CHEM 221 section 01

LECTURE #18 Thurs., Nov.03, 2005

ASSIGNED READINGS:

TODAY'S CLASS: continue Ch.5

NEXT LECTURE: finish Ch.5

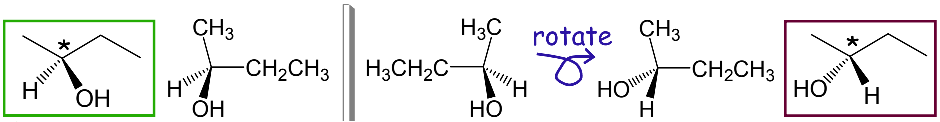
http://artsandscience.concordia.ca/facstaff/P-R/rogers

5.5 Drawing enantiomers

- **perspective drawings:** use dashes & wedges to show 3D geometry
  - practice: drawing & rotating molecules on paper & in your head…

To draw a molecule's enantiomer:

1. Draw molecule as a perspective drawing
   - only need to show all 3D information for *asymmetric* atoms
2. Imagine reflecting molecule in a mirror
   - configuration of EVERY asymmetric atom will be inverted
3. Check: is this really a different compound?
   - original & mirror image are only enantiomers if they are *nonsuperimposable* mirror images of each other



Draw its enantiomer…

mirror

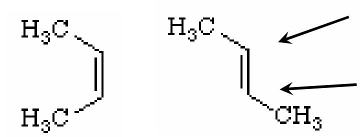
Can now see: configuration opposite to original

Shortcut: to draw a chiral C (*i.e.*, C*) with opposite configuration, detach any 2 groups from that C* & switch their places

5.9 Diastereomers (stereoisomers that are not mirror images)

→ **only SOME of their stereocentres have opposite configuration**

cis / trans isomers:

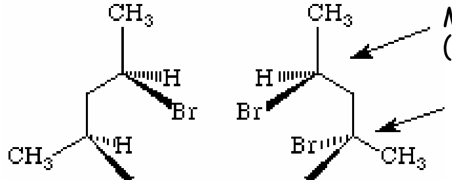


NOT mirror images at this point (C's with same configuration)

Mirror images at this point (C's with opposite configuration)

Each one here is achiral: each has a horizontal internal mirror plane
thus: each is superimposable on its own mirror image
thus: neither molecule has an enantiomer

compounds with chiral centres:



Mirror images at this point (C's with opposite configuration)

NOT mirror images at this point (C's with same configuration)

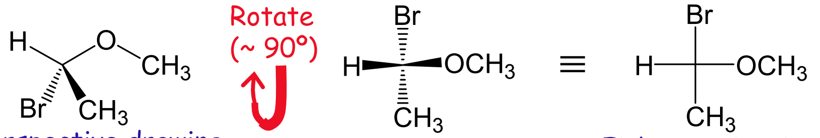
Achiral: Br
internal mirror plane

H Chiral: no internal mirror plane
does have an enantiomer (not shown)

Perspective drawings *vs.* Fisher projections

Fisher projections: a short-hand often used by biologists
showing your for your information (will not test…)

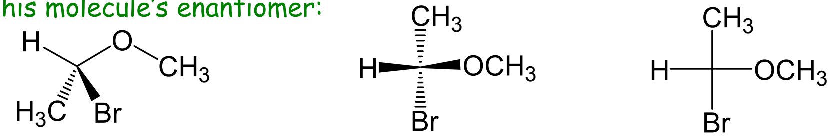
- each chiral C looks like a planar cross, but REALLY means this:
  horizontal lines: aimed towards you (out of page)
  vertical lines: aimed away from you (into page)



perspective drawing
(intuitively meaningful)

Fisher projection
(use carefully…)

This molecule's enantiomer:

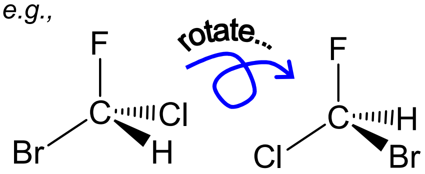


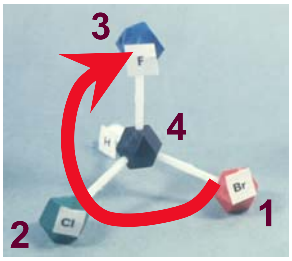
BEWARE: a Fisher projection does look flat, but it is NOT flat…
Thus: if rotate by 180 ° ⇨ still represents same molecule
if rotate by 90° ⇨ no longer represents the same molecule!

