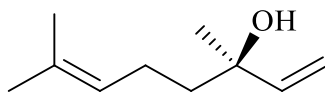


Marks
4

- The structure of (–)-linalool, a commonly occurring natural product, is shown below.



What is the molecular formula of (–)-linalool?

C₁₀H₁₈O

Which of the following best describes (–)-linalool?
achiral compound, racemic mixture,
(*R*)-enantiomer, or (*S*)-enantiomer

(*R*)-enantiomer

What functional groups are present in (–)-linalool?

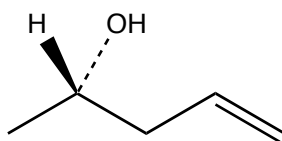
Tertiary alcohol and alkene

Is it possible to obtain (*Z*) and (*E*) isomers of (–)-linalool? Give a reason for your answer.

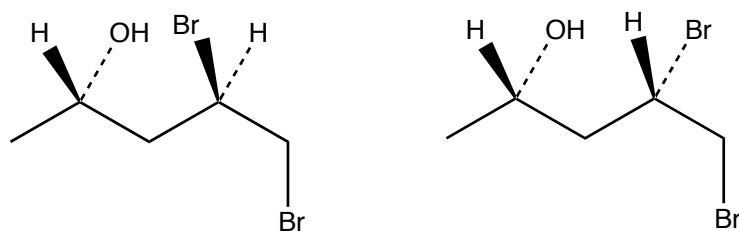
No. One end of each double bond has two identical groups (methyl or hydrogen) attached to it.

Marks
3

- Draw the structure of (*S*)-pent-4-en-2-ol.

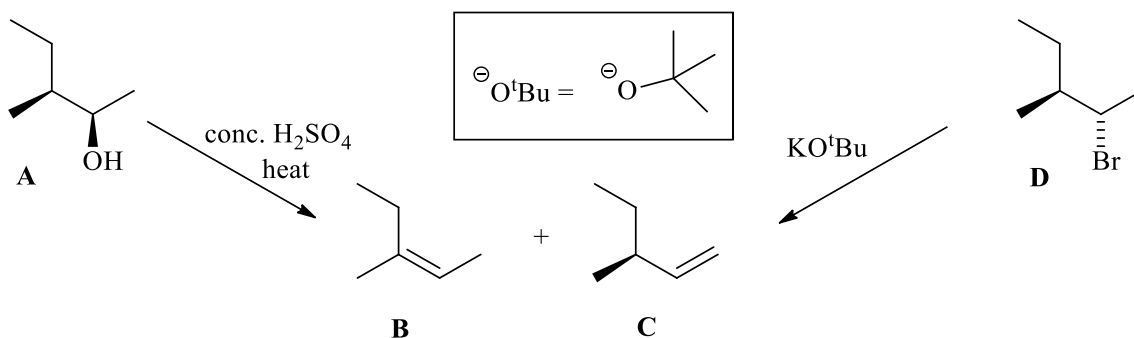


When (*S*)-pent-4-en-2-ol reacts with bromine, Br₂, two stereoisomers are formed. Draw the structure of both products.

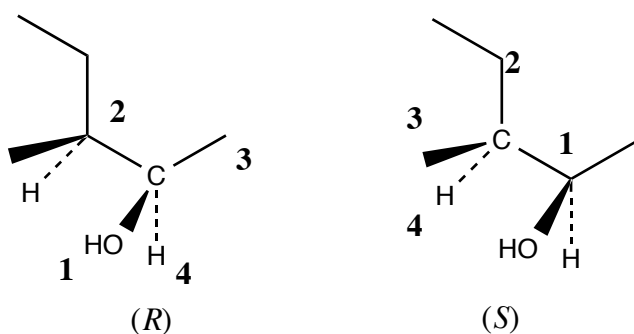


- The elimination of H_2O from alcohol **A** can form the isomeric alkenes **B** and **C**. Elimination of HBr from the alkyl halide **D** can generate the same two alkenes.

Marks
7



Assign the absolute configuration of alcohol **A**. Show your working.



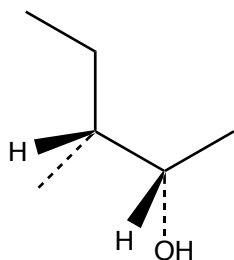
There are 2 chiral centres. On the diagram on the left, the priorities are as shown and are in an (*R*) configuration. On the diagram on the right, the priorities are in an (*S*) arrangement.

Name compound **B** fully.

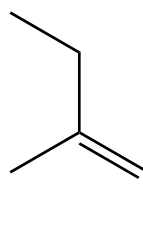
(Z)-3-methylpent-2-ene

A diastereoisomer of **B** is also formed in these reactions. Draw the enantiomer of **A** and the diastereoisomer of **B**.

