09 Extension Topic - Organic Chemistry
Isomerism

GUIDING QUESTIONS

- What is isomerism? What are the different types of isomerism
- What are the structural criteria for exhibition of the different types of isomerism?
- How do the physical and chemical properties of different types of isomers differ?

LEARNING OUTCOMES

Students should be able to:

11.2(a) describe constitutional (structural) isomerism

11.2(b) describe *cis–trans* isomerism in alkenes, and explain its origins in terms of restricted rotation due to the presence of π bonds

11.2(c) explain what is meant by a chiral centre

11.2(d) deduce whether a given molecule is chiral based on the presence or absence of chiral centres and/or a plane of symmetry

11.2(e) recognize that an optically active sample rotates plane – polarised light and contains chiral molecules

11.2(f) recognise that enantiomers have identical physical properties except in the direction in which they rotate plane – polarised light

11.2(g) recognise that enantiomers have identical chemical properties except in their interaction with another chiral molecule

11.2(h) recognise that different stereoisomers exhibit different biological properties, for example in drug action

11.2(i) deduce the possible isomers for an organic molecule of known molecular formula

11.2(j) identify chiral centres and/or *cis–trans* isomerism in a molecule of given structural formula

REFERENCES

1. Albert Lehninger, *Principles of Biochemistry*, 5th Edition, W.H. Freeman
2. Peter Cann, *Chemistry for Advanced Level*, Hodder Education
3. IUPAC Compendium of Chemical Terminology, The Gold Book, http://goldbook.iupac.org/index.html

1 INTRODUCTION

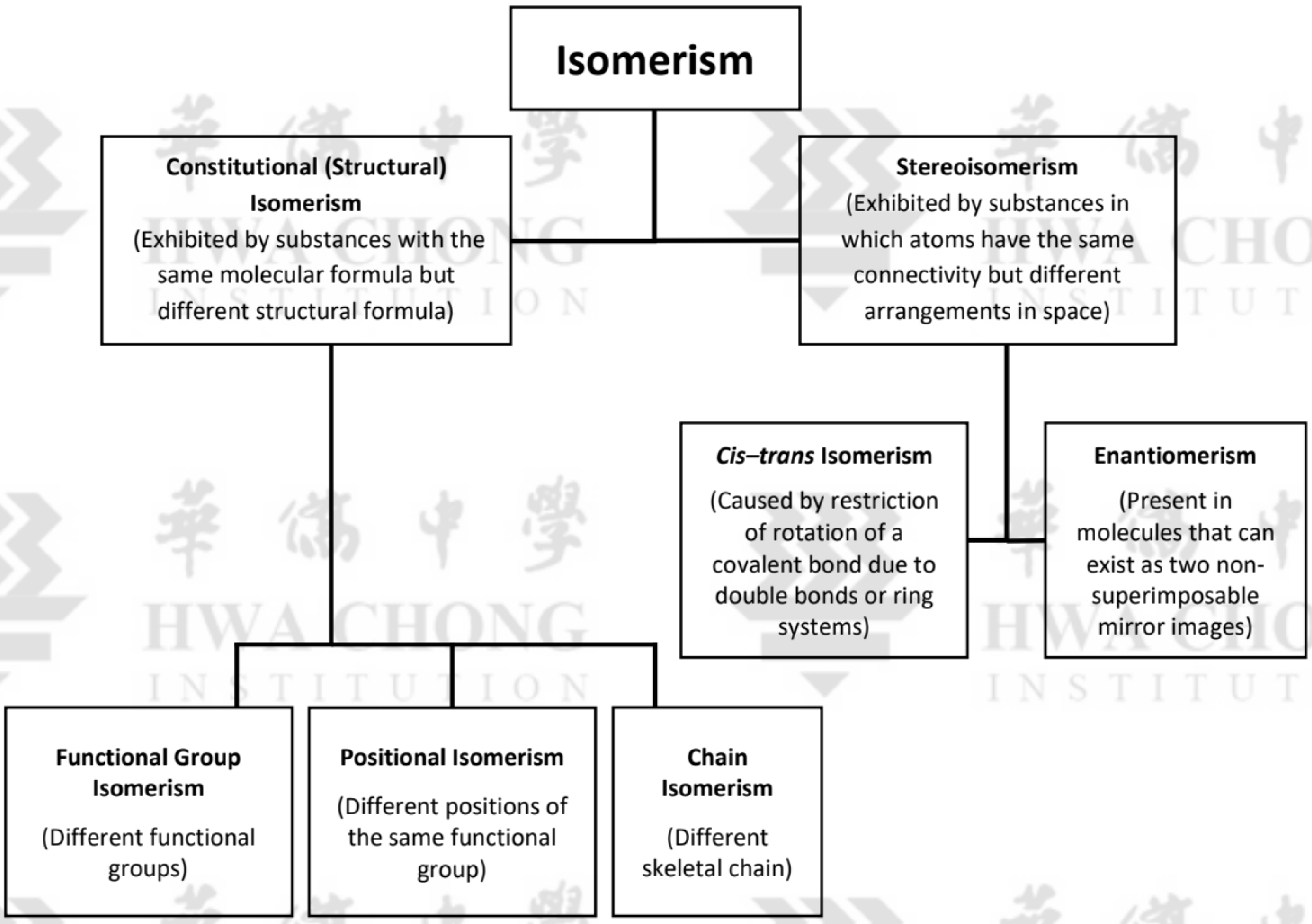
Molecules having the same molecular formula can have different arrangement of the atoms, giving rise to different forms called **isomers**. Isomers may have vastly different physical and chemical properties depending on the structure and functional groups present. These properties may affect the way the compounds are used and how they are applied in laboratories and the industry.

Isomerism can be broadly classified into 2 types:

(a) **constitutional isomerism**, in which atoms are linked together in different ways, and

(b) **stereoisomerism**, in which atoms have the same connectivity but different arrangements in space.

These two broad classes can be sub-divided into different categories which describe more precisely the various types of isomerism.



Note: Other textbooks and websites may list the various terms differently as the A-level syllabus. You are required to use the terms listed above. The short list below is provided for clarity should you read beyond the notes.

Constitutional Isomerism may be referred to as structural isomerism
Cis–trans isomerism may be referred to as geometric isomerism
Enantiomerism may be referred to as optical isomerism

2 CONSTITUTIONAL ISOMERISM

There are three types of constitutional isomerism.

2.1 Positional isomerism

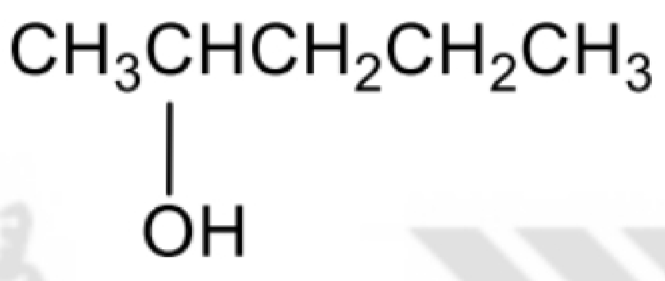
Positional isomers are molecules with the same molecular formula and same functional group but differ in the position of that functional group. They have similar chemical properties but different physical properties.

Examples of positional isomers:

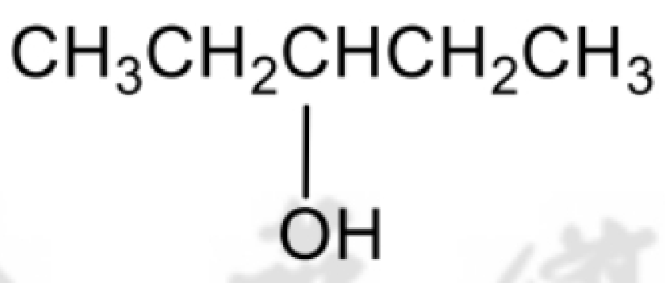
Pentane parent chain with one alcohol functional group

$CH_3CH_2CH_2CH_2CH_2OH$

pentan-1-ol


$CH_3\underset{OH}{\underset{|}{C}}HCH_2CH_2CH_3$

pentan-2-ol


$CH_3CH_2\underset{OH}{\underset{|}{C}}HCH_2CH_3$

pentan-3-ol

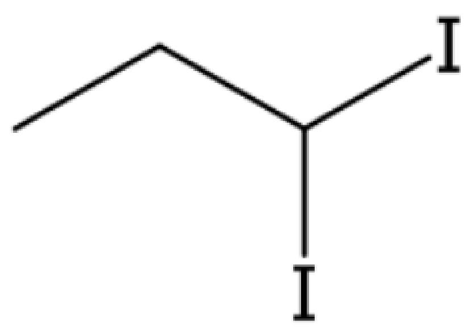
Hexane parent chain with single alkene functional group


hex-1-ene

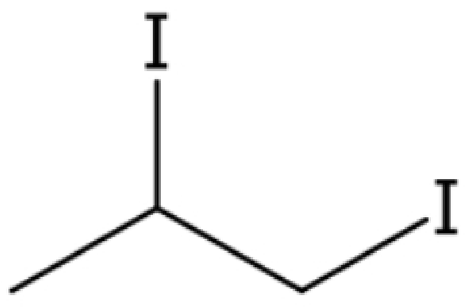

hex-2-ene


hex-3-ene

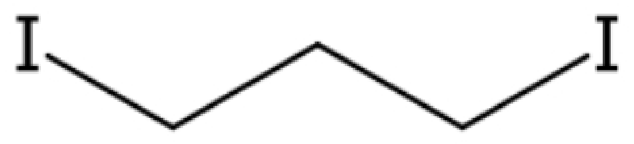
Propane parent chain with 2 iodo substituents



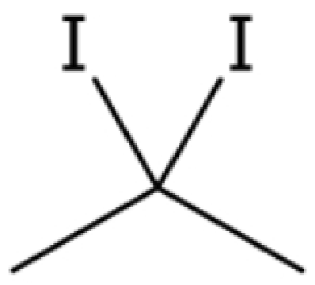
1,1-diiodopropane



1,2-diiodopropane



1,3-diiodopropane

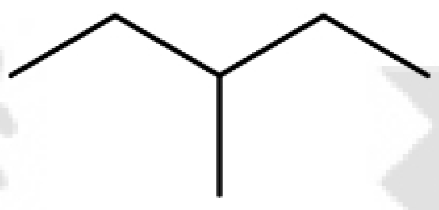


2,2-diiodopropane

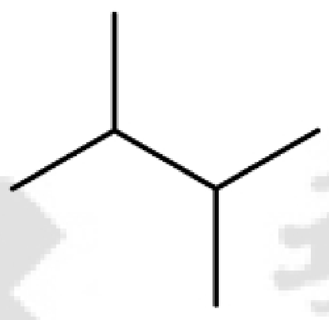
2.2 Chain isomerism

Chain isomers are molecules with the same molecular formula and same functional group, but **different carbon skeleton**. They typically have similar chemical properties but different physical properties.

hexane
C_6H_{14}



3-methylpentane
C_6H_{14}

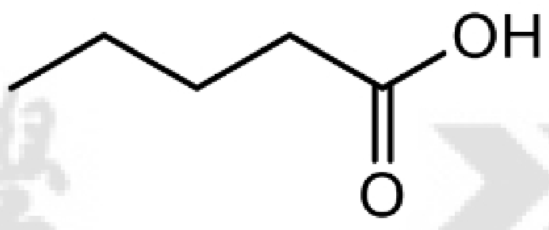
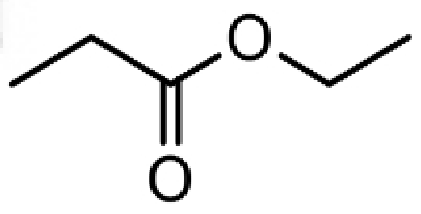
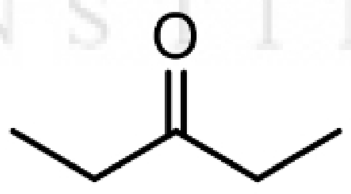


2,3-dimethylbutane
C_6H_{14}

2.3 Functional group isomerism

Functional group isomers are molecules that have the same molecular formula but different functional groups. They have very different physical and chemical properties.

For example, three pairs of isomers are shown below. In each separate example, the isomers share the same molecular formula but each contains a different functional group (other than the hydrocarbon skeleton).

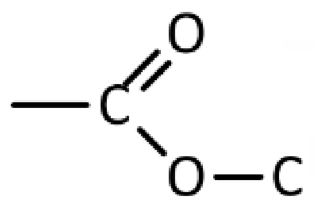
Example 1	Example 2	Example 3
$C_5H_{12}O$	**$C_5H_{10}O_2$**	**$C_5H_{10}O$**
 pentan-1-ol *Functional Group: 1° alcohol*	 pentanoic acid *Functional Group: carboxylic acid*	 pentanal *Functional Group: aldehyde*
 1-ethoxypropane *Functional Group: ether*	 ethyl propanoate *Functional Group: ester*	 pentan-3-one *Functional Group: ketone*

Self-Practice 2.1

(a) How many constitutional isomers are there in $C_3H_6Br_2$? Draw the skeletal formulae for all that you have identified. (Tip: Do this systematically)

(b) The carboxylic acid $CH_3CH_2CO_2H$ (propanoic acid) and the hydroxyl-ketone CH_3COCH_2OH (hydroxypropanone) are isomers having the molecular formula $C_3H_6O_2$.

