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(v)	An answer that makes reference to the following points: Addition of magnesium sulfate solution: • equilibrium position shifts to the left / in the backwards direction **(1)** • because increased concentration / amount of magnesium ions / Mg^{2+}((aq)) **(1)** Addition of dilute hydrochloric acid: • equilibrium shifts to the right / in the forwards direction **(1)** • because the hydrogen ions / H^+((aq)) react with / neutralise / removes the hydroxide ions / OH^-((aq)) **(1)**	Mark independently Allow more magnesium hydroxide precipitates / forms Allow more Mg^{2+} ions present Allow more magnesium hydroxide dissolves / dissociates Allow H^+((aq)) + OH^-((aq)) $\rightarrow H_2O$((l)) Allow magnesium hydroxide reacts with / is neutralised by acid / equation to show this Allow acid / HCl reacts with / neutralises / removes hydroxide ions Penalise reference to K_c changing once only	**(4)**

Q10.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following point: • carbon / solid has no (vapour / partial) pressure **or** (partial) pressure of carbon / solid is constant **or** carbon does not contribute to the overall pressure (of the system)	Allow the reaction is heterogeneous **and** (partial) pressure of a pure solid is not included (in K_p expression) Do not allow just 'because carbon is a solid' or 'carbon is not a gas'	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • there are fewer moles / molecules / particles of **gas** on the left / reactant side **(1)** • so equilibrium position/ it moves / shifts to the left / reactant side **(1)**	Allow 2 moles / molecules of **gas** on right and 1 mole / molecule on left M2 is conditional on M1 **or** the idea of fewer particles on the left / decreasing the value of the quotient / Q Do not allow any indication of K_p changing	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points: • (forward) reaction is endothermic **and** so equilibrium constant / K_p increases as temperature increases **(1)** • so equilibrium position / it moves / shifts to the right / product side **(1)**	Ignore references to ΔG and ΔS M2 is conditional on M1 **or** endothermic or equilibrium constant increases	(2)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>(iv)</td>
<td>

calculation of moles of each substance at equilibrium
(1)
calculation of partial pressure of each substance
(1)
calculation of K_p
(1)
units (stand alone mark)
(1)

</td>
<td>
Example of calculation:
<table>
<tr><th></th><th>$H_2O(g)$</th><th>$H_2(g)$</th><th>$CO(g)$</th></tr>
<tr><td>Initial moles</td><td>1.00</td><td>0</td><td>0</td></tr>
<tr><td>Eqm moles</td><td>1.00 − 0.81 = 0.19</td><td>0.81</td><td>0.81</td></tr>
<tr><td colspan="4">Total moles = 0.19 + 0.81 + 0.81 = 1.81</td></tr>
<tr><td>Mole fraction</td><td>0.19/1.81 = 0.10497</td><td>0.81/1.81 = 0.4475</td><td>0.81/1.81 = 0.4475</td></tr>
<tr><td>Partial pressure /atm</td><td>0.10497 x 2.0 =0.20994</td><td>0.4475 x 2.0 = 0.895</td><td>0.4475 x 2.0 =0.895</td></tr>
</table>
$K_p = \frac{0.895 \times 0.895}{0.20994}$
= 3.815 / 3.82 / 3.8 atm

3.8144 / 3.814 / 3.81 / 3.8 atm from 0.105 and 0.210

Correct answer with units but no working scores (4)

Allow TE for M2 and M3

Ignore SF except 1 SF
</td>
<td>(4)</td>
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</table>

Q11.

Question Number	Answer	Mark
(i)	**The only correct answer is C** (120° and 109.5°) ***A*** *is incorrect because both angles are incorrect* ***B*** *is incorrect because 90° is incorrect* ***D*** *is incorrect because 109.5° is incorrect for the left hand O−C−H angle*	(1)

Question Number	Answer	Mark
(ii)	**The only correct answer is D** (atm^{-1}) ***A*** *is incorrect because it is the inverse of the units for* K_C ***B*** *is incorrect because it is the units for* K_C ***C*** *is incorrect because it is the inverse of the units for* K_p	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to the following points • K_p will remain unchanged (1) • equilibrium moves to right-hand side (to keep K_p constant) / only temperature affects K_p (1)	Allow answers in terms of quotient Do not award M2 if K_p is described as changing Ignore comments related to rate	(2)

Q12.

Question Number	Answer	Additional Guidance	Mark
(i)	• $K_c = \frac{[CH_3COOCH_2CH_3(l)][H_2O(l)]}{[CH_3COOH(l)][CH_3CH_2OH(l)]}$	Ignore omission of state symbols Do not award round brackets	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	• expression for equilibrium amounts in terms of x (1) • use equilibrium amounts in K_c expression and rearrangement to find amount of product / express as correct quadratic expression (1) • calculation of amount of product (1)	Example of calculation Amounts $CH_3CH_2OH = 1.2 - x$; $CH_3COOH = 1.2 - x$; $CH_3COOCH_2CH_3 = x$; $H_2O = x$ $K_c = \frac{(x \div vol)^2}{[(1.2-x) \div vol]^2}$ $K_c = (x^2 \div vol^2) \div ((1.2-x)^2 \div vol^2)$ $K_c = x^2 \div (1.2-x)^2$ so $x^2 = K_c \times (1.2-x)^2$ $x = \sqrt{K_c} \times (1.2-x)$ $x = 0.63498 \div 1.52915$; $x = 0.41525 = 0.42$ (So amounts of each product = 0.42 (mol)) Allow use of quadratic equation for M2 Allow M2 for expression without inclusion of volume Correct answer with no working scores 3 marks Ignore SF except 1 SF Ignore negative amounts Allow alternative methods Allow TE throughout (a)(ii) for use of $x / (1.2-x)^2$ in K_c expression	(3)

Q13.

Question Number	Answer	Additional Guidance	Mark
	An explanation that makes reference to the following points: • there are fewer moles / molecules / particles of (gas) on the right (1) • so (equilibrium) yield of ammonia increases (1)	Any reference to equilibrium constant changing scores (0) overall Allow 4 moles / molecules of gas on the left **and** 2 moles / molecules on right Allow 'equilibrium shifts to the right' M2 is conditional on M1 or the idea of fewer particles on the right / increasing the value of the quotient / Q Allow reverse argument	(2)

Q14.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• K_c expression **(1)** • units based on their K_c expression **(1)**	$(K_c =)\ \dfrac{[N_2(g)]^2\,[H_2O(g)]^6}{[NH_3(g)]^4[O_2(g)]^3}$ ignore missing state symbols do not award round brackets mol dm^{-3} or mol/dm^3	**(2)**

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	$(K_c =)\ \dfrac{[SO_3]^2}{[O_2][SO_2]^2}$	Do not award just K or K_p. must be square brackets do not accept partial pressures ignore units or lack of units ignore state symbols Allow x sign in the denominator but not +	**(1)**

Question Number	Answer	Mark
(ii)	**The only correct answer is B** ***A*** *is not correct because it refers to the inverted expression for* K_c ***C*** *is not correct because units do not cancel for concentration*^{2}*/concentration*^{3} ***D*** *is not correct because it refers to concentration*^{3}*/concentration or similar ratio of powers*	(1)