enantiomer of **A**

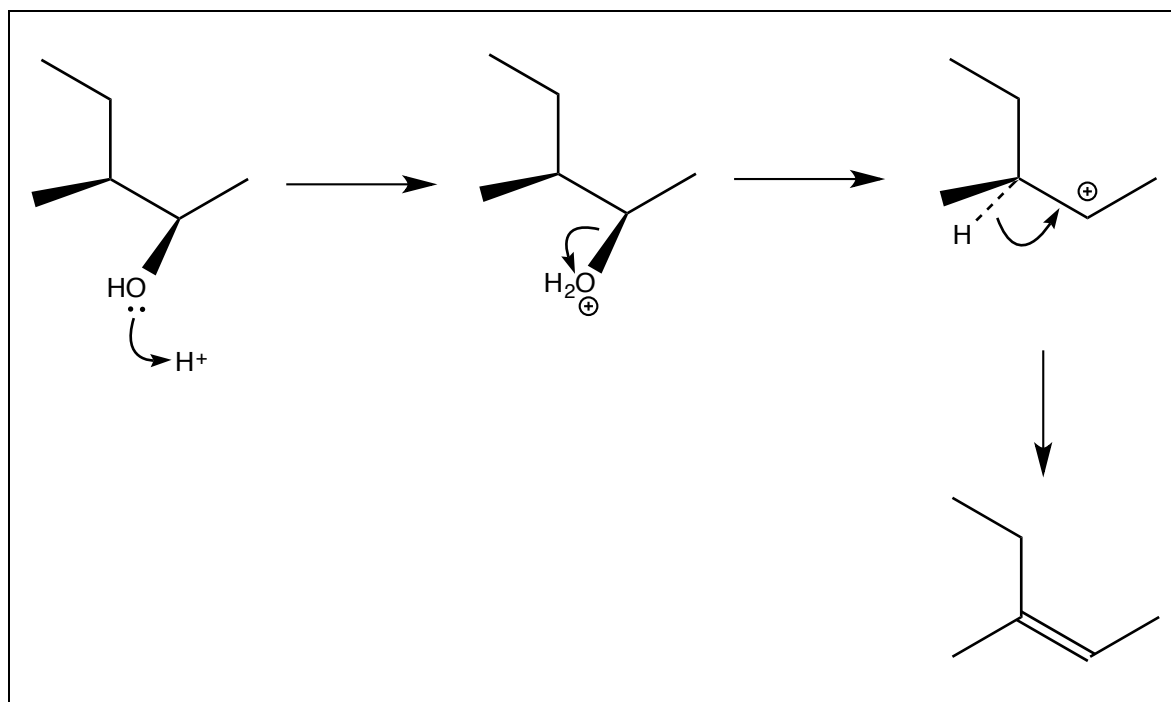


diastereoisomer of **B**



ANSWERS CONTINUES ON THE NEXT PAGE

Propose a mechanism for the formation of **B** from **A** under the conditions shown.
Use curly arrows and draw the structures of any intermediates.



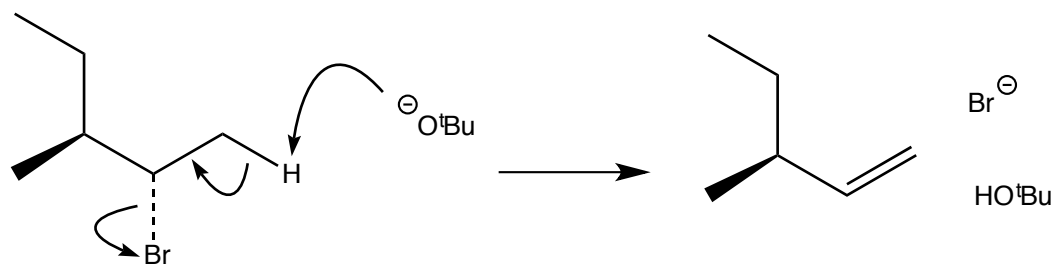
THIS QUESTION CONTINUES ON THE NEXT PAGE.

Explain why compound **C** is the minor product of this reaction.

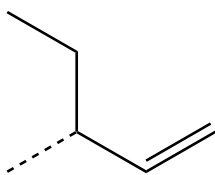
Marks
4

C has the new C=C bond with fewer substituents. This is an example of Zaitsev's rule: the more substituted alkene is more thermodynamically stable.

Propose a mechanism for the formation of **C** from **D** under the conditions shown. Use curly arrows and draw the structures of any intermediates.



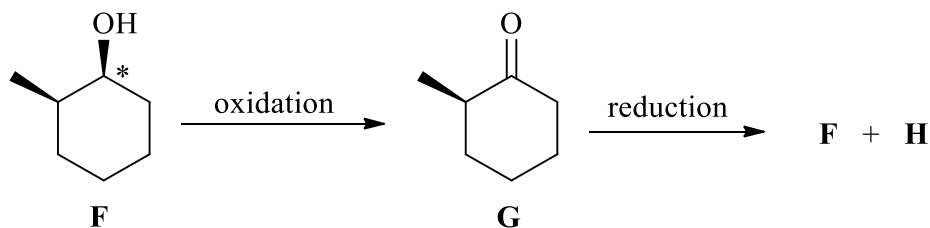
Compound **C** is the major product formed from **D** under these conditions. What would be the major product if the enantiomer of **D** were exposed to the same reaction conditions?



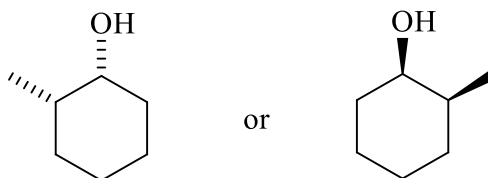
THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Marks
7

- Shown below is a reaction sequence beginning with the chiral alcohol, **F**.



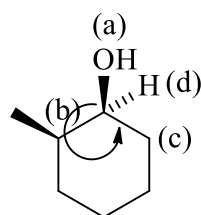
Draw the enantiomer of **F**.



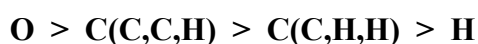
The specific optical rotation of **F** is $+24^\circ$. What is the optical rotation of a mixture consisting of equal amounts of **F** and its enantiomer?

0°

Assign the stereochemistry of the atom in alcohol **F** indicated by the asterisk (*), showing how you arrived at your answer.



The order of priority is:

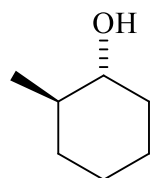


With lowest priority (d) at back, the order of the groups goes anticlockwise as shown. Therefore the stereochemistry is (S).

Alcohol **F** is oxidised to give the corresponding ketone, **G**. Is this molecule still chiral? Why/why not? Explain your answer.

The molecule is still chiral as the molecule still contains a stereogenic centre.

Ketone **G** is reduced with sodium borohydride, to give a mixture of two alcohols, **F** and **H**. **H** is a diastereomer of **F**. Draw the diastereomer **H**. What is the expected ratio of alcohols **F** and **H** in this mixture? Why?

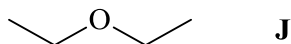


The approximate ratio will be 1:1 as attack by hydride ion is equally likely from above or below the ring.

(There may be a slight excess of **F as the methyl group may slightly inhibit attack from above by steric interference.)**

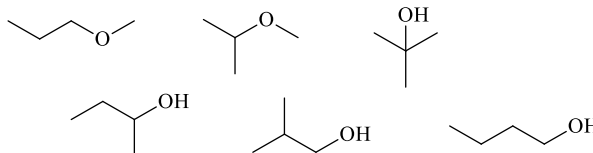
Marks
5

- Below is the structure of an ether, **J**.



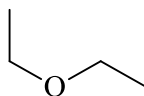
Draw a constitutional isomer of **J**.

Any of the following:



Draw a conformational isomer of **J**.