Draw the structures of another two isomers which are esters, i.e. they possess the following functional group:



ester

(c) How many constitutional isomers are there in $C_4H_{11}N$? Draw the skeletal formulae for all you have identified.

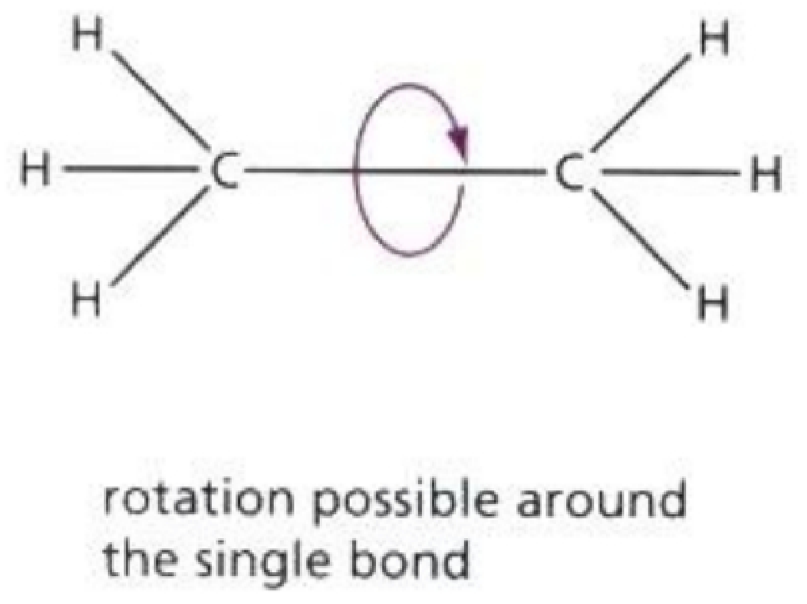
3 STEREOISOMERISM

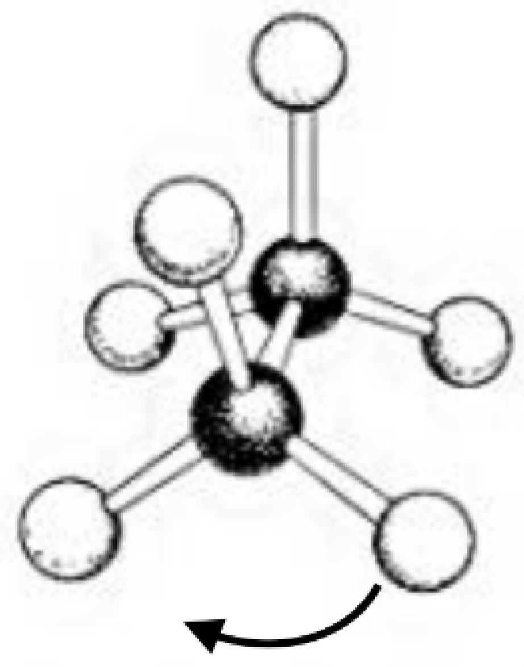
Stereoisomers have the same structure and functional groups but differ in the way their atoms are arranged in space (orientated differently with respect to each other).

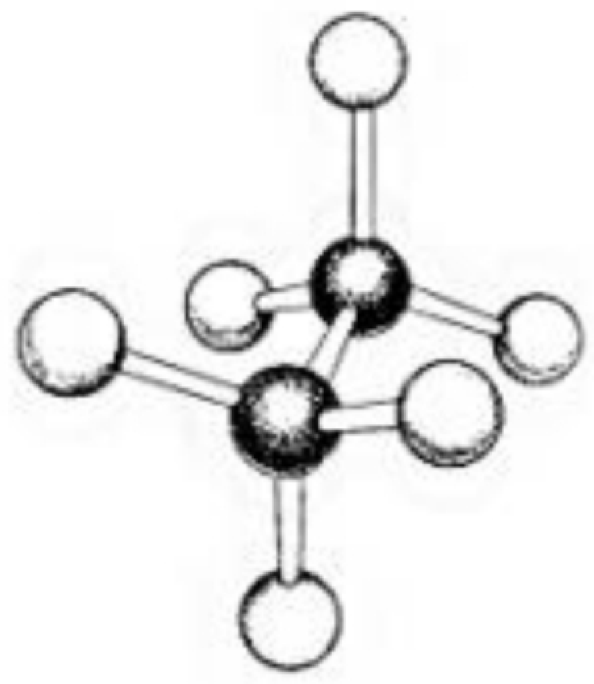
3.1 *Cis–trans* isomerism

3.1.1 Restricted rotation of a covalent bond

A single σ covalent bond can be rotated freely without the bond breaking. For example, the C–C bond in ethane can be rotated with minimal energy, about 12 kJ mol^{-1}. The hydrogen atoms bonded to each carbon are constantly rotating about the C–C bond axis.

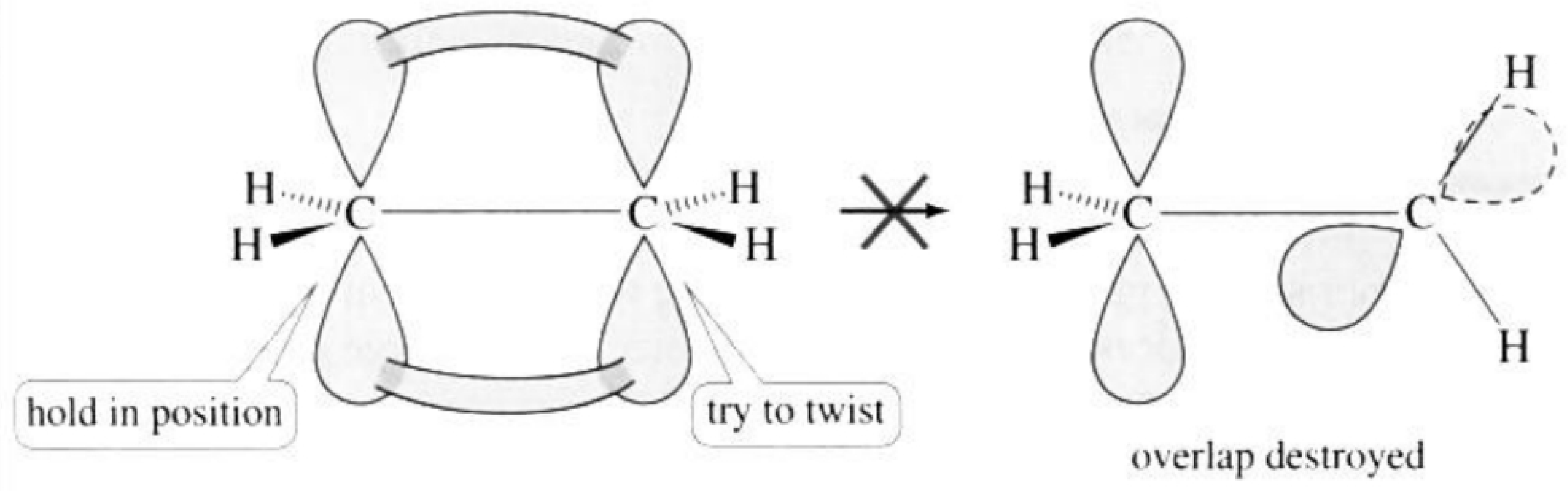




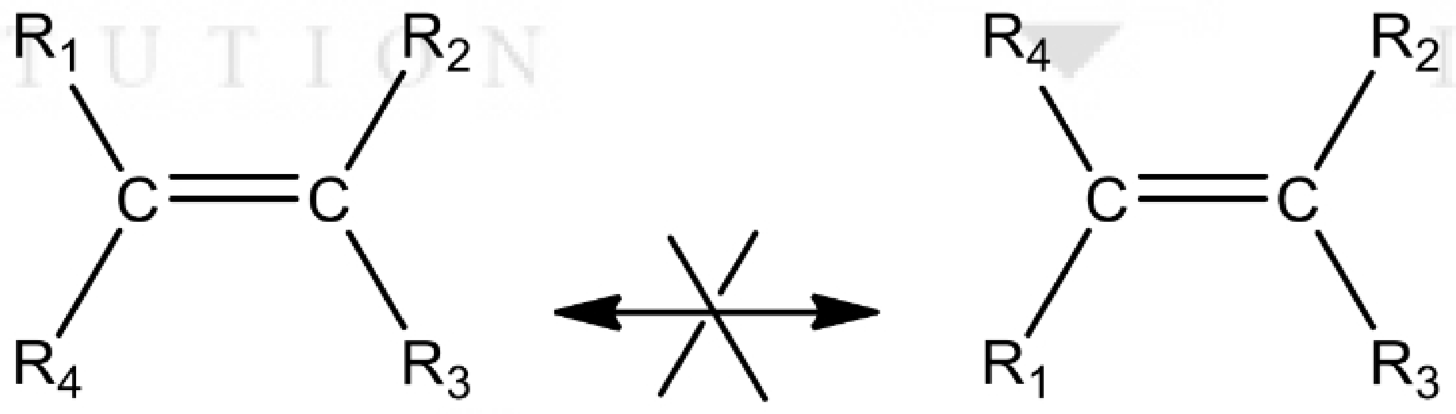


However, this rotation can be restricted in either the presence of double bonds or the presence of ring structures.

For rotation to occur when there's a double bond, the π bond must break and reform. Thus, the energy barrier to double bond rotation is at least as great as the energy needed to break the π bond, an estimated 268 kJ mol^{-1} for a C=C double bond, which is far beyond the energy available at normal temperatures.



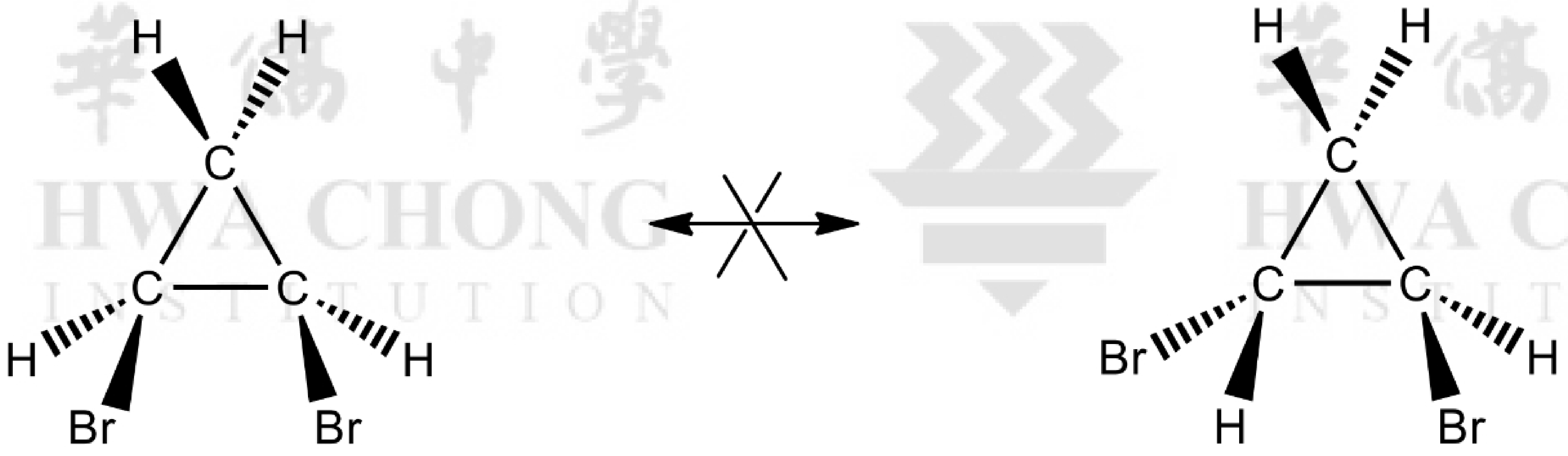
The result is that the atoms or groups of atoms bonded to each carbon are fixed in space with respect to one another and the 4 positions relative to the double bond are not easily interchangeable.



For example, the groups on the R$_1$ and R$_4$ positions cannot be switched relative to R$_2$ and R$_3$ without breaking the double bond.

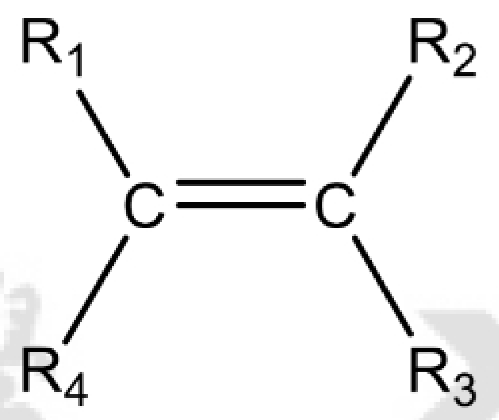
Rotation around the single bonds in a ring is prevented by the linkages in the ring.