5.6 Assigning configuration of chiral centres: "the R,S system"

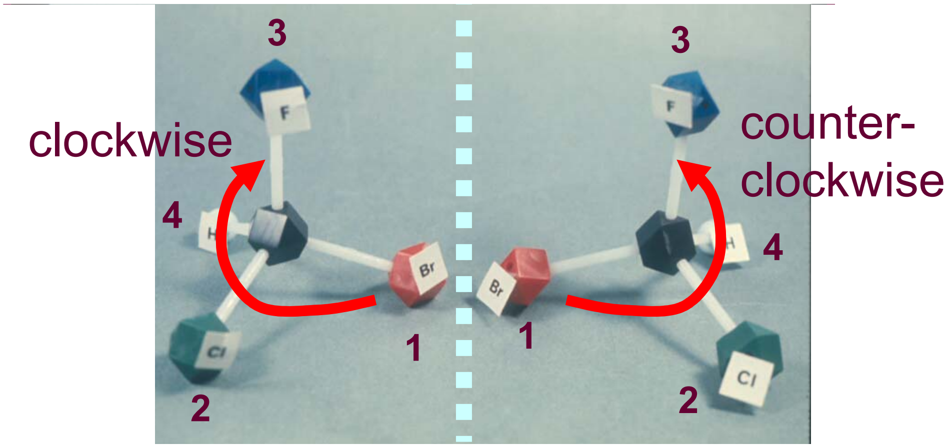
1. Assign priority to the 4 groups attached to the stereocenter.
   using Cahn-Ingold-Prelog rules: higher atomic # ⇨ higher priority
2. Picture molecule with LOWEST priority group aimed AWAY from you
3. Trace other groups in a circle: highest → lowest priority:
   Clockwise = (R) for *rectus*, Latin for right
   or Counterclockwise = (S) for *sinister*, left

e.g.,





Traces in a clockwise direction
⇨"R"
Like turning right on a steering wheel



(R) configuration

Rectus = right

The (R) enantiomer of bromochlorofluoromethane

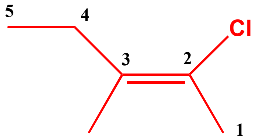
(S) configuration

Sinister = left

The (S) enantiomer of bromochlorofluoromethane

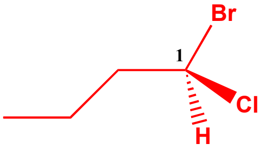
5.6 & 5.11: IUPAC naming of stereoisomers

Geometric isomery: defined in front of name by using cis/trans (Z/E for double bonds), followed by a dash:



cis-1-chloro-3-methylpent-2-ene
or Z-chloro-3-methylpent-2-ene

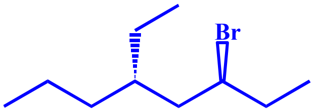
Configuration of chiral carbon atoms: noted using R/S letters after position number of chiral atom, in brackets followed by dash:

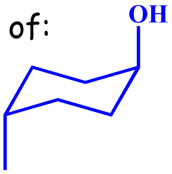


(1R)-1-Bromo-1-chlorobutane
or (R)-Bromochlorobutane

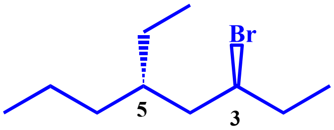
If more than one chiral carbon, just use a comma to separate the number-letter combinations *(see next example…)*

Assign configuration and name of:



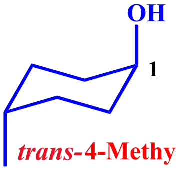


How many stereoisomers do these compounds have?