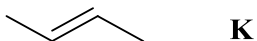
There is an infinite number of conformational isomers. Only one is given



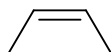
There are no configurational isomers of **J**. Why not?

As there are no rings, double bonds or stereogenic centres, the molecule does not have any diastereomers or enantiomers.

Below is the structure of an alkene, **K**, which *does* have a configurational isomer.



Draw this configurational isomer.



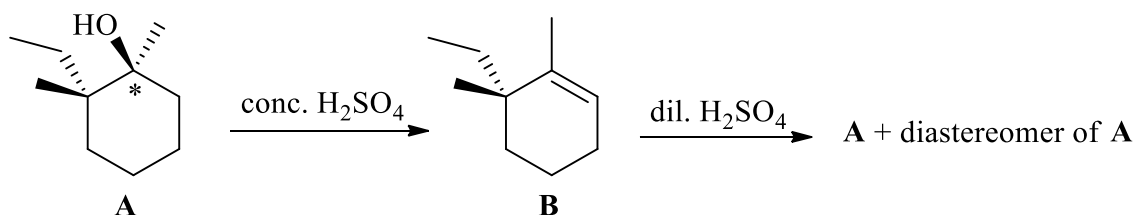
Name **K**, making sure your name distinguishes **K** from its isomer.

(E)-2-butene

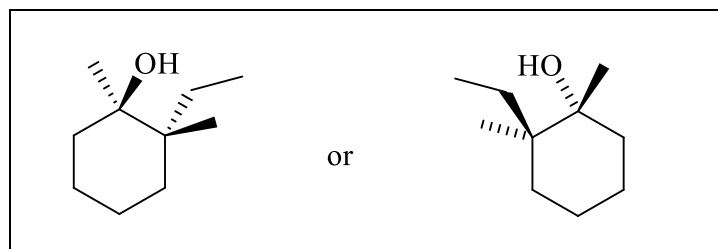
Marks

7

- Shown below is a reaction sequence beginning with the chiral alcohol, **A**.



Draw the enantiomer of **A**.



The specific optical rotation of **A** is +30. If equal amounts of **A** and its enantiomer are mixed, what is the optical rotation of the mixture?

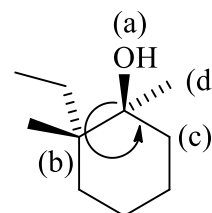
0°

Assign the stereochemistry of the atom in alcohol **A** indicated by the asterisk (*), showing how you arrived at your answer.

The order of priority is:

O > C(C,C,C) > C(C,H,H) > C(H,H,H)

With lowest priority (d) at back, the order of the groups goes anticlockwise as shown. Therefore the stereochemistry is (S).



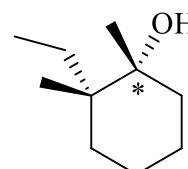
Alcohol **A** is dehydrated to give the alkene **B**. Is alkene **B** chiral? Why/why not?

The molecule is still chiral as the molecule still contains a stereogenic centre.

Alkene **B** is hydrated with dilute sulfuric acid, to give a sample that contains **A** and a diastereomer of **A**. Draw this diastereomer. In this sample, what do you expect to be the ratio of **A** and its diastereomer? Why?

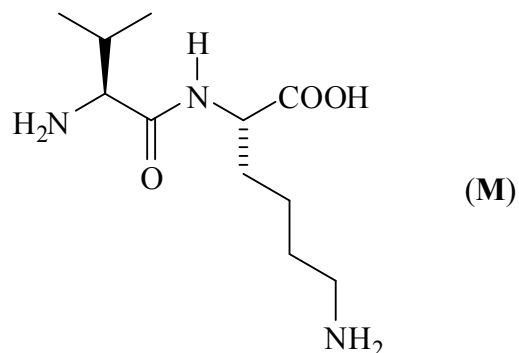
Ratio A : diastereomer is approximately 1 : 1.

The tertiary carbocation intermediate has trigonal planar geometry, so the attacking nucleophile (H₂O) is equally likely to attack from above or below the plane of the ring.



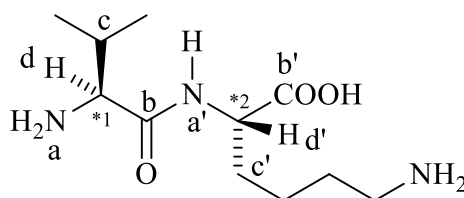
Marks
6

- Consider the following molecule (**M**) isolated from a natural source.



Indicate on the above structure all stereogenic centres in molecule (**M**).
Use numbered asterisks (*1, *2, *etc.*).

Select one of these stereogenic centres and determine its absolute configuration.
Show your working.

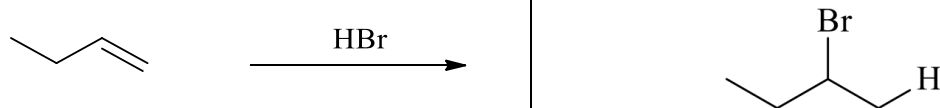


Around C*1, the priority of the groups are $a > b > c > d$. Looking down the C-H bond the groups $a \rightarrow b \rightarrow c$ go anticlockwise. Therefore configuration is (*S*)-.

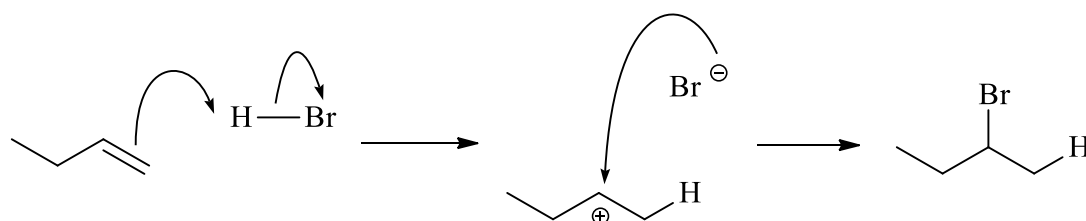
Around C*2, the priority of the groups are $a' > b' > c' > d'$. Looking down the C-H bond (i.e. from behind the plane of the paper) the groups $a' \rightarrow b' \rightarrow c'$ go anticlockwise. Therefore configuration is (*S*)-.

Marks
6

- Give the major product from the following reaction.



