

Markscheme

May 2019

Chemistry

Higher level

Paper 2

18 pages

No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without written permission from the IB.

Additionally, the license tied with this product prohibits commercial use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, is not permitted and is subject to the IB's prior written consent via a license. More information on how to request a license can be obtained from <http://www.ibo.org/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite de l'IB.

De plus, la licence associée à ce produit interdit toute utilisation commerciale de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, n'est pas autorisée et est soumise au consentement écrit préalable de l'IB par l'intermédiaire d'une licence. Pour plus d'informations sur la procédure à suivre pour demander une licence, rendez-vous à l'adresse <http://www.ibo.org/fr/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin que medie la autorización escrita del IB.

Además, la licencia vinculada a este producto prohíbe el uso con fines comerciales de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales— no está permitido y estará sujeto al otorgamiento previo de una licencia escrita por parte del IB. En este enlace encontrará más información sobre cómo solicitar una licencia: <http://www.ibo.org/es/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Question			Answers	Notes	Total
1.	a		$\text{C}_2\text{H}_2(\text{g}) + 2.5\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ OR $2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \checkmark$		1
1.	b	i	$\text{H}:\text{C}::\text{C}:\text{H} / \text{H}-\text{C}\equiv\text{C}-\text{H} \checkmark$	Accept any valid combination of lines, dots and crosses.	1
1.	b	ii	«ethyne» shorter AND a greater number of shared/bonding electrons OR «ethyne» shorter AND stronger bond \checkmark		1
1.	b	iii	London/dispersion/instantaneous dipole-induced dipole forces \checkmark	Do not accept just “intermolecular forces” or “van der Waals’ forces”.	1
1.	c	i	ethanal \checkmark		1
1.	c	ii	«sum of bond enthalpies of reactants \Rightarrow $2(\text{C}-\text{H}) + \text{C}\equiv\text{C} + 2(\text{O}-\text{H})$ OR $2 \times 414 \text{ «kJ mol}^{-1}\text{»} + 839 \text{ «kJ mol}^{-1}\text{»} + 2 \times 463 \text{ «kJ mol}^{-1}\text{»}$ OR $2593 \text{ «kJ»} \checkmark$ «sum of bond enthalpies of A \Rightarrow $3(\text{C}-\text{H}) + \text{C}=\text{C} + \text{C}-\text{O} + \text{O}-\text{H}$ OR $3 \times 414 \text{ «kJ mol}^{-1}\text{»} + 614 \text{ «kJ mol}^{-1}\text{»} + 358 \text{ «kJ mol}^{-1}\text{»} + 463 \text{ «kJ mol}^{-1}\text{»}$ OR $2677 \text{ «kJ»} \checkmark$ «enthalpy of reaction = $2593 \text{ kJ} - 2677 \text{ kJ}$ » = $-84 \text{ «kJ»} \checkmark$	Award [3] for correct final answer.	3

(continued...)

(Question 1c continued)