(3S, 5S)-3-Bromo-5-ethyloctane

- 2 chiral centres
- Thus:
  2^2 = 4 stereoisomers possible
  (2 pairs of enantiomers)



trans-4-Methylcyclohexan-1-ol

- No chiral centres
- Internal plane of symmetry
  ⇨ achiral
  ⇨ does not have an enantiomer
- But: groups could be *cis*…
- Thus: 2 stereoisomers possible
  (diastereomers; geometric…)

5.7: Optical activity **Chiral compounds are optically active**

Enantiomers: have identical physical properties (mp, bp, solubility…)

→ cannot be separated by direct physical means such as distillation or crystallization

BUT: they DO interact differently with CHIRAL things

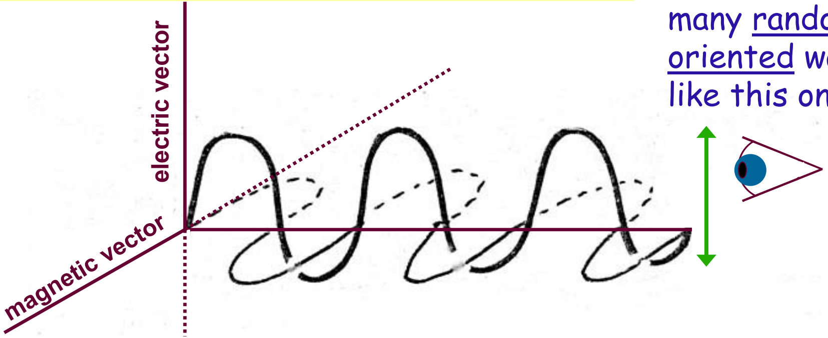
- example: plane-polarized light (it is chiral!)
- PPL is rotated by chiral molecules
- enantiomers rotate PPL to same extent, but in opposite directions (clockwise *vs.* counterCW)

Chiral compounds rotate the plane of plane-polarized light
→ exhibit "optical activity"

…WHAT IS PLANE-POLARIZED LIGHT??

Refresher on the nature of light

In a light beam: many randomly oriented waves like this one…



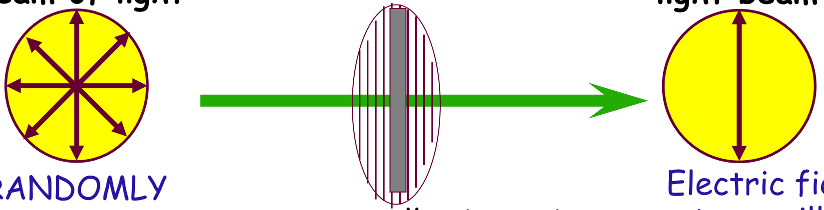
Light = a wave with oscillating electric & magnetic fields that are perpendicular to each other *and* the direction of propagation

LET'S PAY ATTENTION TO THE ELECTRIC VECTOR
i.e., picture an arrow ↔ that maps out the amplitude of the electric field's oscillation

Unpolarized beam of light

Pass light through a POLARIZING FILTER

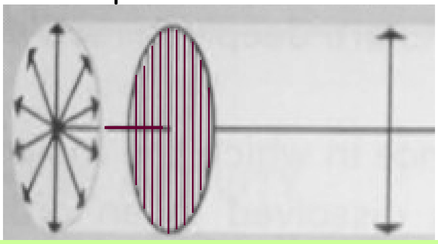
"Plane-polarized" light beam



RANDOMLY ORIENTED electric field vectors

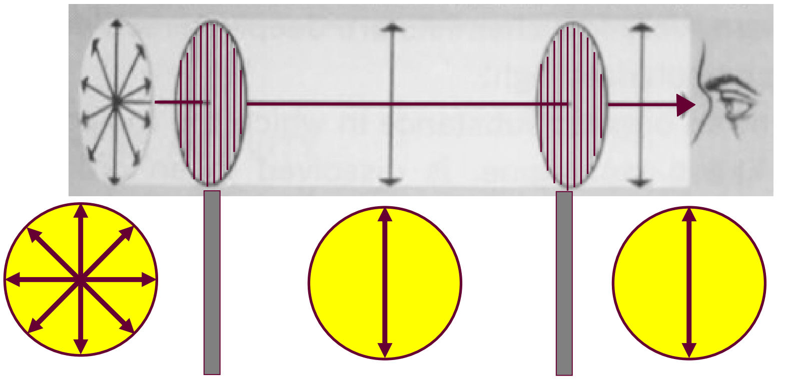
removes all orientations except for one

Electric field vector oscillates IN SAME PLANE for all waves



ONLY light waves with their direction of vibration aligned PARALLEL TO THE FILTER'S SLITS can pass through!!