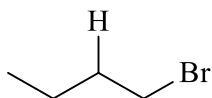
Show the mechanism of the reaction. Make sure you show structural formulas for all relevant intermediate species and the final product, as well as using curly arrows to indicate the movement of electrons (*i.e.* the breaking and formation of bonds).



What is the appropriate stereochemical descriptor for the major product of this reaction? Give a reason for your answer.

Racemic mixture. The carbon where the Br is attached has 4 different groups around it, so is stereogenic. The carbocation from which it forms is planar and so attack by the Br⁻ is equally likely from either the top or bottom side. This results in equal amounts of both enantiomers being formed.

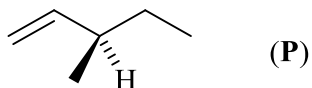
Give the structure of the minor product of this reaction and explain why very little of it forms.



This product is derived from the primary carbocation intermediate. Secondary carbocations are more stable than primary carbocations, so little of this product forms.

Marks
4

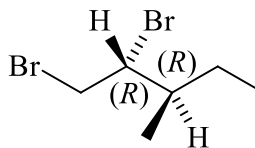
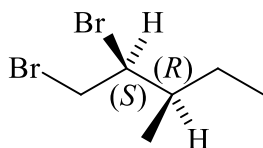
- Consider compound (**P**), whose structure is shown below.



Give the full name of compound (**P**) that unambiguously describes its stereochemistry.

(R)-3-methyl-1-pentene

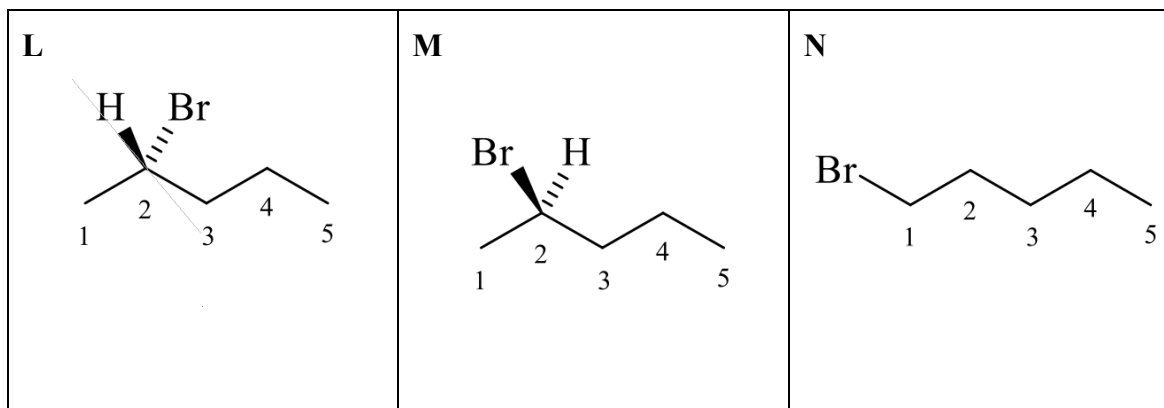
When compound (**P**) reacts with bromine (Br_2), two stereoisomers are formed. Draw the structure of both products and label all stereogenic centres appropriately.



Marks
6

- When HBr reacts with 1-pentene, three products, **L**, **M** and **N**, are formed. **L** and **M** are enantiomers, whilst **L** and **N** (and **M** and **N**) are constitutional isomers. Give the structures of these products and explain how they form? Discuss the relative amounts of each product, paying attention to the regioselectivity and stereoselectivity of the reaction.

Hint: You need to discuss important aspects of the reaction mechanism, including the relative stabilities of any intermediates, but you do not need to give the full mechanism using curly arrows.




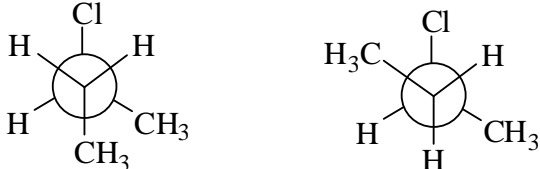
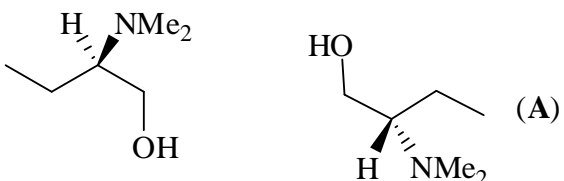
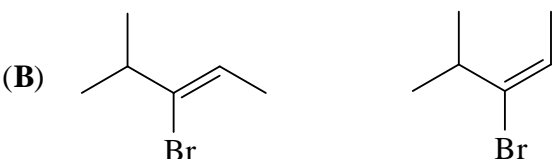
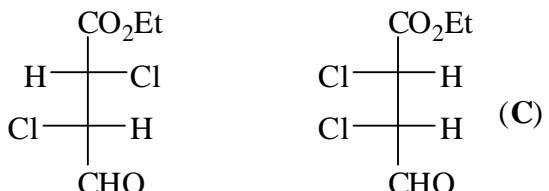
Electrophilic addition of H^+ to the double bond gives 2 possible carbocations.

The more stable carbocation leads to the major products **L and **M**, which are formed in equal amounts as attack by Br^- ion on the planar carbocation is equally likely from either top or bottom.**

The minor product, **N, comes from the less stable carbocation.**

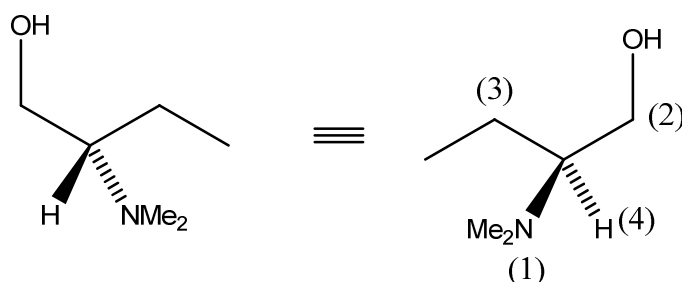
THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

- Consider the following pairs of compounds. Indicate the isomeric relationship that exists between the compounds in each set.

	constitutional isomers (different connectivity)
	conformational isomers (related by a rotation about a C-C bond)
	enantiomers (non-superimposable mirror images)
	diastereoisomers (different arrangement in space but not enantiomers)
	diastereoisomers (different arrangement in space but <i>not</i> enantiomers – the molecules are not mirror images of one another)

What is the configuration of the stereogenic centre in compound (A)?