For example, the structure of cyclopropane is shown below. Due to the ring structure, the C–C bonds that make up the ring cannot rotate without breaking the other C–C bonds. Again, the result is that the atoms or groups of atoms bonded to each carbon are fixed in space with respect to one another. i.e. The atoms on one side of the plane of the ring will stay on that side.



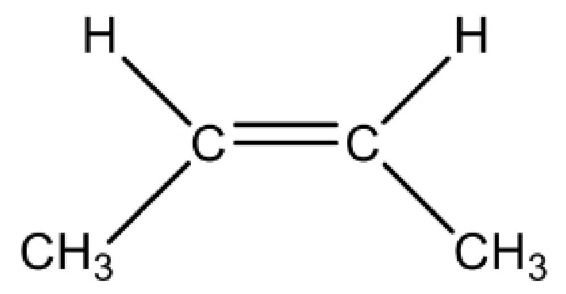
3.1.2 Occurrence of *cis–trans* isomerism in alkenes

In a compound with an alkene functional group, *cis–trans* isomerism occurs when the two groups on each carbon of the restricted bond are not identical.



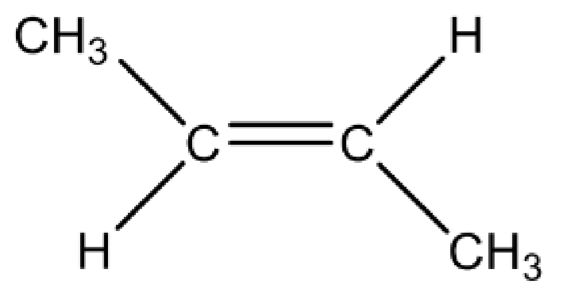
For example, the groups on R_1 and R_4 cannot be identical AND the groups on R_2 and R_3 cannot be identical.

Consider the molecule but-2-ene:



cis-but-2-ene

both methyl groups are
on the same side of the double bond

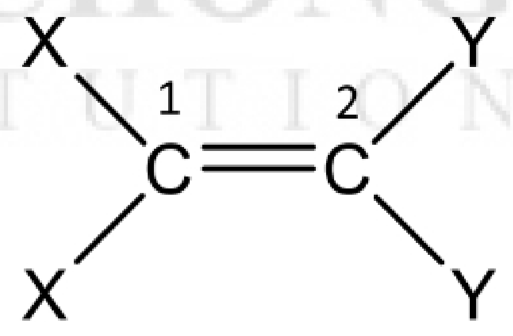


trans-but-2-ene

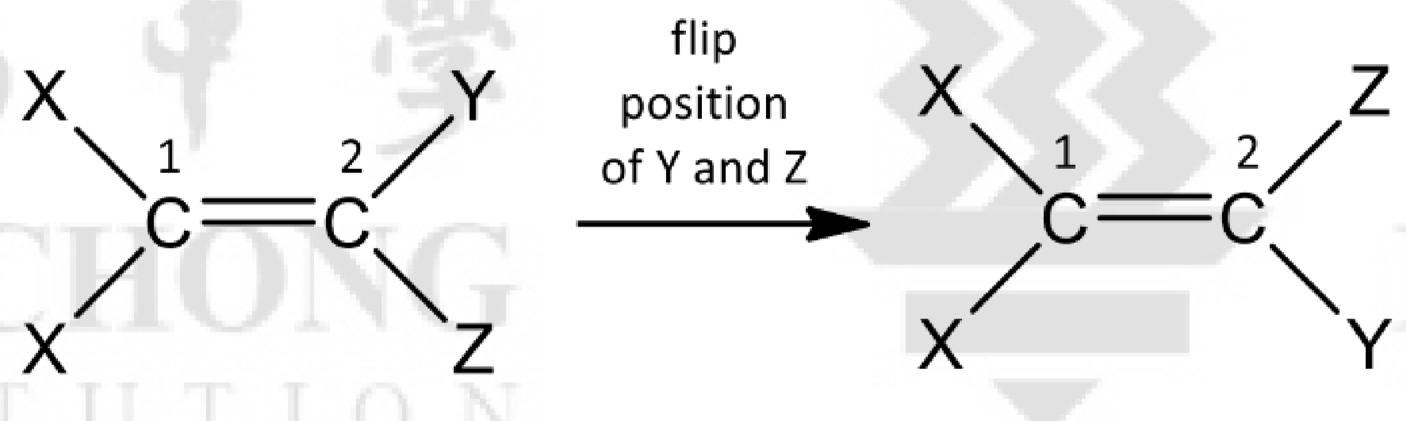
the methyl groups are
on opposite sides of the double bond

The criteria for *cis–trans* isomerism are fulfilled, and but-2-ene exists as distinct and separate isomers. The isomer where the **same groups** are on the **same side** of the double bond is called the ***cis*** isomer while the isomer where the **same groups** are on the **opposite side** of the double bond is called the ***trans*** isomer.

The following molecules **do not** fulfill the criteria for *cis*–*trans* isomerism to occur:



Molecule A



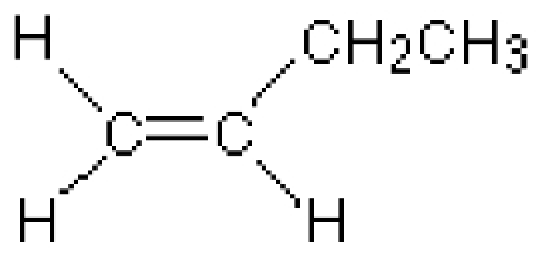
Molecule B Still molecule B

Reason:

Molecule **A** has 2 identical groups on both C-1 and C-2, while molecule **B** has identical groups on C-1.

Self-Practice 3.1

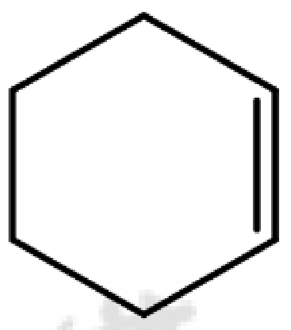
But-1-ene is shown below, and does not exhibit *cis*–*trans* isomerism. Draw another *constitutional* isomer of but-1-ene that does not exhibit *cis*–*trans* isomerism.



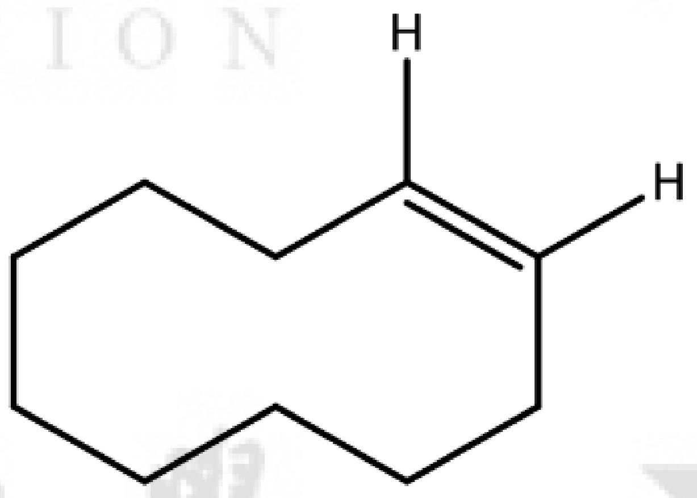
3.1.3 Occurrence of *cis*–*trans* isomerism in cycloalkenes

Cycloalkenes with **up to 7 carbon atoms** exist only as the *cis* isomer as the rings are not large enough to accommodate the *trans* double bond. Thus, molecules such as cyclohexene, do not exhibit *cis*–*trans* isomerism around the double bond.

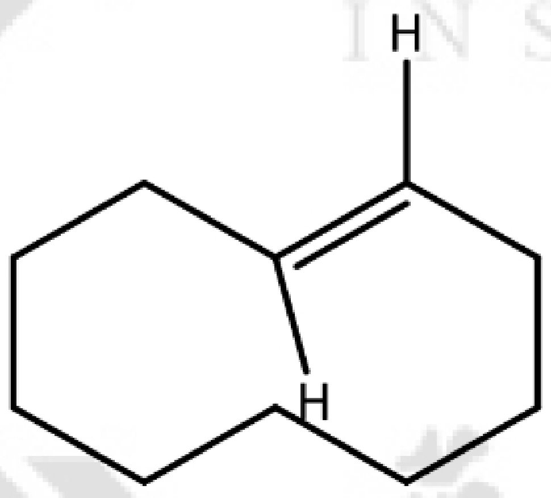
Cycloalkenes with **8 or more carbon atoms** can exist as *cis*-*trans* isomers and they are usually named together with the prefix (*cis* or *trans*) to avoid ambiguity.



cyclohexene



cis-cyclodecene

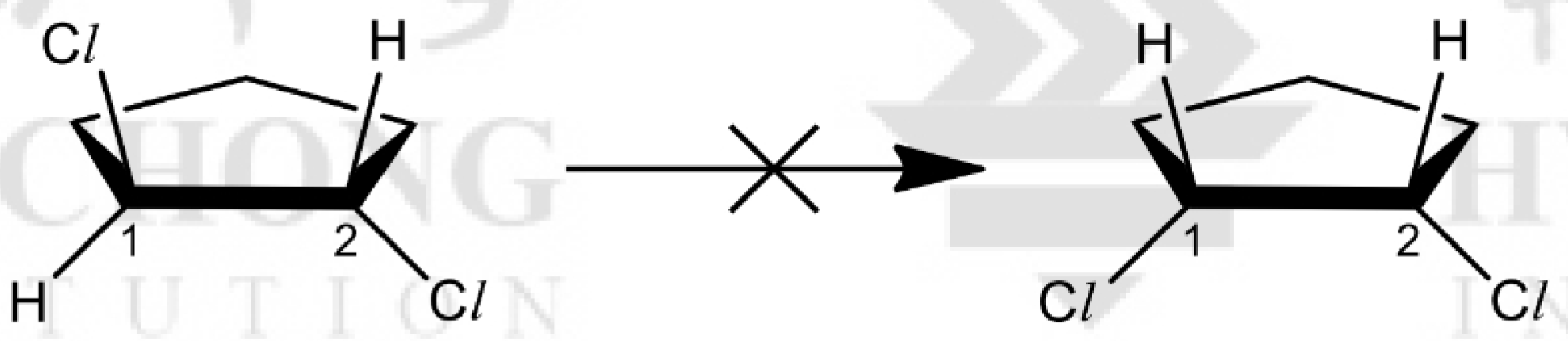


trans-cyclodecene

3.1.4 Occurrence of *cis–trans* isomerism in ring structures

Similar to double bonds, the restricted rotation of a covalent bond due to a ring structure allows for *cis–trans* isomerism.

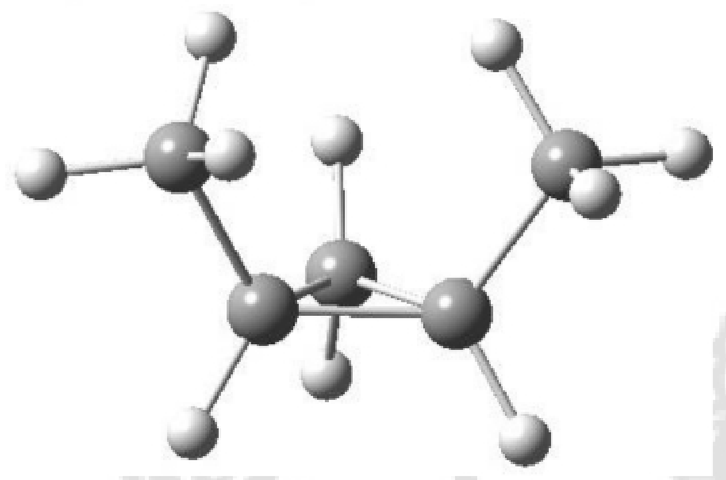
For example, the compound 1,2-dichlorocyclopentane exists as *cis–trans* isomers. This is due to the restricted bond rotation **between C1 and C2 in the ring**.



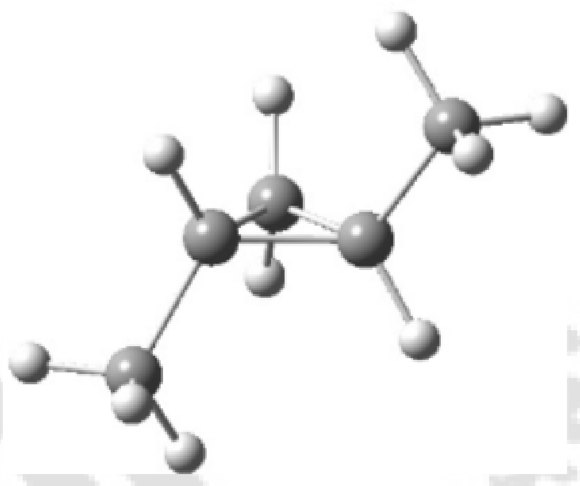
trans-1,2-dichlorocyclopentane *cis*-1,2-dichlorocyclopentane

The *cis* isomer is the one where the same groups exist on the same side with respect to the plane of the ring, whereas the *trans* isomer is the one where the same groups exist on opposite sides of the plane of the ring.