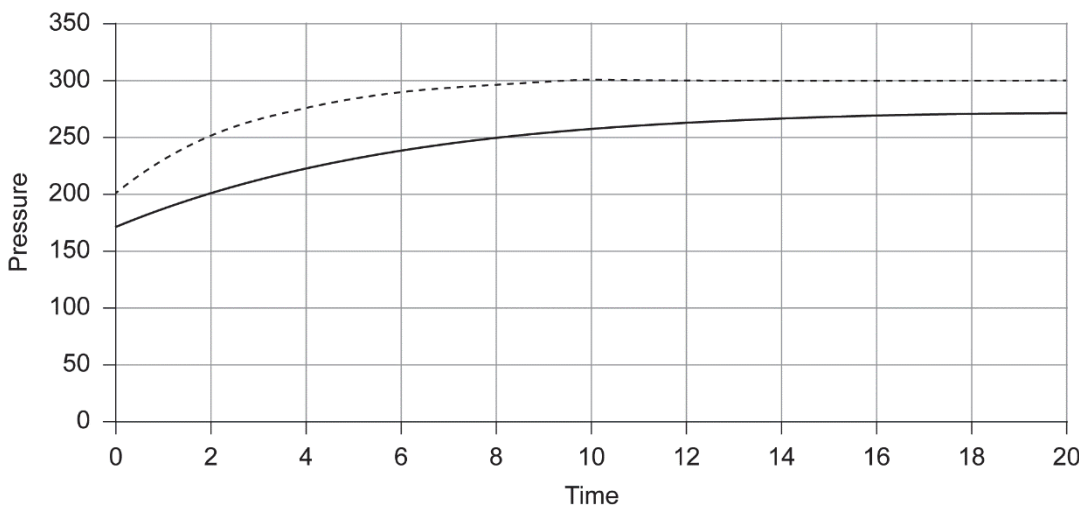
Question			Answers	Notes	Total
1.	c	iii	B AND it has a more negative/lower enthalpy/«potential» energy OR B AND more exothermic «enthalpy of reaction from same starting point» ✓		1
1.	c	iv	<p>Identity of product: «B»</p> <p>IR spectrum:</p> <p>1700–1750 «cm⁻¹ band» AND carbonyl/CO group present</p> <p>OR</p> <p>no «band at» 1620–1680 «cm⁻¹» AND absence of double bond/C=C</p> <p>OR</p> <p>no «broad band at» 3200–3600 «cm⁻¹ » AND absence of hydroxyl/OH group ✓</p> <p>¹H NMR spectrum:</p> <p>«only» two signals AND A would have three</p> <p>OR</p> <p>«signal at» 9.4–10.0 «ppm» AND «H atom/proton of» aldehyde/–CHO present</p> <p>OR</p> <p>«signal at» 2.2–2.7 «ppm» AND «H atom/proton of alkyl/CH next to» aldehyde/CHO present</p> <p>OR</p> <p>«signal at» 2.2–2.7 «ppm» AND «H atom/proton of» RCOCH₂- present</p> <p>OR</p> <p>no «signal at» 4.5–6.0 «ppm» AND absence of «H atom/proton next to» double bond/C=C ✓</p>	<p>Accept a specific value or range of wavenumbers and chemical shifts.</p> <p>Accept “two signals with areas 1:3”.</p>	2

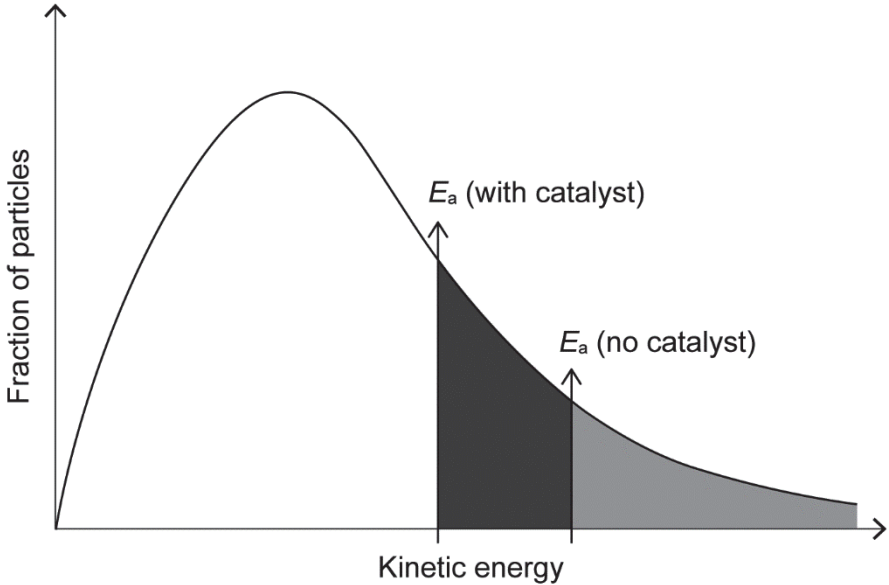
(continued...)