If we have two polarizers in a row…
…light passes through if they are aligned (both at 0°)



unpolarized light

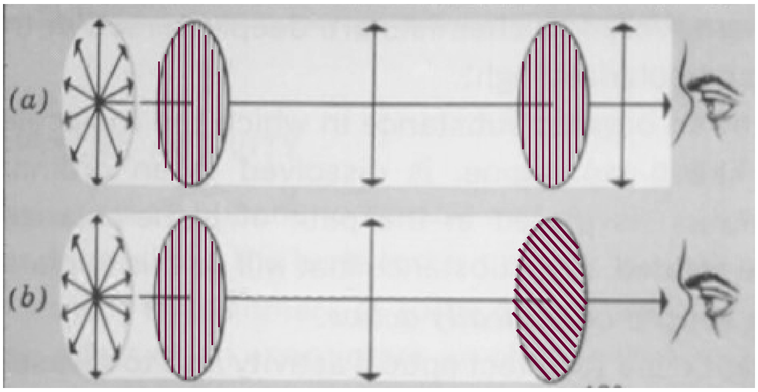
Polarizing filter (0°)

Plane-polarized light

Polarizing filter (0°)

Plane-polarized light

If not aligned: less light passes through…

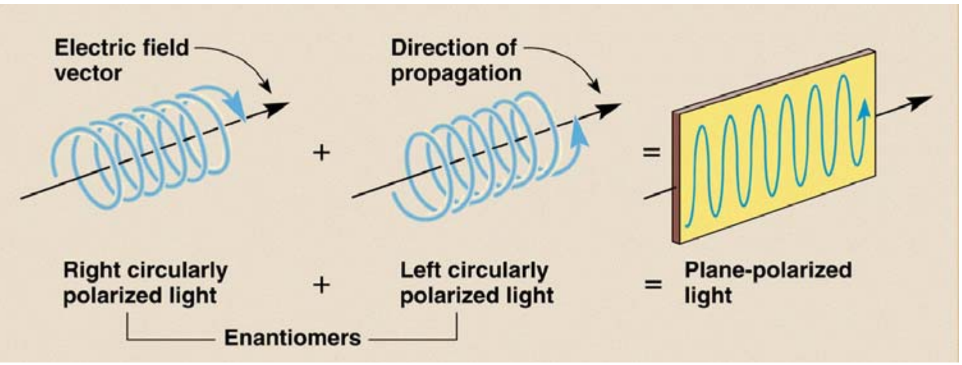


NO LIGHT passes if polarizers are "crossed"
(oriented at 90° to each other)

A more accurate description of polarized light…

Plane-polarized light = made up of two chiral light waves!
(right CPL) + (left CPL)

Circularly polarized light (CPL) propagates through space as helices, either right-handed or left-handed
i.e., CHIRAL light beams!



Brown & Foote (on reserve) Figure 3.6

Remember: right hands fit better into right gloves…
***i.e.*, interactions of chiral species are hand-specific**

When plane-polarized light interacts with chiral molecules, rotation of the plane of polarization occurs.

- right CPL & left CPL are each chiral…
- interact to different extents with chiral molecules!
- result: one CPL gets slowed down more than other
  ⇨ net rotation of polarization plane

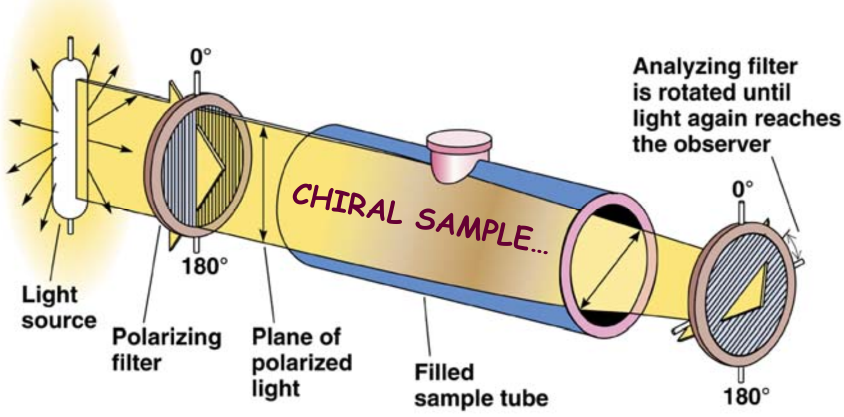
Clockwise rotation: (+) *"dextrorotatory" species* (*d or* D)
e.g., (d)-methionine