Another example is illustrated below, showing the *cis* and *trans* isomers of 1,2-dimethylcyclopropane.



cis-1,2-dimethylcyclopropane



trans-1,2-dimethylcyclopropane

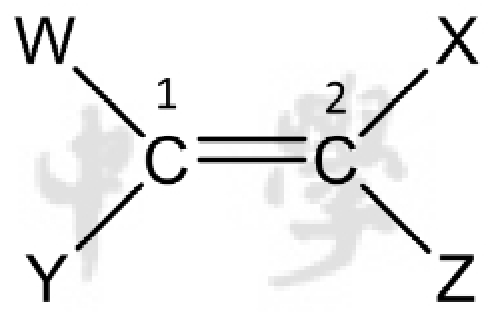
3.1.5 Summary

The definitive criteria for a molecule to exhibit *cis–trans* isomerism are:

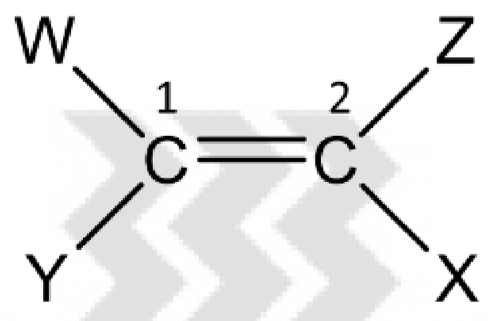
1) The molecule has a covalent bond with restricted rotation;
2) The groups bonded to each of the atoms on each end of the bond with restricted rotation cannot be the same.

What if all 4 groups are different?

In the molecules below, W, X, Y, and Z are 4 different groups. The molecules satisfy the criteria for *cis–trans* isomerism to occur. Hence, molecules C and D are *cis–trans* isomers. But their naming convention is not covered under the A-level H2 syllabus.



Molecule C



Molecule D

Lecture Exercise 3.1

Which of the following alkenes may exist as *cis-trans* isomers? Draw the isomers.

(a) $CH_3CH_2CH=CH_2$ **(b)** $ClCH=CHCl$

Lecture Exercise 3.2

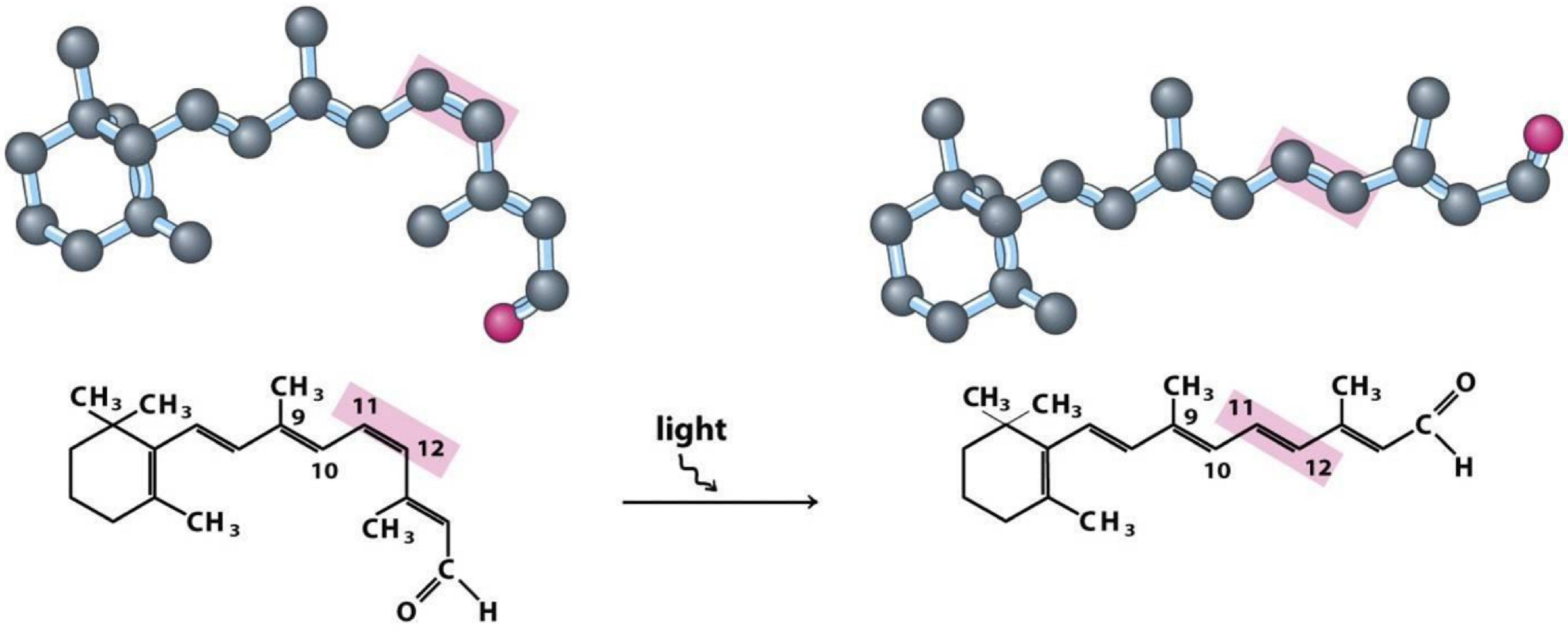
Which molecules have isomers that exhibit *cis-trans* isomerism? *(N2005/I/21)*

C_3H_6BrI	C_3H_5I	$C_3H_4I_2$	C_3H_4BrI
I	**II**	**III**	**IV**

A **I**, **II** and **III** only
B **II**, **III** and **IV** only
C **II** and **IV** only
D **III** and **IV** only

3.1.6 Example of *cis–trans* isomers in biological systems

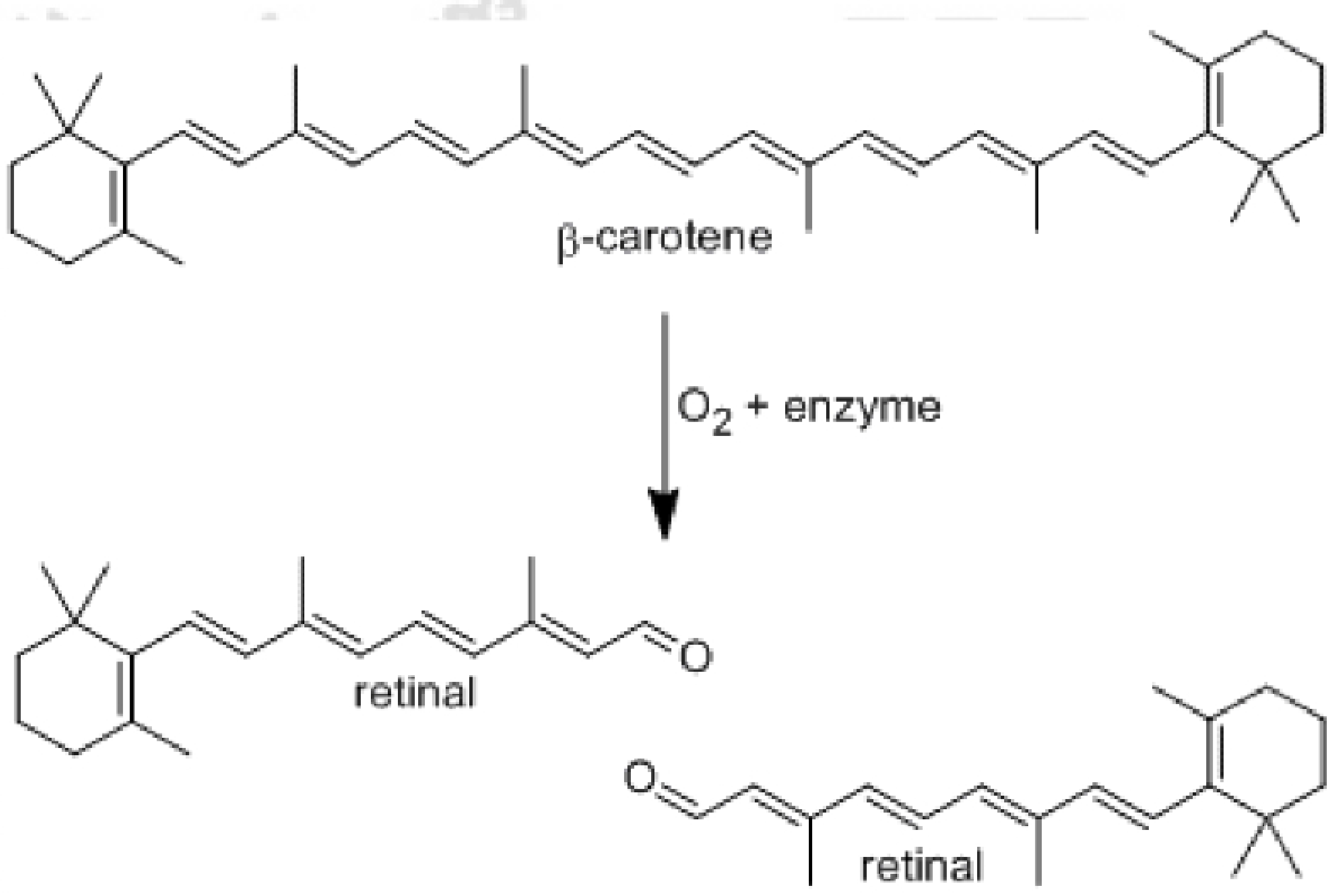
Visual perception or sight is dependent on a compound known as retinal. The process is complicated but generally retinal molecules that are bound to opsin proteins in the eye are converted from the 11–*cis* isomer to the all–*trans* isomer, which starts the visual cycle. The visual cycle is a circular enzymatic pathway that eventually regenerates the *cis* isomer.



11-*cis*-Retinal **All-*trans*-Retinal**

Source: Lehninger, Principles of Biochemistry, Fifth Edition

Retinal is usually produced by the biological system through consumption of beta-carotene present in foods such as carrots, sweet potatoes and apricots. The beta-carotene then undergoes enzyme catalysed oxidative cleavage to produce retinal.



Self-Practice 3.2

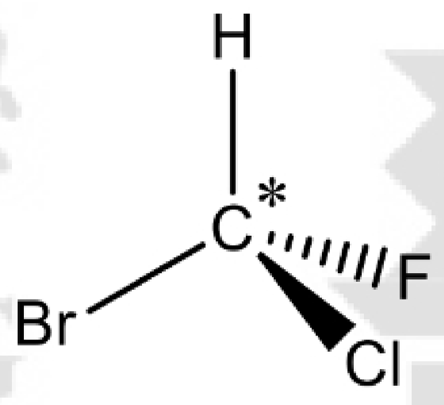
Linoleic acid is an essential fatty acid in human diet, with the following structural formula:

$$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7CO_2H$$

In linoleic acid, both double bonds are in the *cis* configuration. Representing the formula by the abbreviated structure A–CH=CH–CH_2–CH=CH–B, draw the displayed formulae of: (a) linoleic acid; and (b) all its *cis–trans* isomers.

3.2 Enantiomerism

The non-superimposability of mirror images is the definitive criterion for a molecule to exhibit enantiomerism, i.e. to be chiral. If the mirror image is non-superimposable, the mirror image is the enantiomer of the compound. If the mirror image of a molecule is superimposable on itself, the compound is said to be achiral and does not have enantiomers.