(S). The groups have the priorities shown below. With the lowest priority group at the back, the other groups are in an anticlockwise order.



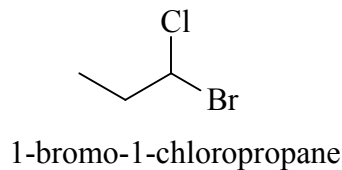
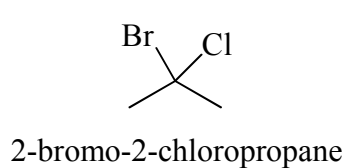
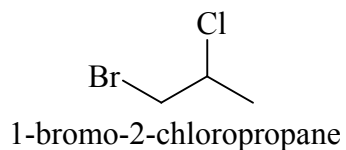
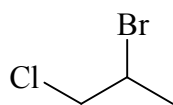
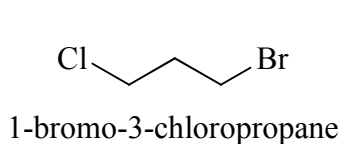
Give the full name of compound (B) that unambiguously describes its stereochemistry.

(Z)-3-bromo-4-methylpent-2-ene

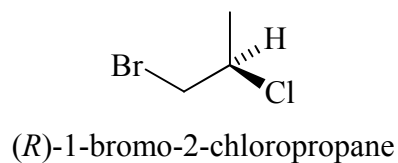
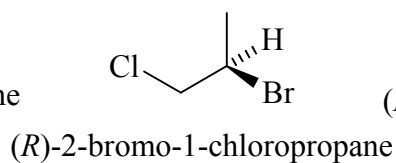
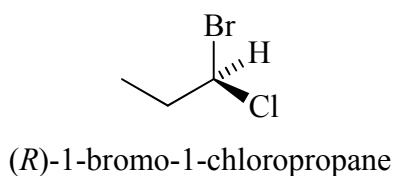
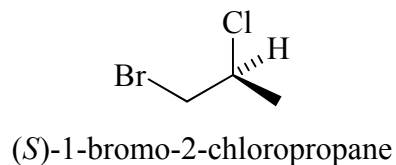
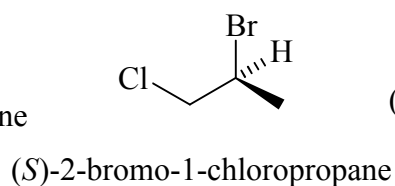
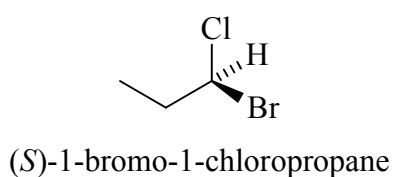
Is compound (C) a *meso* isomer? Give a reason for your answer.

No. It has no plane of symmetry.

- Draw the constitutional formulas of all isomers of C_3H_6BrCl .



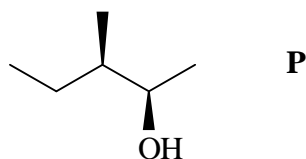
A number of the above isomers are optically active. For all such compounds, draw the two enantiomers.



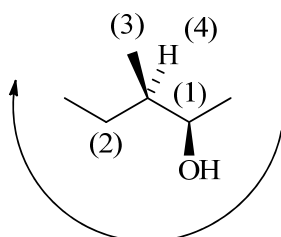
Select any **one** of the structures you have drawn on this page and write its full systematic name just below it. **See above.**

Marks
8

- The structure of a chiral molecule, **P**, is shown below. **P** has a specific optical rotation of $+26^\circ$.

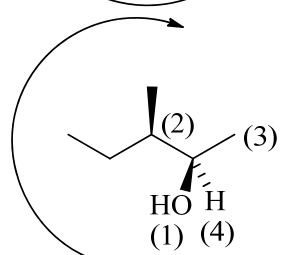


Assign the stereochemistry at the two stereogenic centres, showing your working.



The priorities around the first stereogenic centre are shown.

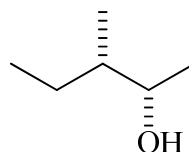
With the lowest priority group at the back, the other groups are related in a clockwise manner: (*R*)



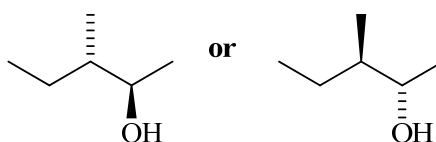
The priorities around the second stereogenic centre are shown.

With the lowest priority group at the back, the other groups are related in a clockwise manner: (*R*)

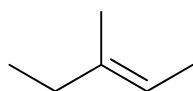
Draw the structure of a molecule that will have a specific optical rotation of -26° .



Draw a diastereoisomer of **P**.

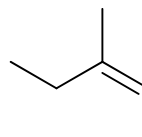


The addition of hot concentrated sulfuric acid causes **P** to transform into another molecule, **Q** (C_6H_{12}) that is optically inactive. What is the structure of molecule **Q** and why is it optically inactive?



(*E*)-3-methyl-2-pentene

or




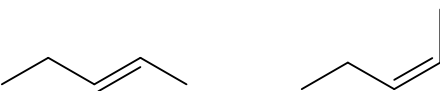
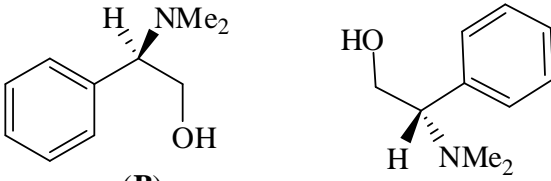
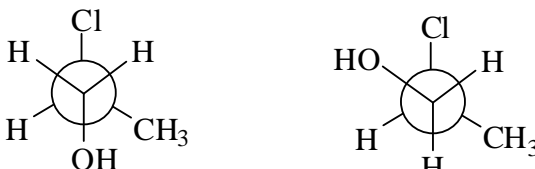
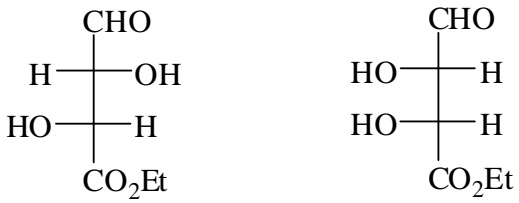
(*Z*)-3-methyl-2-pentene

Neither compound has a stereogenic centre, so neither is optically active.