(Question 1c continued)

Question			Answers	Notes	Total
1.	c	v	2.3 ppm: doublet ✓ 9.8 ppm: quartet ✓		2
1.	d	i	<i>Reagents:</i> acidified/H ⁺ AND «potassium» dichromate(VI)/K ₂ Cr ₂ O ₇ /Cr ₂ O ₇ ²⁻ ✓ <i>Conditions:</i> distil «the product before further oxidation» ✓	Accept “«acidified potassium» manganate(VII)/KMnO ₄ /MnO ₄ ⁻ /permanganate”. Accept “H ₂ SO ₄ ” or “H ₃ PO ₄ ” for “H ⁺ ”. Accept “more dilute dichromate(VI)/manganate(VII)” or “excess ethanol”. Award M1 if correct reagents given under “Conditions”.	2
1.	d	ii	–1 ✓		1
1.	d	iii	<i>Any three of:</i> has an oxygen/O atom with a lone pair ✓ that can form hydrogen bonds/H-bonds «with water molecules» ✓ hydrocarbon chain is short «so does not disrupt many H-bonds with water molecules» ✓ «large permanent» dipole-dipole interactions with water ✓		3 max

Question			Answers	Notes	Total
2.	a		increase in the amount/number of moles/molecules «of gas» ✓ from 2 to 3/by 50 % ✓		2
2.	b		«rate of reaction decreases» concentration/number of molecules in a given volume decreases OR more space between molecules ✓ collision rate/frequency decreases OR fewer collisions per unit time ✓	<i>Do not accept just "larger space/volume" for M1.</i>	2
2.	c	i	half «of the initial rate» ✓	<i>Accept "lower/slower «than initial rate»".</i>	1
2.	c	ii	1 slower than 2 OR 1 rate determinant step/RDS ✓ 1 is unimolecular/involves just one molecule so it must be first order OR if 1 faster/2 RDS, second order in N ₂ O OR if 1 faster/2 RDS, first order in O ✓		2

Question			Answers	Notes	Total
2.	d		 <p>smaller initial gradient ✓</p> <p>initial pressure is lower AND final pressure of gas lower «by similar factor» ✓</p>		2
2.	e		<p>no AND it is a systematic error/not a random error</p> <p>OR</p> <p>no AND «a similar magnitude» error would occur every time ✓</p>		1

Question	Answers	Notes	Total
2. f	 <p>catalysed and uncatalysed E_a marked on graph AND with the catalysed being at lower energy ✓</p> <p>«for catalysed reaction» greater proportion of/more molecules have $E \geq E_a$ / $E > E_a$ OR «for catalysed reaction» greater area under curve to the right of the E_a ✓</p>	<p>Accept “more molecules have the activation energy”.</p>	2
2. g	<p>i</p> <p>$\Delta S^\ominus = 2(S^\ominus(\text{N}_2)) + S^\ominus(\text{O}_2) - 2(S^\ominus(\text{N}_2\text{O}))$ OR $\Delta S^\ominus = 2 \times 193 \text{ «J mol}^{-1} \text{ K}^{-1}\text{»} + 205 \text{ «J mol}^{-1} \text{ K}^{-1}\text{»} - 2 \times 220 \text{ «J mol}^{-1} \text{ K}^{-1}\text{»} \checkmark$ $\text{«}\Delta S^\ominus = +\text{»}151 \text{ «J K}^{-1}\text{»} \checkmark$</p>	<p>Award [2] for correct final answer.</p>	2

(continued...)