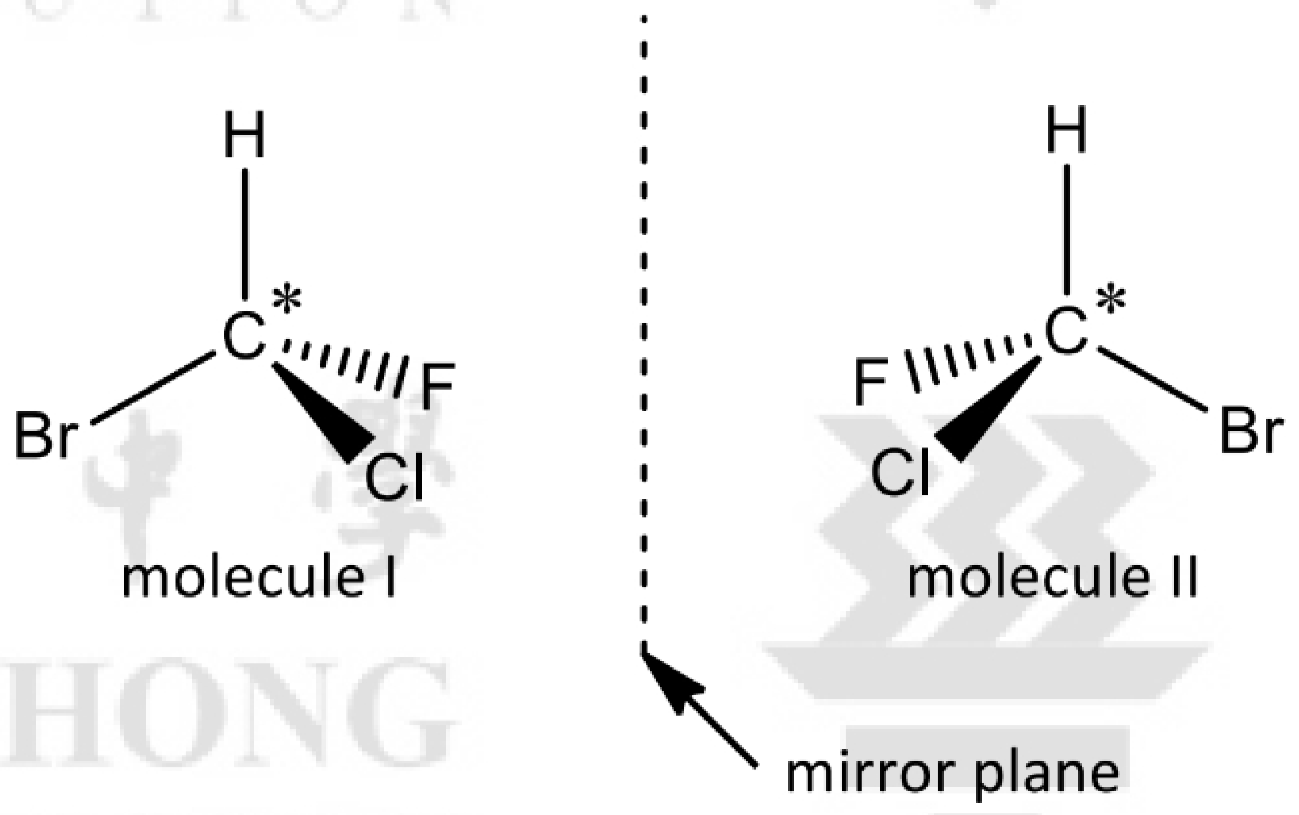


molecule I

Consider the molecule above, the carbon atom has four different groups attached to it and has a tetrahedral geometry about it. When this occurs, the carbon atom is referred to as a **chiral centre**. Similarly, any atom with a tetrahedral geometry around it that is bonded to four different groups is known as a chiral centre.

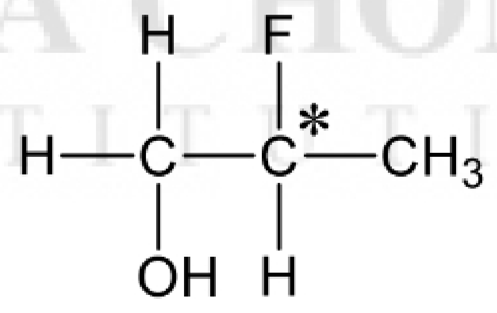
A chiral centre is denoted with an asterisk on the structure.

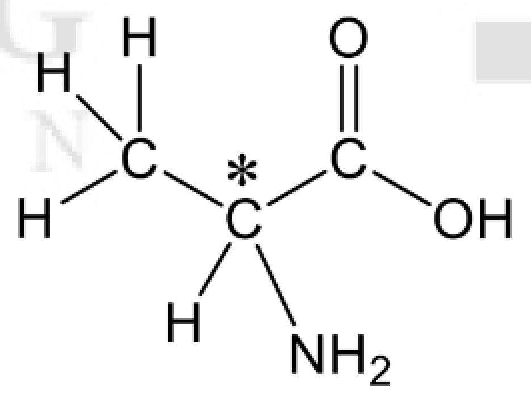
Now consider the **mirror image** of the above molecule – molecule II.

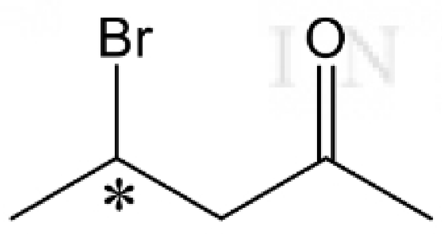


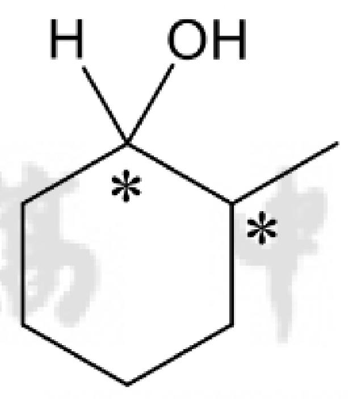
Molecule II also has a chiral centre attached to the same four groups that are present in molecule I. However, the two molecules differ in the spatial arrangement of these groups around the chiral centre. Because of this different arrangement in space, the two molecules are **not superimposable on each other**. In this situation, the two molecules, which are non-superimposable mirror images of each other, are known as **enantiomers**. Each of these molecules is also said to be **chiral**.

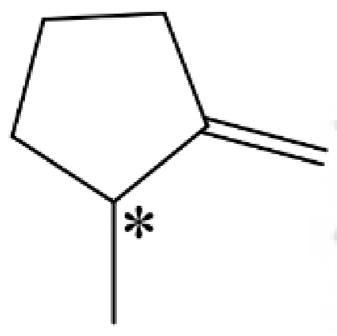
Further examples of compounds with chiral centres are shown below:

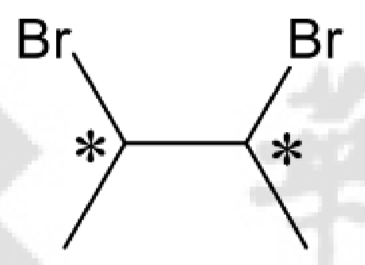








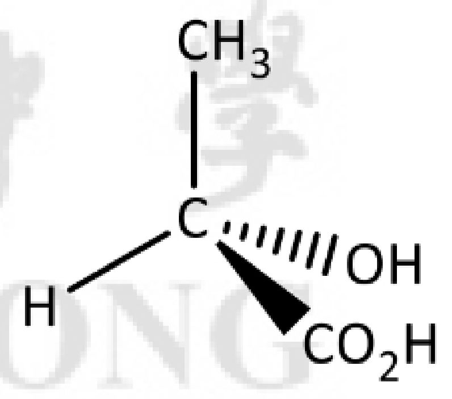




You will need to learn how to draw a pair of enantiomers showing the three-dimensional orientation about their chiral centres, just as seen for molecules I and II on the previous page.

Lecture Exercise 3.3

Draw the mirror image of the following molecule.



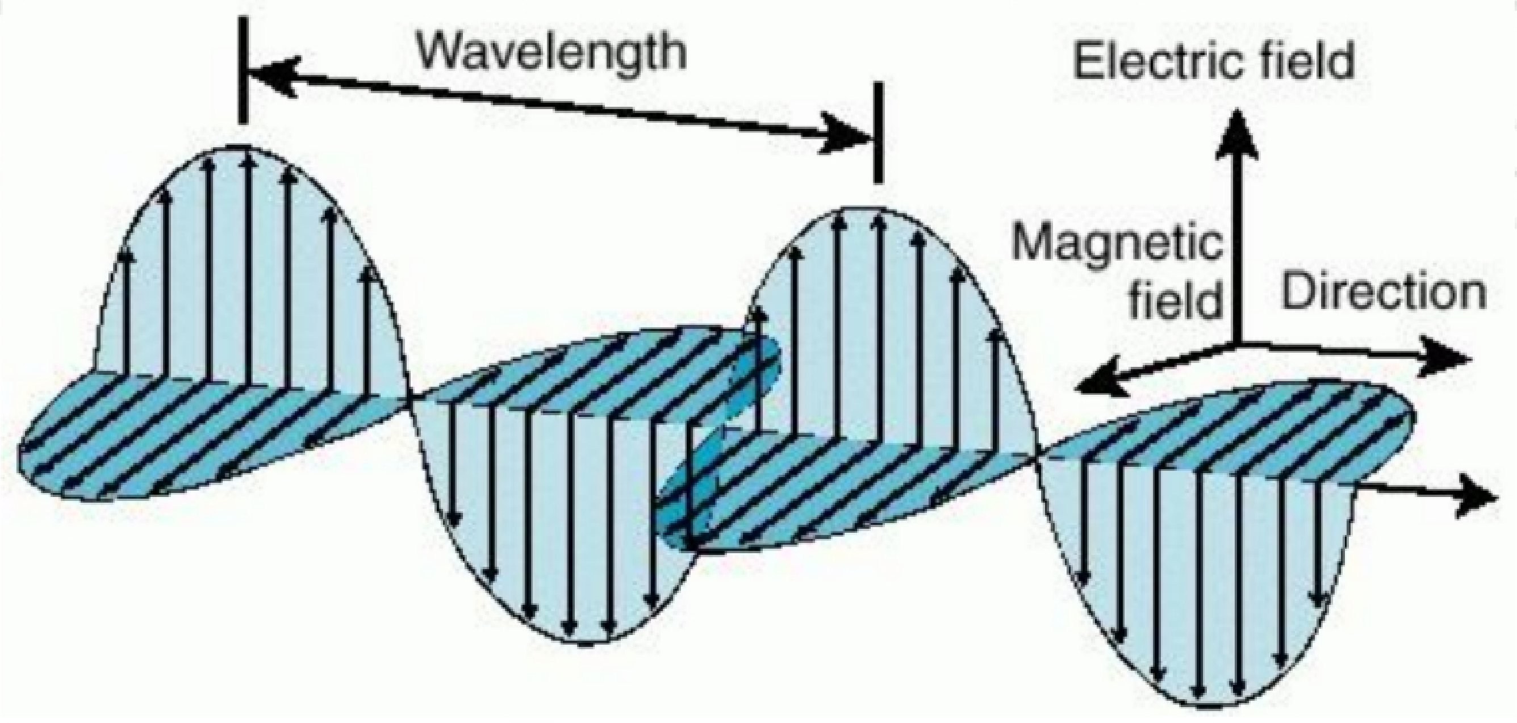
lactic acid

Note to students: You are required to use the presentation above (dashed and wedged bonds, with dotted mirror plane) to illustrate the 3D orientation about the chiral centre.

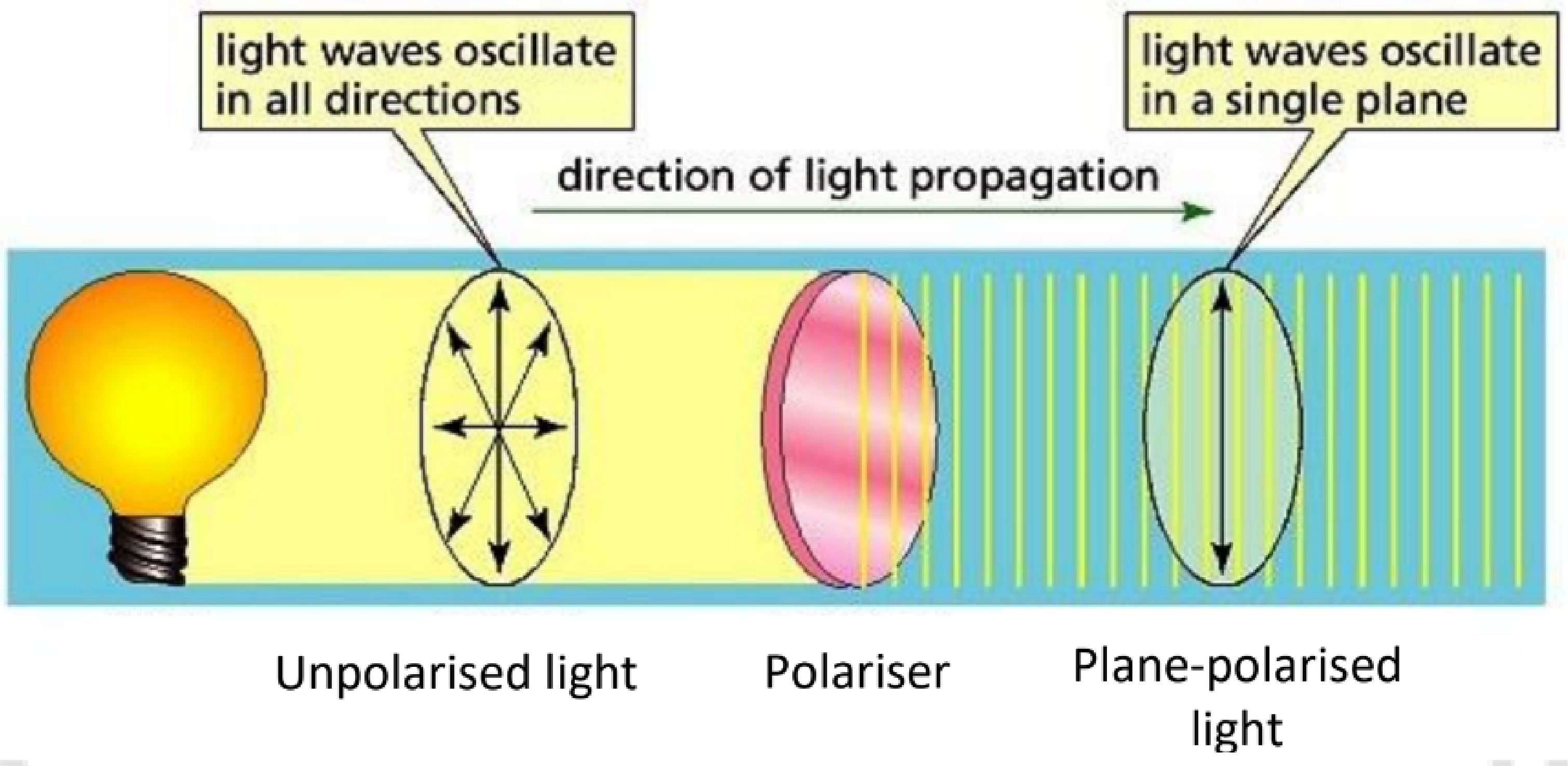
Enantiomers rotate **plane-polarised light** in opposite directions and are said to show **optical activity**.