Name molecule **Q**.

See above.

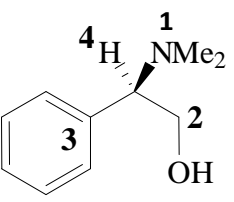
- Consider the following pairs of compounds. Indicate the isomeric relationship that exists between the compounds in each set.

	<p>constitutional isomers (different connectivity)</p>
 (A)	<p>diastereoisomers (same connectivity but different 3D arrangement)</p>
 (B)	<p>enantiomers (non-superimposable mirror images)</p>
	<p>conformational isomers (can be interconverted by rotation of the central C-C bond)</p>
 (C)	<p>diastereoisomers (same connectivity but different 3D arrangement. Not enantiomers)</p>

Give the full name of compound (A) that unambiguously describes its stereochemistry.

(E)-2-pentene. (The alkyl groups are on opposite sides of the C=C hence (E)).

What is the configuration of the stereogenic centre in compound (B)?


(B)

The priorities are indicated on the figure. With the lowest priority at the back, the sequence 1-2-3 is in a clockwise direction: **(R)**.

Is compound (C) a *meso* isomer? Give a reason for your answer.

No. C does not have a plane of symmetry so is optically active.

Marks
5

- 1,2-Dichloropropane can exist in two enantiomeric forms, compounds I and II. In the boxes below draw structures of the two enantiomers of 1,2-dichloropropane clearly showing the stereochemistry at the chiral carbon.

compound I (S)-enantiomer	compound II (R)-enantiomer
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There are three other compounds, III, IV and V with molecular formula $C_3H_6Cl_2$. In the boxes below, give the constitutional formulas and names of these compounds.

Structure	Name
compound III 	2,2-dichloropropane
compound IV 	1,1-dichloropropane
compound V 	1,3-dichloropropane

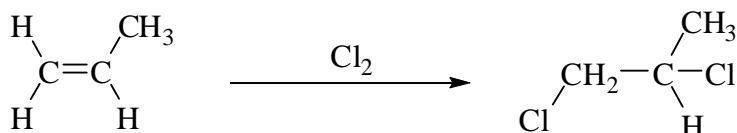
ANSWER CONTINUES ON THE NEXT PAGE

Compounds I, II, III, IV and V are isomers. From the list *enantiomers*, *diastereomers*, *conformers*, *constitutional isomers* complete the following table.

Marks
4

PAIR OF COMPOUNDS	ISOMERIC RELATIONSHIP BETWEEN PAIR OF COMPOUNDS
I and III	constitutional isomers
I and IV	constitutional isomers
II and IV	constitutional isomers

1,2-Dichloropropane can be synthesised in the laboratory by treatment of propene with chlorine as is shown in the following equation.

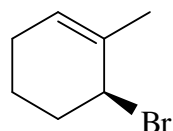


Which of the following best describes the product: (*R*)-enantiomer, (*S*)-enantiomer, racemate?

racemate
(equal amounts of (*R*) and (*S*) will be formed)

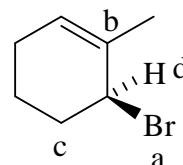
Marks
8

- Consider compound **F** shown below.

**F**

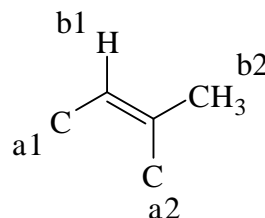
Assign the stereocentre in compound **F** as (*R*) or (*S*), explaining your reasoning.

(*S*) The four groups at the stereogenic centre are assigned priorities based on atomic numbers. Br has highest priority, H the lowest. The carbon labelled b, C(C,C,C) has higher priority than the carbon labelled c C(C,H,H) by examining the atoms attached to them. With d at the back, a→b→c is anticlockwise, so the configuration is (*S*).

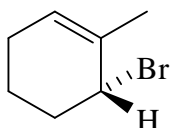


Assign the double bond stereochemistry in compound **F**, explaining your reasoning.

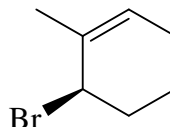
(*Z*) Compare the priorities of the two groups at each end of the double bond: i.e. a1 with b1 and a2 with b2. The two low priority groups (b) are on the same side of the double bond, so the configuration is (*Z*).



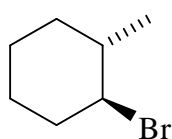
Draw the enantiomer of compound **F**.



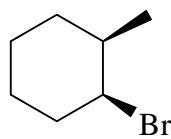
or



When compound **F** is reacted with hydrogen gas in the presence of a palladium catalyst, two stereoisomeric products, **G** and **H**, are formed. Draw these products.



+

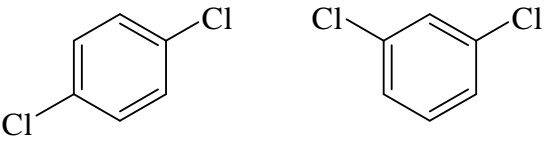
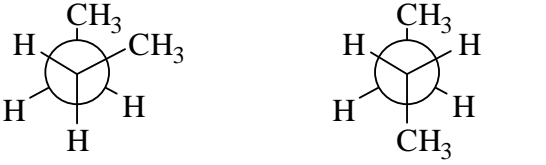
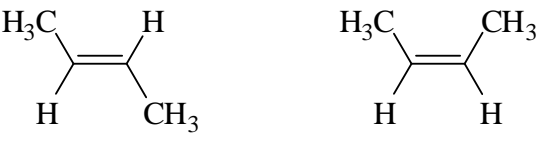

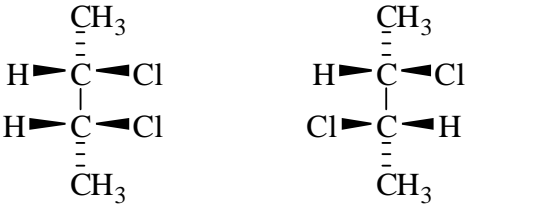


What word is used to describe the stereochemical relationship between **G** and **H**?

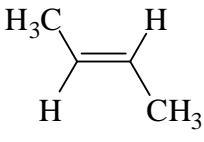
They are *diastereomers*. They differ in the arrangement of the bonds in space but are not mirror images.