Counterclockwise: (-) *"levorotatory" species* (*l or* L)
e.g., (l)-methionine

A polarimeter:
- used to measure rotation of polarized light
- substance of interest placed between two polarizers

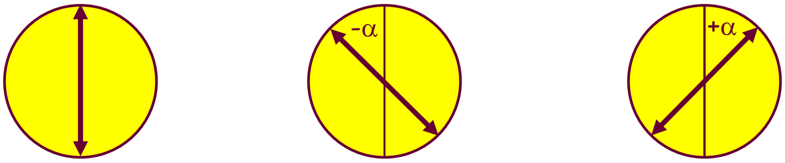
USING A POLARIMETER

chiral sample rotates plane ⇨ less light passes…
→ YOU turn one polarizer until appears bright again
→ angle polarizer rotates = sample's optical rotation (α)



Similar: Bruice Fig.5.2

Rotation of Plane Polarized Light

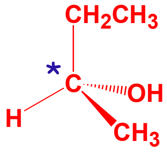


Direction of the electric vector of plane-polarized light	Plane rotated counterclockwise: angle of rotation = - α	Plane rotated clockwise: angle of rotation = + α

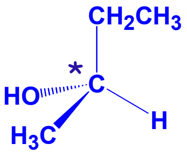
Compound is “levorotatory” (-) *or l*

Compound is “dextrotatory” (+) *or d*

- For a pair of enantiomers: one is (+), other is (-)
  magnitude of rotation is identical
- “racemic mixture” : 50/50 mixture of enantiomers
  +/- rotations equal ⇨ no net rotation!



A



B

A and B are chiral
∴ optically active

A and B are enantiomers
∴ opposite optical rotation

	bp °C	solubility	$[\alpha]_D$
A	99.5	12.5	+13.8
B	99.5	12.5	-13.8

A racemic mixture of A & B would have
α = **0** *(rotations cancel)*

Quantifying optical rotation: an extensive property…

How much the plane of polarized light is rotated depends on:

nature of compound & its concentration
temperature, length of sample tube, wavelength of the light

Temperature °C

measured rotation

“Specific rotation” = $[\alpha]^{T}_{D} = \frac{\alpha}{l\,c}$ (concentration, solvent)

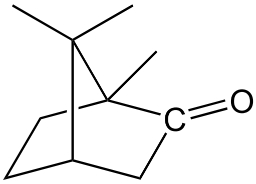
D line of sodium spectrum

Tube length in decimeters

concentration in g/mL … & we specify the solvent

ENANTIOMERS ARE EQUAL BUT OPPOSITE:
Once the optical rotation for one enantiomer is known… the other enantiomer will have the same degree of rotation, but in the opposite direction.

EXAMPLE: *A solution (100 mL) of 16.5 g of (l)-camphor in ethanol has an optical rotation of -7.29° at 20°C, using a 10 cm sample tube and a sodium lamp. What is its specific rotation?*



$$\text{Specific rotation} = [\alpha]^{20}_{D} = \frac{\alpha}{l\,c}$$

$$= \frac{-7.29°}{1\ \text{dm} \times 16.5\ \text{g}/100\ \text{mL}}$$

$$[\alpha]^{20}_{D} = -44.2° \quad (0.165;\ \text{ethanol})$$

Conc. g/mL

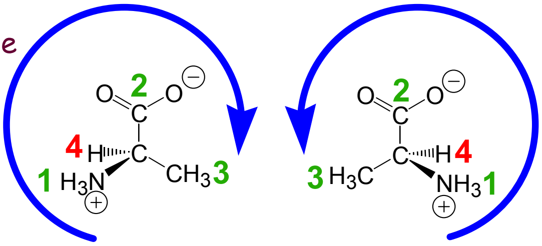
solvent

Knowing the absolute configuration (R/S) of a compound does NOT let us predict the sign of the optical rotation, d(+) *or* l(-)

Likewise, absolute configuration CANNOT be determined from the sign of the optical rotation.

BUT: if sign of rotation of one enantiomer IS known… the other enantiomer <u>will</u> have opposite sign.