3.2.1 Plane-polarised light

Light is an electromagnetic wave. This means that it is made up of both an electric field and magnetic field oscillating perpendicular to each other and also perpendicular to the direction of propagation of the light wave. The plane of polarisation of each light wave is assigned with respect to the oscillation of the electric field.



Typical light sources are non-polarised, meaning the light consists of light of all polarisations. However, by passing the light through a polariser, only light of one particular polarisation is allowed to pass through. The light that has passed through the polariser is called plane-polarised light.



3.2.2 Optical activity

All molecules, whether chiral or achiral, are able to rotate plane-polarised light due to interaction with the electron cloud of the molecule. For a particular molecule, the extent and direction of rotation depends on the orientation of the molecule in relation to the plane-polarised light.

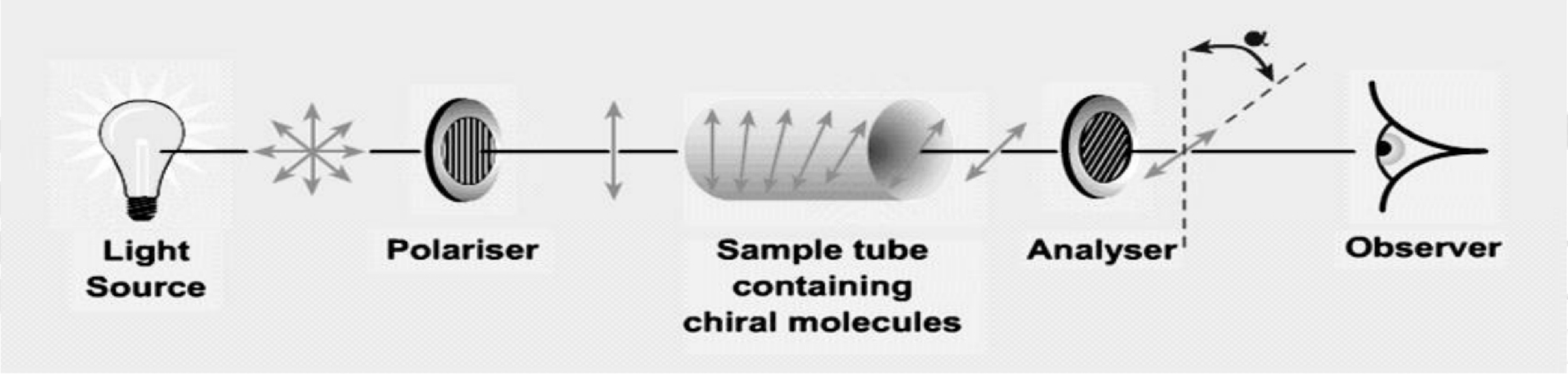
In the case of achiral molecules, due to the symmetry of the molecules and the large number and random distribution of the molecules in a sample, each of these rotations are cancelled out, leading to no net rotation of the plane-polarised light and hence no optical activity is observed.

In the case of chiral molecule (compounds exhibiting enantiomerism), when the sample is of a pure enantiomer or one that is enantiomerically enriched, such exact cancellation of individual rotations is not possible as the chiral molecules are not symmetric. This results in optical activity, i.e. rotation of the plane-polarised light. This optical activity can be measured with a polarimeter. In a **racemic mixture**, where there are equal amounts of both enantiomers, the equal and opposite rotation of plane-polarised light cancels out, and results in optical inactivity.

How a polarimeter works

Normally what we see is unpolarised light, which vibrates randomly in all directions. Plane-polarised light is composed of waves that vibrate in only one plane. When unpolarised light passes through a polariser, the randomly vibrating light waves are filtered so that the light passing through is vibrating in only one direction.

In a polarimeter, which measures the rotation of polarised light, monochromatic (one-colour) light from the source passes through a polariser, then through the sample cell containing a solution of optically active compound. On leaving the sample cell, the polarised light encounters another polariser, called the analyser. The analyser is movable and the operator rotates it until the maximum amount of light is transmitted, then reads the angle of observed rotation.



Try this!

When buying sunglasses, some are advertised to have polarising effects. How do you know that you are not being cheated? Very simple, here is a trick:

- If they are on the same rack with others, take two pairs and hold them such that you are looking through both. Then slowly rotate one pair of glasses through 90 degrees. You should see the lenses turn darker and darker.

Trivia

Honeybees are capable of using the pattern of polarized light in the sky to navigate to a food source! A group of researchers led by Mandyam Srinivasan of the University of Queensland in Brisbane, Australia, have examined whether bees can be trained to find their way through a maze composed of four interconnected tunnels, by using directional information provided by polarised light illumination from the ceilings of the tunnels. The results show that bees can learn this task, thus demonstrating directly, and for the first time, that bees are indeed capable of using the polarised light information in the sky as a compass to steer their way to a food source.

3.2.3 Physical Properties of Enantiomers

Enantiomers have identical physical properties (e.g. b.p., m.p, conductivity, etc) except towards plane-polarised light.

Each enantiomer rotates plane-polarised light by the **same angle**, but in **opposite directions**. The direction in which a particular enantiomer rotates plane-polarised light cannot be predicted from the structure, but **must be determined experimentally**.

The enantiomer that rotates the plane-polarised light in a clockwise direction is said to be *dextrorotatory* (from the Latin *dextro* = "to the right"), and we use the identifier (+) prefixed to its name. The enantiomer that rotates the plane-polarised light in an anticlockwise direction is said to be *laevorotatory* (Latin, *laevo* = "to the left"), and we use the identifier (–) prefixed to its name.

A mixture containing equal proportion of both enantiomers is called a **racemic mixture** or racemate. A racemic mixture is **not** optically active. (Why?)

A note on nomenclature

Since the (+)/(-) nomenclature can be assigned only from experiment, chemists use the R/S nomenclature to distinguish between enantiomers based on structure alone. Using systematic rules, each chiral centre can be assigned either an (R) or (S) configuration. However, learning how to assign these configurations is not part of the A-level H2 syllabus.

3.2.4 Chemical Properties of Enantiomers

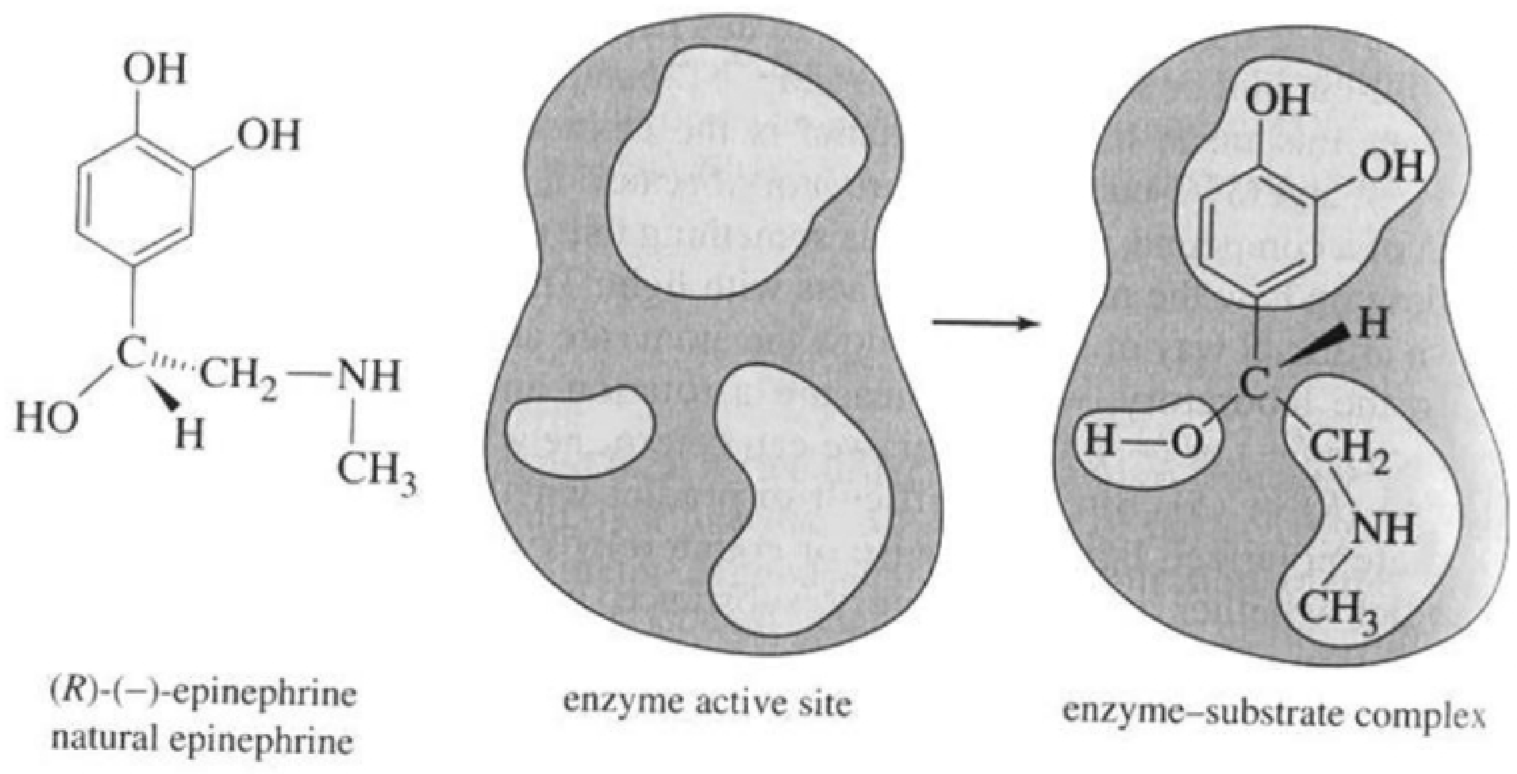
Enantiomers have the same chemical properties except in the way they interact with other chiral molecules.

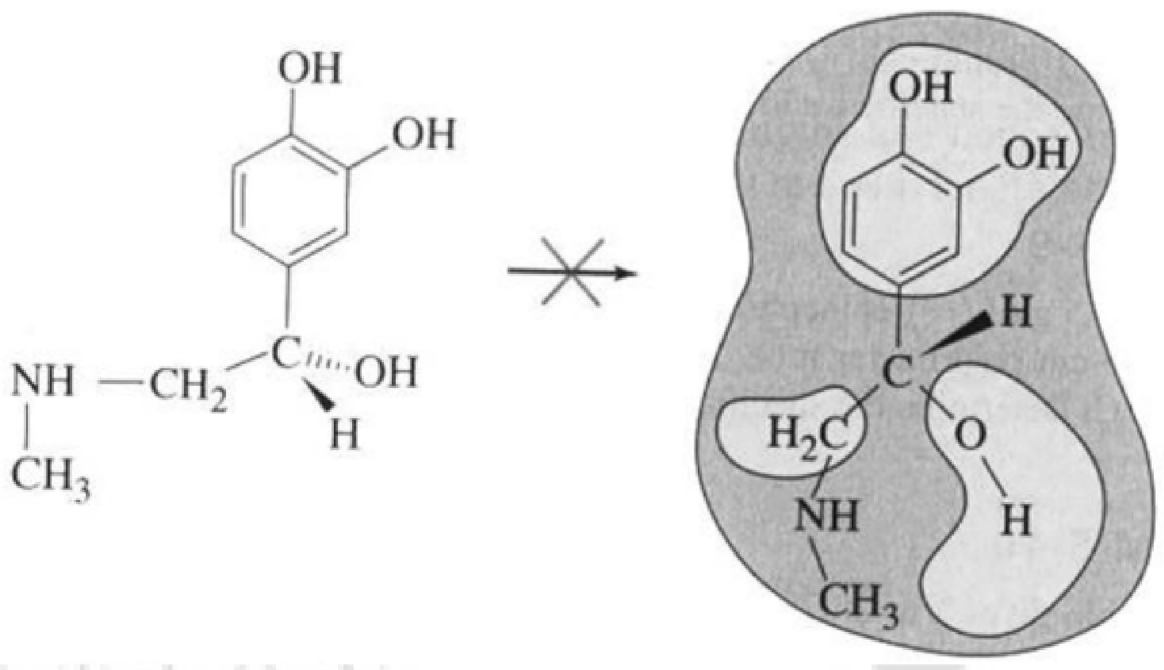
This has a lot of biological relevance, particularly in drug action. The body is a chiral environment, and will have a different response depending on which enantiomer is involved.

Example:

The action of adrenaline differs depending on which enantiomer is used:

- (–)-Adrenaline is a natural hormone with a stimulating effect.
- On the other hand, (+)-adrenaline cannot fit into the enzyme active site and is mildly toxic.