Marks
8

- Consider the following pairs of compounds. Indicate the isomeric relationship that exists between the compounds in each set.

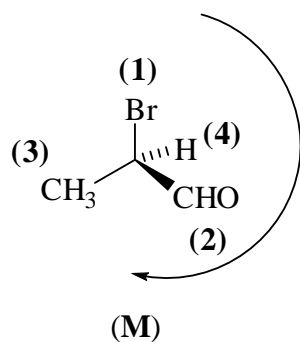
	Constitutional isomers. They differ in the interatomic connectivity.
	Conformational isomers. They differ only by rotation about the central C-C bond.
 <p>(L)</p>	Diastereomers. They differ in the arrangement of the atoms in space. They are <i>not</i> mirror-image stereoisomers.
 <p>(M)</p>	Identical. They are superimposable mirror images of each other.
 <p>(N)</p>	Diastereomers. They differ in the arrangement of the atoms in space. They are <i>not</i> mirror-image stereoisomers.

Give the name of compound (L) that unambiguously describes its stereochemistry.

 <p>(L)</p>	<p>(E)-but-2-ene</p> <p>The two CH₃ groups on either end of the double bond have higher priority than the two H groups. As they are located on opposite sides of the double bond, the stereochemistry is designated as (E).</p>
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ANSWER CONTINUES ON THE NEXT PAGE

Give the name of compound (M) that unambiguously describes its stereochemistry.



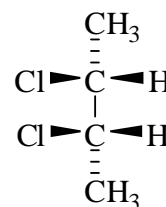
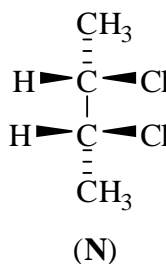
The priority of the groups is $\text{Br} > \text{CHO} > \text{CH}_3 > \text{H}$. With the lowest priority (H) at the back, the path from highest to lowest ((1)-(2)-(3)) is clockwise. The stereochemistry is designed as (R).

(R)-2-bromopropanal

Is compound (N) optically active? Give a reason for your answer.

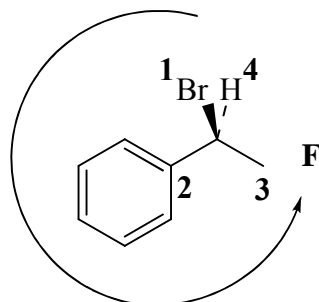
Compound (N) is meso and is *not* optically active. It is superimposable on its mirror image. Simple rotation of the mirror image on the right generates the molecule on the left.

(N) possesses an internal mirror plane (between the carbon atoms) and is thus not chiral.



Marks
8

- Consider compound **F** shown below.

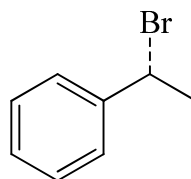


Assign the stereocentre in compound **F** as (*R*) or (*S*), explaining your reasoning.

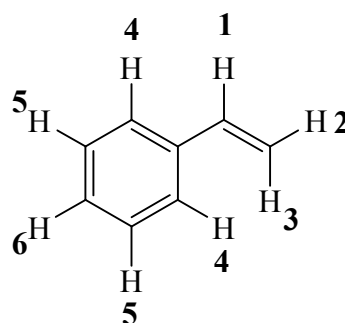
The priority of the groups around the stereocentre in **F** is shown above. Br has the highest atomic number and has the highest priority. H has the lowest atomic number and has the lowest priority. It is placed at the back. The other two groups both have carbon bonded to the stereocentre but the group on the left has a higher priority as it has C atoms attached whereas the group on the right has H atoms attached.

With the H atom at the back, the groups are arranged anti-clockwise and so the stereocentre is assigned as (*S*).

Draw the enantiomer of compound **F**.



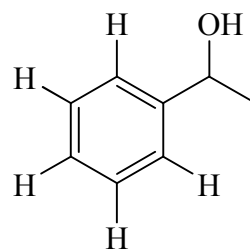
When compound **F** is reacted with hot KOH solution, a product (**G**) is formed that shows three peaks in the ^1H NMR spectrum in the region 7-8 ppm and three peaks in the region 5-6 ppm. Draw the structure of this product.



The signals due to H atoms 1, 2 and 3 are all different and occur in the region 5-6 ppm. The signals due to the aromatic H atoms appear in the 7-8 ppm region and are due to the groups 4, 5 and 6.

ANSWER CONTINUES ON THE PAGE

When **G** is reacted with dilute sulfuric acid, a further product, **H**, is formed. **H** has a peak at 3300 cm^{-1} in its IR spectrum. Draw the structure of product **H**.

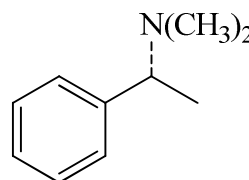


Markovnikov addition of H-OH across double bond, with OH adding to more substituted end of double bond. IR peak at 3300 cm^{-1} is due to O-H stretch.

Is **H** formed as a single enantiomer, as a racemate, or is **H** achiral?

The alcohol C is stereocentre but the addition reaction generates equal amounts of both enantiomers: a racemic mixture is formed.

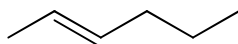
Assuming an S_N2 mechanism, draw the product of the substitution reaction between **F** and $(\text{CH}_3)_2\text{NH}$, indicating stereochemistry where appropriate.



The S_N2 reaction involves attack from the back, leading to inversion of the stereochemistry.

Marks
5

- Consider the compound **J** below.

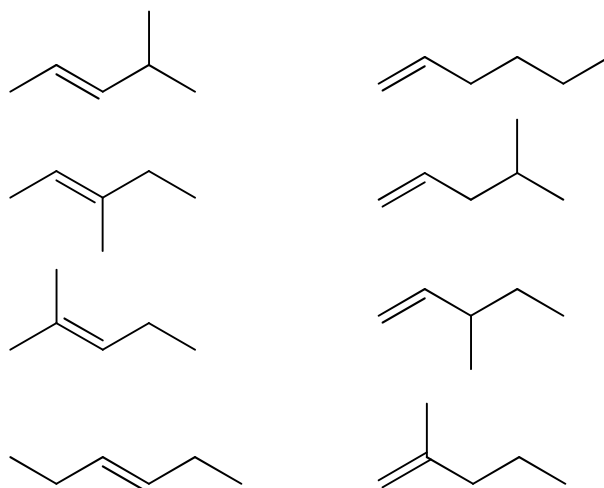
**J**

What is the systematic name for compound **J**.