(Question 2g continued)

Question			Answers	Notes	Total
2.	g	ii	<p>exothermic decomposition</p> <p>OR</p> <p>$\Delta H_{(\text{decomposition})} < 0 \checkmark$</p> <p>$T\Delta S^{\ominus} > \Delta H^{\ominus}$</p> <p>OR</p> <p>$\Delta G^{\ominus} \ll \Delta H^{\ominus} - T\Delta S^{\ominus} \ll 0$ «at all temperatures» \checkmark</p> <p>reaction spontaneous at all temperatures \checkmark</p>		3

Question			Answers	Notes	Total
3.	a	i	absorbs <u>UV/ultraviolet</u> light «of longer wavelength than absorbed by O ₂ » ✓		1
3.	a	ii	$\text{NO (g)} + \text{O}_3 \text{ (g)} \rightarrow \text{NO}_2 \text{ (g)} + \text{O}_2 \text{ (g)} \checkmark$ $\text{NO}_2 \text{ (g)} + \text{O}_3 \text{ (g)} \rightarrow \text{NO (g)} + 2\text{O}_2 \text{ (g)} \checkmark$	Ignore radical signs. Accept equilibrium arrows. Award [1 max] for $\text{NO}_2 \text{ (g)} + \text{O (g)} \rightarrow \text{NO (g)} + \text{O}_2 \text{ (g)}$.	2
3.	b	i	mass spectrometry/MS ✓		1
3.	b	ii	$\ll \frac{(98 \times 14) + (2 \times 15)}{100} \Rightarrow 14.02 \checkmark$ $\ll M_r = (14.02 \times 2) + 16.00 \Rightarrow 44.04 \checkmark$		2
3.	b	iii	Any two: same AND have same nuclear charge /number of protons/ Z_{eff} ✓ same AND neutrons do not affect attraction/ionization energy/ Z_{eff} OR same AND neutrons have no charge ✓ same AND same attraction for «outer» electrons ✓ same AND have same electronic configuration/shielding ✓	Accept “almost the same”. “Same” only needs to be stated once.	2 max

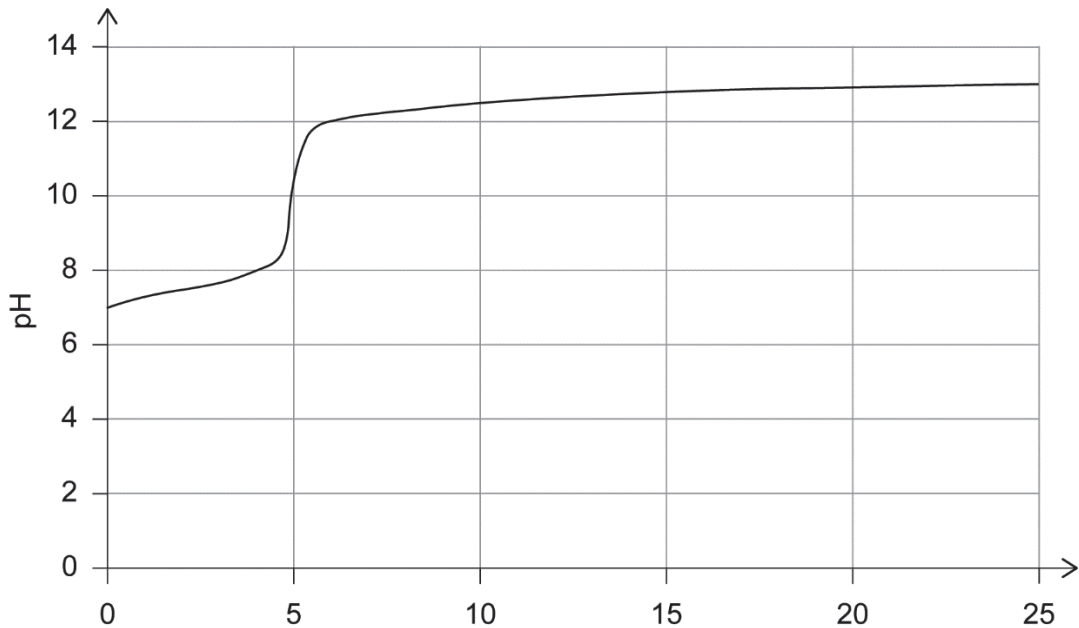
Question			Answers	Notes	Total
3.	c		<p><i>Nitrogen and carbon:</i> N has greater nuclear charge/«one» more proton «and electrons both lost from singly filled p-orbitals» ✓</p> <p><i>Nitrogen and oxygen:</i> O has a doubly filled «p-»orbital OR N has only singly occupied «p-»orbitals ✓</p>	<p>Accept “greater e⁻ – e⁻ repulsion in O” or “lower e⁻ – e⁻ repulsion in N”.</p> <p>Accept box annotation of electrons for M2.</p>	2
3.	d	i	<p>delocalization OR delocalized π-electrons ✓</p>	Accept “resonance”.	1
3.	d	ii	<p>linear AND 2 electron domains OR linear AND 2 regions of electron density ✓</p>	Accept “two bonds AND no lone pairs” for reason.	1
3.	d	iii	sp ✓		1