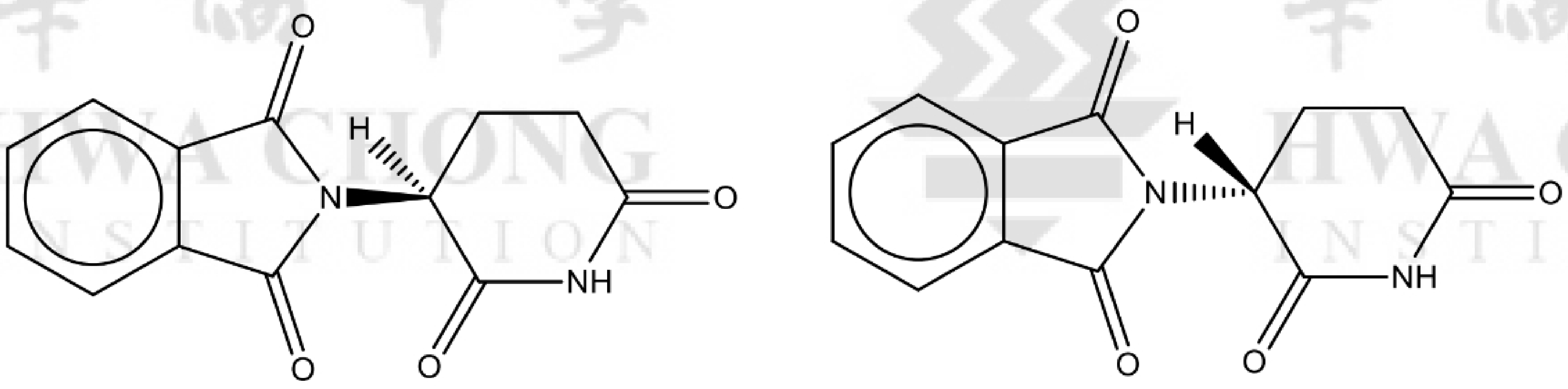
Some methods of separation of enantiomers also depend on the difference in interaction with other chiral molecules. (Refer to **Kinetic Resolution** in appendix section for more information.)

The story of thalidomide

In the late 1950s and early 1960s, thalidomide was a drug prescribed to pregnant women for morning sickness. Thousands of pregnant women took the drug to relieve their symptoms. After the introduction of thalidomide, there was a huge increase in birth defects, especially in Europe and Canada. It was discovered that thalidomide was responsible for this, causing children to be born with various defects such as amelia (absence of limbs) and dysmelia (malformation, missing or extra limbs).

Photo by Leonard McCombe//Time Life Pictures/Getty Images)

Thalidomide was prescribed as a racemic mixture, containing both the left-handed and right-handed isomers in equal amounts. It was later determined that only one of the isomers, the (R) isomer was effective against morning sickness, whereas the other isomer, the (S) isomer, was teratogenic (caused birth defects). However, the enantiomers can interconvert *in vivo* (in the human body), so if a human is given pure (R)-thalidomide or (S)-thalidomide, both isomers will be present in the body eventually. Therefore, even administering the (R) isomer will NOT prevent the teratogenic effects in humans.



The two enantiomers of thalidomide

An important lesson

Following the thalidomide incident, there was increased fear in the safety of pharmaceutical drugs. It brought on a change in drug testing and increased awareness of potential side effects of drugs. It led to much stricter testing before drug licensing.

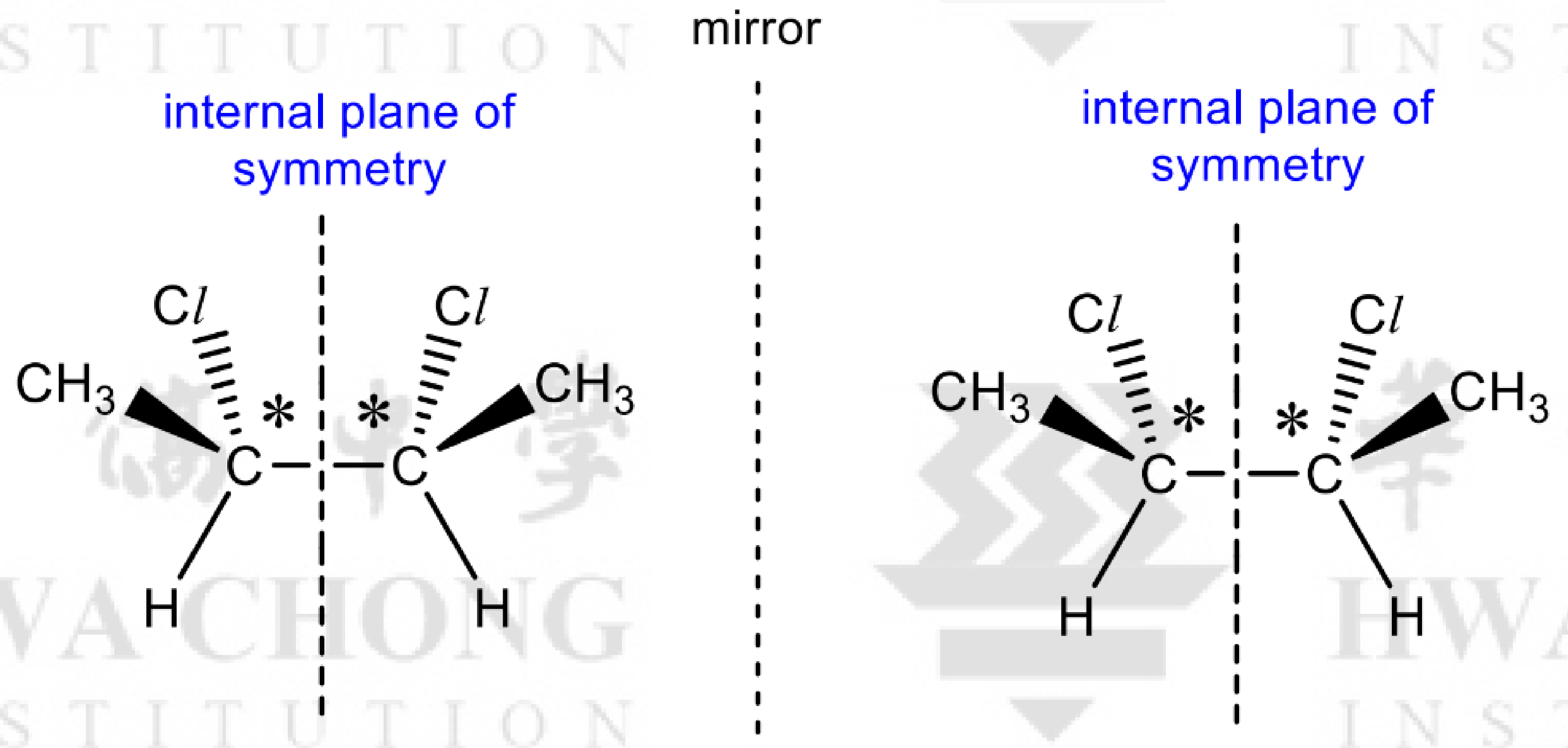
The biological impact of enantiomers also highlights the importance of enantiomeric purity in the medicinal industry. This has to be achieved either through synthesis of only one particular enantiomer or the separation of mixtures of enantiomers.

3.2.5 Unusual cases of chirality and achirality

***Meso* compounds**

Meso compounds are **achiral** molecules that possess multiple chiral centres. The reason why they are achiral is because they possess an **internal plane of symmetry** which cause their mirror image to be superimposable.

In the example below, there are 2 chiral carbons in molecule E, but because of the internal plane of symmetry, the molecule's mirror image is identical to itself. As such, molecule E is the ***meso*** isomer of 2,3-dichlorobutane, and is therefore **achiral**. A pure sample of this molecule would be **optically inactive**.



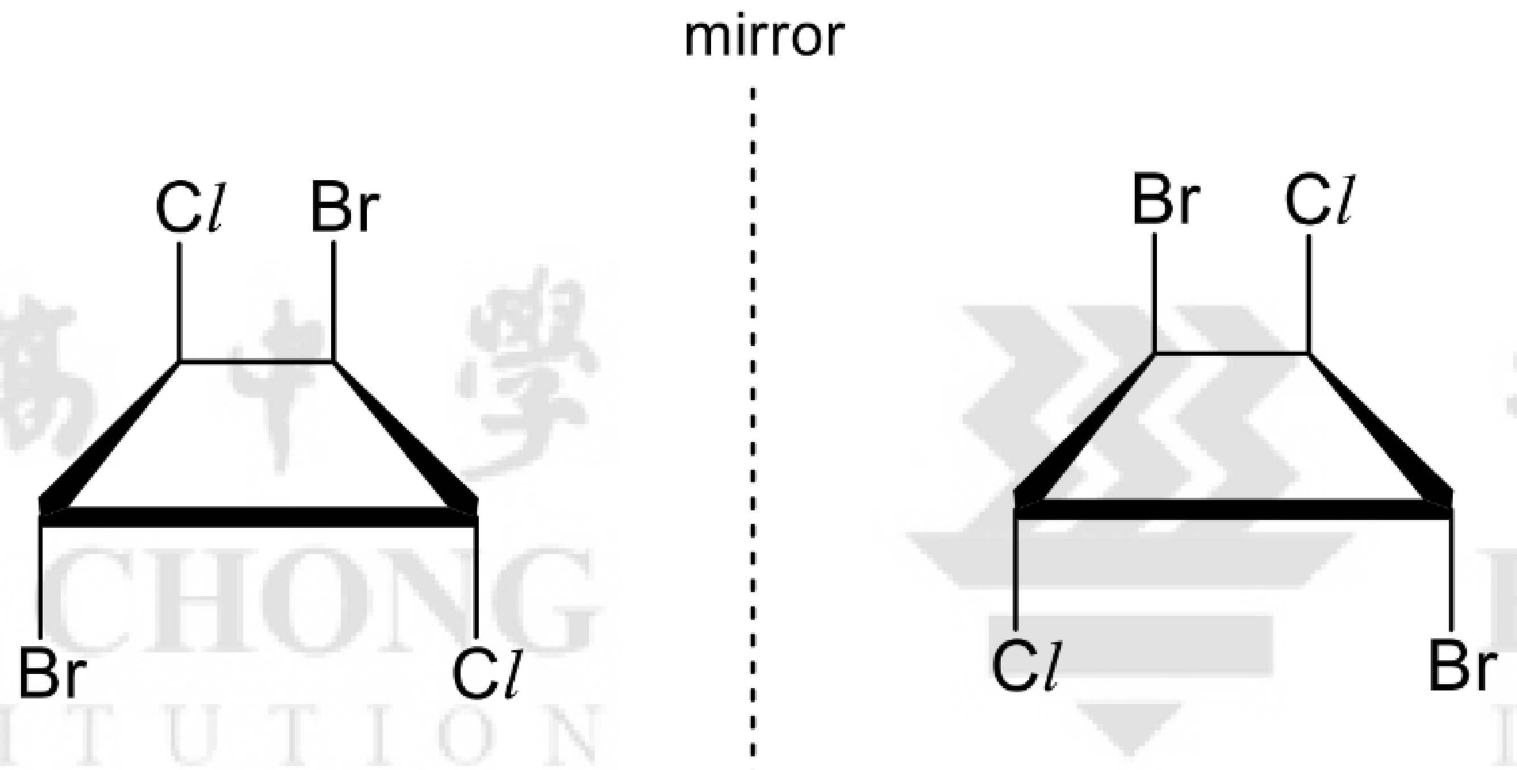
molecule E

mirror image:
identical to molecule E

Some molecules without a plane of symmetry can also be achiral

While a molecule with an internal plane of symmetry must be achiral, *some* molecules without an internal plane of symmetry can also be achiral.

Molecule F, for example, has no internal plane of symmetry, yet its mirror image is superimposable on itself. Molecule F is therefore achiral.