(E)-hex-2-ene

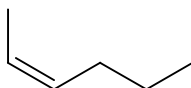
Draw a constitutional isomer of **J**.

Constitutional isomers have different atomic connectivities. Possible constitutional isomers include those below:



Draw a configurational isomer of **J**.

Configurational isomers have the same atomic connectivity but different spatial arrangements of the atoms. Because of the restricted rotation about a C=C double bond, the following compound is a configurational isomer of **J:**



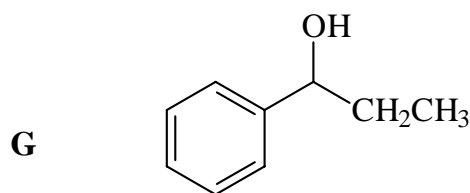
Draw the structure of the product formed when compound **J** is reacted with hydrogen gas (H_2) and a palladium on carbon (Pd/C) catalyst.

Treatment with H_2 a Pd/C catalyst will lead to addition of H-H across the C=C bond:



Marks
5

- Propionaldehyde (propanal) is treated first with phenylmagnesium bromide in dry diethyl ether and then with dilute aqueous acid, to yield alcohol **G**.



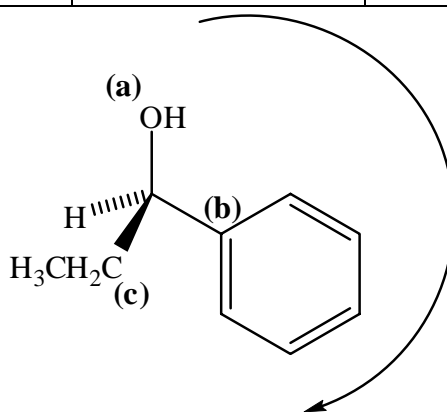
State whether **G** is obtained as the (*R*)-enantiomer, the (*S*)-enantiomer, a racemic mixture, or is achiral.

Racemic mixture

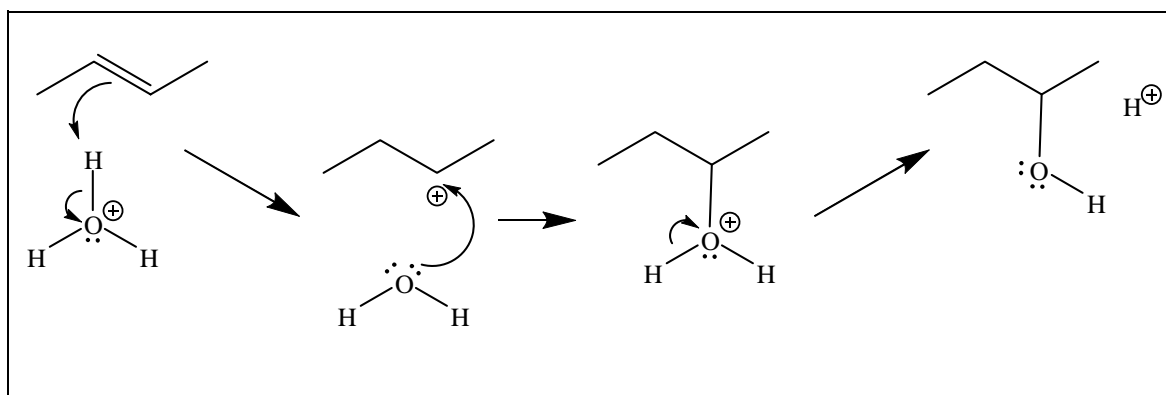
List below, the substituents on the stereogenic carbon atom in **G**, in decreasing priority (*i.e.* from highest to lowest priority), as determined by the sequence rules.

highest priority			lowest priority
-OH		-CH₂CH₃	-H

Draw the (*R*) enantiomer of **G**, showing the correct absolute stereochemistry.

**5**

- The incomplete proposed mechanism for the reaction of (*E*)-but-2-ene with aqueous acid is shown below. Complete the mechanism by adding curly arrows and relevant lone pairs to illustrate the bonding changes that take place.

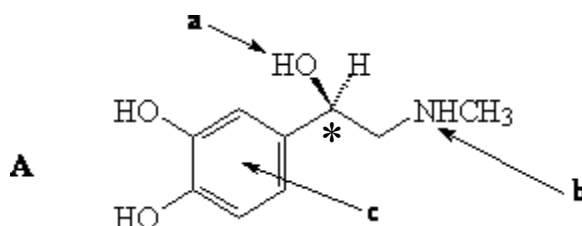


What two-word description may be used for the name of this mechanism?

electrophilic addition

Marks
6

- Adrenaline (**A**) is produced by the body as part of its “flight or fight” response.



- On the above diagram, clearly mark the stereogenic centre in (**A**) with an asterisk (*).
- List the substituents attached to the stereogenic centre in descending order of priority according to the sequence rules.

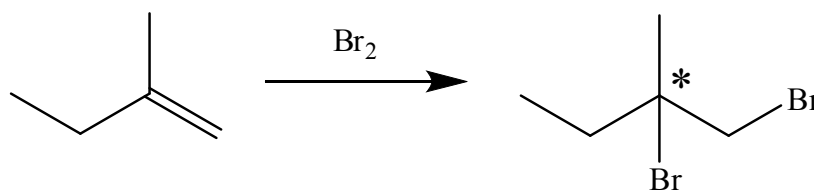
highest priority		lowest priority	
OH	CH₂NHCH₃	aromatic ring	H
(iii) What is the absolute stereochemistry of adrenaline (A)? Write (<i>R</i>) or (<i>S</i>).			(<i>R</i>)

- Name the functional groups **a**, **b** and **c**, present in adrenaline (**A**)?

a = alcohol
b = amine
c = aromatic

2

- Give the stick representation of the product formed when bromine reacts with 2-methylbutene.



State whether the product formed by this reaction is *achiral*, the (*S*)-*enantiomer*, the (*R*)-*enantiomer*, a *meso*-compound or a *racemic mixture*?

There is a single stereogenic centre in the product. Although addition of Br₂ is stereospecific, either enantiomer can be formed: a racemic mixture