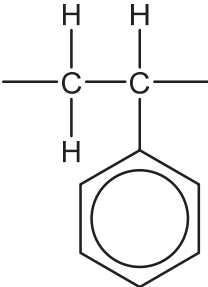
Question			Answers	Notes	Total
4.	a		$^{185}_{75}\text{Re}$ ✓		1
4.	b	i	gap in the periodic table OR element with atomic number «75» unknown OR break/irregularity in periodic trends ✓ «periodic table shows» regular/periodic trends «in properties» ✓		2
4.	b	ii	electrolyze «a solution of /molten» rhenium salt/ Re^{n+} ✓ graphite as cathode/negative electrode OR rhenium forms at cathode/negative electrode ✓	Accept “using rhenium anode” for M1.	2
4.	b	iii	Any two of: variable oxidation states ✓ forms complex ions/compounds ✓ coloured compounds/ions ✓ «para»magnetic compounds/ions ✓	Accept other valid responses related to its chemical metallic properties. Do not accept “catalytic properties”.	2 max
4.	c		place «pieces of» Re into each solution ✓ if Re reacts/is coated with metal, that metal is less reactive «than Re» ✓	Accept other valid observations such as “colour of solution fades” or “solid/metal appears” for “reacts”.	2

Question			Answers	Notes	Total
4.	d	i	rhenium(III) chloride OR rhenium trichloride ✓		1
4.	d	ii	$\ll M_r \text{ReCl}_3 = 186.21 + (3 \times 35.45) = \gg 292.56 \checkmark$ $\ll 100 \times \frac{186.21}{292.56} = \gg 63.648 \text{ \%} \gg \checkmark$		2
4.	e	i	same group as Mn «which forms MnO_4^- » OR in group 7/has 7 valence electrons, so its «highest» oxidation state is +7 ✓		1
4.	e	ii	$\text{ReO}_4^- (\text{aq}) + 6\text{H}^+ (\text{aq}) + 3\text{e}^- \rightleftharpoons [\text{Re}(\text{OH})_2]^{2+} (\text{aq}) + 2\text{H}_2\text{O} (\text{l}) \checkmark$		1
4.	e	iii	no AND ReO_4^- is a weaker oxidizing agent than Fe^{3+} OR no AND Fe^{3+} is a stronger oxidizing agent than ReO_4^- OR no AND Fe^{2+} is a weaker reducing agent than $[\text{Re}(\text{OH})_2]^{2+}$ OR no AND $[\text{Re}(\text{OH})_2]^{2+}$ is a stronger reducing agent than Fe^{2+} OR no AND cell emf would be negative/–0.41 V ✓		1