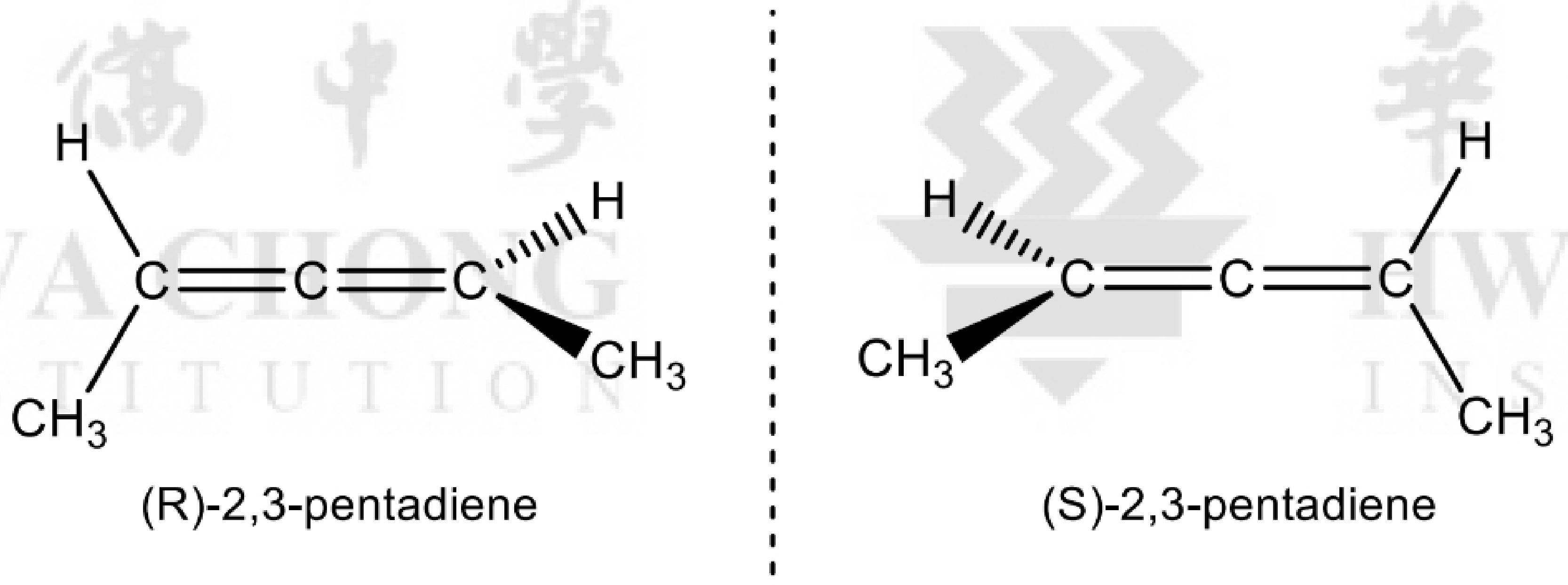
molecule F

mirror image:
identical to molecule F

<u>*Visualisation help:*</u> flip the mirror image of F about the plane of the ring (↷), then rotate it 180° (↺) to superimpose it with the molecule on the left-hand side.

Chiral molecules despite lack of chiral centres

Enantiomers may exist in compounds without chiral centres. Consider the molecule 2,3-pentadiene below. Due to restriction of rotation about the double bonds, the two terminal methyl groups lie in perpendicular planes, and there is no internal plane of symmetry in the molecule. As such, two non-superimposable enantiomers of 2,3-pentadiene exist, and the molecule is chiral.



(R)-2,3-pentadiene

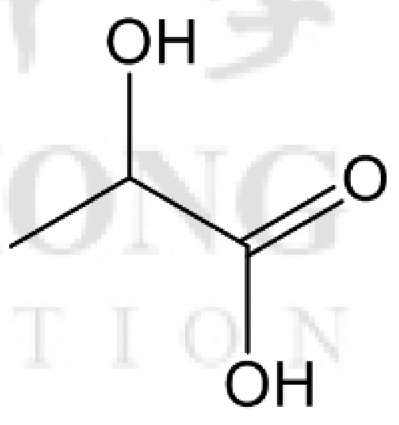
(S)-2,3-pentadiene

Enantiomers of 2,3-pentadiene

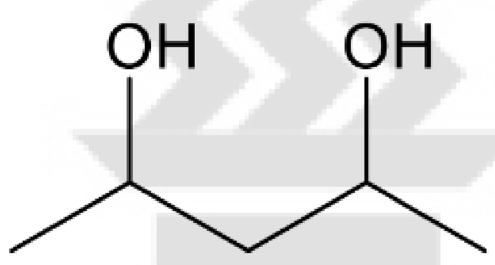
Self-practice 3.3

1. Draw structures to show the enantiomers of butan-2-ol. Indicate the chiral centres (*).

2. Identify the chiral centres in the following molecules. Do these molecules exhibit enantiomerism?



lactic acid



pentane-2,4-diol

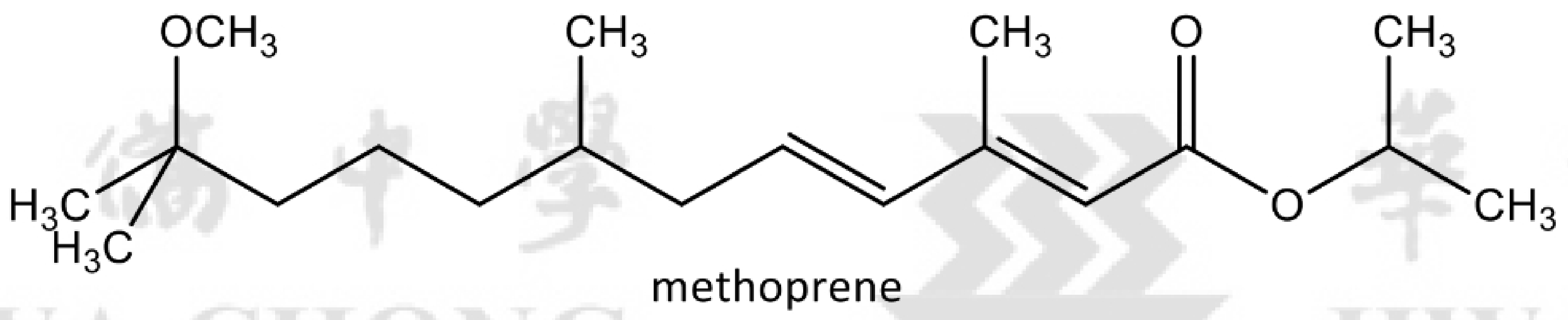
3.3 Counting the total number of stereoisomers

Stereoisomers include both *cis–trans* isomers and enantiomers. Provided there is no internal plane of symmetry in the structure of a molecule, and chirality occurs only due to chiral centres, then:

the maximum number of stereoisomers a molecule can have = $\mathbf{2^{m+n}}$

where m = number of chiral centres; and
n = the number of double bonds that can give rise to *cis–trans* isomers.

For example, in the methoprene molecule shown below, there is only one chiral centre, and both double bonds allow for *cis-trans* isomerism. As such, the maximum number of possible stereoisomers for methoprene is $2^{(1+2)} = 8$.



methoprene

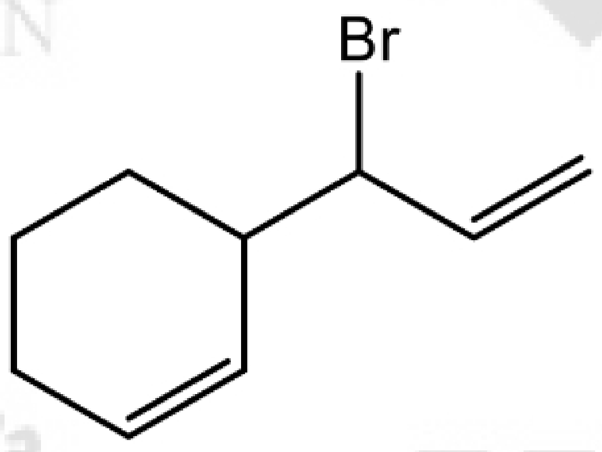
Lecture Exercise 3.4

Consider a compound with structural formula $CH_3CH{=}CHCH(CH_3)CH_2CH_3$.

i. What is the maximum number of stereoisomers?
ii. Draw the structure of each stereoisomer.

Self-practice 3.4

What is the total number of stereoisomers for the following compound?



A. 2 **B**. 3 **C**. 4 **D**. 8

Glossary of important terms

chiral	*(with reference to a molecule)* A molecule whose mirror image is non-superimposable on itself. Chiral molecules **cannot** possess an internal plane of symmetry.
chiral centre	*(with reference to an atom in a molecule)* An atom with tetrahedral geometry around it and bonded to four chemically distinct groups.
achiral	*(with reference to a molecule)* A molecule whose mirror image is identical to itself (superimposable). Achiral molecules often possess an internal plane of symmetry.
enantiomers	*(with reference to molecules)* A pair of enantiomers are non-superimposable mirror images of each other.
plane-polarised	*(with reference to light)* Light whose electromagnetic waves oscillate in a single plane, via the effect of a polariser.
optically active	*(with reference to a sample)* A sample that causes rotation of plane-polarised light. Optically active samples must contain chiral molecules – either a pure enantiomer, or enriched in one of the enantiomers over the other.
optically inactive	*(with reference to a sample)* A sample that has no effect on plane-polarised light. Optically inactive samples could contain achiral compounds, or a racemic mixture of enantiomers.
racemic mixture	*(with reference to a sample)* A sample that contains equal molar proportions of each enantiomer. Racemic mixtures are optically inactive.
stereoisomers	*(with reference to molecules)* Includes both *cis-trans* isomers and enantiomers of a particular substance. Stereoisomers must have the same structure (in terms of atom connectivity).

APPENDIX

DEGREES OF UNSATURATION

Calculating degrees of unsaturation is a useful tool to elucidate the structure of an organic compound. The degrees of unsaturation can tell us how many possible double/triple bonds or ring structures there are in a compound.

The degrees of unsaturation in a compound is determined from its molecular formula.

A straight chain or branched aliphatic alkane has the general molecular formula, C_nH_{2n+2}. It is considered saturated and has zero degrees of unsaturation. For example, butane has the molecular formula C_4H_{10} and therefore is saturated and has zero degrees of unsaturation.

For hydrocarbons, every decrease of 2 hydrogen atoms from the general formula of C_nH_{2n+2} contributes to 1 degree of unsaturation. For example, the molecular formulae C_4H_8, C_3H_6, and C_8H_{16} indicate 1 degree of unsaturation. The molecular formulae C_4H_6, C_5H_8, and C_8H_{14} indicate 2 degrees of unsaturation.

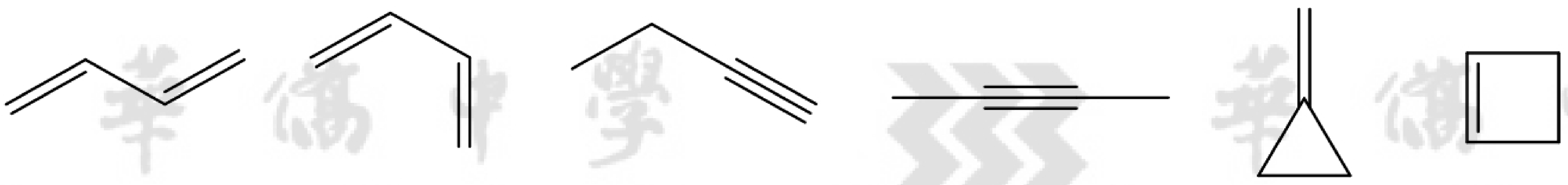
Singly bonded atoms like halogens can be counted towards the hydrogen atom count. For example, the molecular formulae C_4H_7Br, and C_3H_5Cl indicate 1 degree of unsaturation.

Divalent atoms like oxygen and sulfur do not affect the degree of unsaturation. For example, the molecular formulae $C_4H_{10}O$, and C_3H_8O indicate a saturated compound. The molecular formulae C_4H_6O, and $C_8H_{14}O$ indicate 2 degrees of unsaturation.

The degree of unsaturation gives us information on the structure of the compound. If the molecular formula shows 1 degree of unsaturation, it can mean that the compound contains a double bond or a single ring. 2 degrees of unsaturation may possibly indicate 2 double bonds, or 2 ring structures, or 1 double bond and 1 ring structure, or a triple bond.

Worked Example 1

The molecular formula C_4H_6 is 4 H atoms short of the formula for saturated alkanes. This indicates 2 degrees of unsaturation. 2 degrees of unsaturation may possibly indicate 2 double bonds, or 2 ring structures, or 1 double bond and 1 ring structure, or a triple bond. Hence, some possible structures of the actual compound are shown below.



Worked Example 2

The molecular formula C_5H_7OF has an oxygen atom and fluorine atom. A saturated molecule should have a hydrogen count of 12. A halogen adds 1 to the hydrogen count but the oxygen atom does not add to the hydrogen count so the molecular formula has a hydrogen count of 8. This indicates that there are $(\frac{12-8}{2}) = 2$ degrees of unsaturation. This can be due to C=C bond/s, C=O bond and/or ring structures. Try drawing out some of the possible structures of C_5H_7OF.

*Try going back and applying this method on Self Practice 2.1(a) and 2.1(c).

APPENDIX

KINETIC RESOLUTION

Due to the nature of enantiomers having similar chemical and physical properties, it is very difficult to separate the enantiomers. The separation of enantiomers requires interaction with other chiral compounds. One such method is kinetic resolution.

In kinetic resolution, a mixture of enantiomers is reacted with a chiral reagent. The chiral reagent has to be chosen such that it reacts quickly with one enantiomer of the compound we are interested in and reacts very slowly with the other enantiomer.

This method of separation is illustrated in the example below. A racemic mixture of excess mandelic acid is reacted with a pure sample of (–)-menthol. Only one enantiomer of mandelic acid reacts with the (–)-menthol to produce an ester. The other enantiomer of mandelic acid, due to difference in rate of reaction, does not form an ester with the (–)-menthol.

The ester now has different physical and chemical properties with the leftover mandelic acid and can be easily separated through conventional separation techniques. The enantiomer of the mandelic acid can then be recovered by hydrolysing the ester.