Question			Answers	Notes	Total
5.	a	i	<p><i>Weak acid</i>: partially dissociated/ionized «in aqueous solution/water»</p> <p>AND</p> <p><i>Strong acid</i>: «assumed to be almost» completely/100 % dissociated/ionized «in aqueous solution/water» ✓</p>		1
5.	a	ii	<p>CO_3^{2-} ✓</p>		1
5.	b		<p>shifts to left/reactants AND to increase amount/number of moles/molecules of gas/CO_2 (g) ✓</p>	<p>Accept “shifts to left/reactants AND to increase pressure”.</p>	1
5.	c		<p>«$K_a \Rightarrow 10^{-6.36}/4.37 \times 10^{-7} = \frac{[\text{H}^+]^2}{[\text{CO}_2]}$</p> <p>OR</p> <p>«$K_a \Rightarrow 10^{-6.36}/4.37 \times 10^{-7} = \frac{[\text{H}^+]^2}{0.200}$ ✓</p> <p>$[\text{H}^+] \llcorner = \sqrt{0.200 \times 4.37 \times 10^{-7}} \llcorner = 2.95 \times 10^{-4} \llcorner \text{«mol dm}^{-3}\llcorner \llcorner$</p> <p>«pH \Rightarrow 3.53 ✓</p>	<p>Award [3] for correct final answer.</p>	3

Question			Answers	Notes	Total
5.	d	i	<p><i>Between sodium and hydrogencarbonate:</i> ionic ✓</p> <p><i>Between hydrogen and oxygen in hydrogencarbonate:</i> «polar» covalent ✓</p>		2
5.	d	ii	<p>«additional HCO_3^-» shifts position of equilibrium to left ✓</p> <p>pH increases ✓</p>	<i>Do not award M2 without any justification in terms of equilibrium shift in M1.</i>	2
5.	d	iii	<p>«molar mass of NaHCO_3 =» 84.01 g mol^{-1}» ✓</p> <p>«concentration = $\frac{3.0 \times 10^{-2} \text{ g}}{84.01 \text{ g mol}^{-1}} \times \frac{1}{0.100 \text{ dm}^3}$ =» $3.6 \times 10^{-3} \text{ mol dm}^{-3}$» ✓</p>	<i>Award [2] for correct final answer.</i>	2
5.	d	iv	« $1.0 - 0.6 = \pm 0.4$ «%» ✓		1
5.	e		<p><i>Equation (3):</i> OH^- donates an electron pair AND acts as a Lewis base ✓</p> <p><i>Equation (4):</i> OH^- accepts a proton/H^+/hydrogen ion AND acts as a Brønsted–Lowry base ✓</p>		2

Question			Answers	Notes	Total
5.	f		 <p>S-shaped curve from ~7 to between 12 and 14 ✓ equivalence point at 5 cm³ ✓</p>	Accept starting point >6~7.	2

Question			Answers	Notes	Total
6.	a		 $\text{ / } -\text{CH}_2\text{CH}(\text{C}_6\text{H}_5)- \checkmark$	<p>Do not penalize the use of brackets and “n”.</p> <p>Do not award the mark if the continuation bonds are missing.</p>	1
6.	b		$\ln k \ll -\frac{10000}{8.31 \times 298} \gg = -4.04 \checkmark$ $k = 0.0176 \checkmark$	Award [2] for correct final answer.	2
6.	c		<p><i>Similarity:</i></p> <p>«both» involve an electrophile OR «both» electrophilic \checkmark</p> <p><i>Difference:</i></p> <p>first/reaction of ring/with NO_2^+ is substitution/$\text{S}_{\text{«E»}}$ AND second/reaction of $\text{C}=\text{C}$/with HBr is addition/$\text{A}_{\text{«E»}}$ \checkmark</p>	<p>Answer must state which is substitution and which is addition for M2.</p>	2

Question			Answers	Notes	Total
6.	d	i	<p>Two forms:</p> <p>chiral/asymmetric carbon</p> <p>OR</p> <p>carbon atom attached to 4 different groups ✓</p> <p>Relationship:</p> <p>mirror images</p> <p>OR</p> <p>enantiomers/optical isomers ✓</p>	Accept appropriate diagrams for either or both marking points.	2
6.	d	ii	benzene ring «of the C ₆ H ₅ –CH ₂ » and the bromine «on the CH ₂ –Br» can take up different relative positions by rotating about the «C–C, σ–»bond ✓	<p>Accept “different parts of the molecule can rotate relative to each other”.</p> <p>Accept “rotation around σ–bond”.</p>	1
6.	e		C ₆ H ₅ –CH ₂ –CH ₂ OH ✓		1