(R)-(-)-alanine



Dextrorotatory

(S)-(+)-alanine

You cannot predict the rotation direction, but once you DO know it, it can be specified in the compound's name…

5.8 Optical purity & enantiomeric excess

Enantiomers rotate PPL in opposite directions

thus: net rotation depends on how much of each is present

A racemic mixture (racemate):

- contains equal #s of molecules of two enantiomers ("optical isomers")
- shows NO optical rotation.

WHY? ⇨ equal concentration of molecules that rotate plane polarized light clockwise and counterclockwise.

In a non-racemic mixture of optical isomers:

- one enantiomer "A" is present in larger amount (excess)
- rotation due to enantiomer B will be cancelled out by A's rotation

⇨ net rotation observed: due to the excess quantity of A

"Enantiomeric excess" *(e.e.)* *or* "optical purity"

$$\frac{\text{Measured specific rotation of the mixture}}{\text{Specific rotation of the pure enantiomer}} \times 100 = \%\ \text{enantiomeric excess}$$

Example: Describe the composition of a particular mixture of enantiomers, with measured optical rotation: $[\alpha] = 10^{\circ}$
if optically pure (+) enantiomer has: $[\alpha] = 20^{\circ}$

THUS: $(10^{\circ} / 20^{\circ}) \times 100$ = 50% optical purity
or, 50% enantiomeric excess

measured rotation has + sign ⇨ means (+) enantiomer is in excess!

What is the ratio of optical isomers present in the mixture?

What is the true meaning of optical purity / enantiomeric excess?

If 50% is optically pure, then the remaining 50% is racemic (+/- or *d / l*)

	%*d*	%*l*
50 % *d l*	25	25
50 % *d*	50	
	75 *total d*	

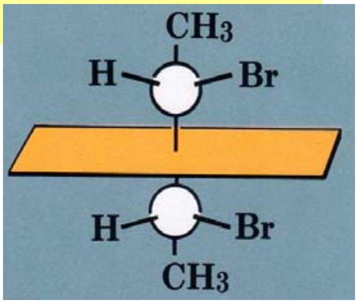
⇨ *d* : *l* = 75 : 25
= 3 : 1

5.10: Meso Compounds

Picture a molecule with two asymmetric centres that have identical groups on them…

Depending on their configurations, the molecule overall can have an INTERNAL plane of symmetry.

→ Molecule overall is **ACHIRAL**
called a "meso compound"



Brown & Foote Fig. 3.4 (textbook on reserve)
Nice pictures in Bruice too

IMPLICATION: optically inactive

<u>stereocentres</u> in SAME molecule <u>are mirror images</u>
⇨ cancel out each other's optical rotation
⇨ like a racemic mixture inside one molecule!

MESO COMPOUNDS: contain mirror-image stereocenters

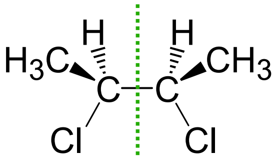

At first glance, these look like enantiomers…

mirror-images
…but….
superimposable
∴ identical!

Internal plane of symmetry ⇨ ACHIRAL molecule

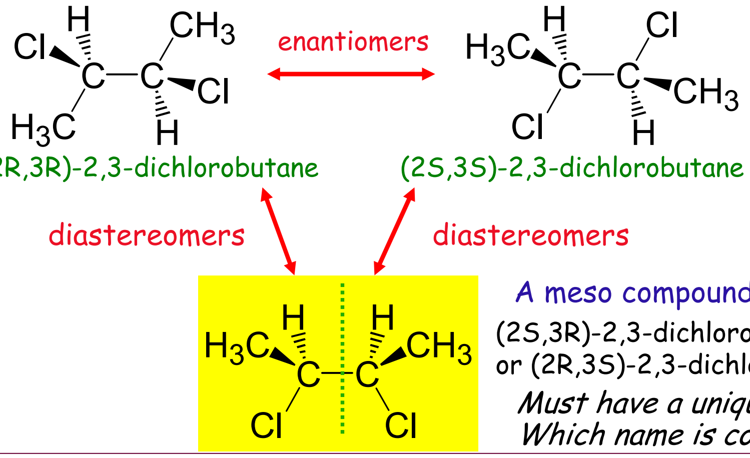
A "MESO" COMPOUND

The molecule is not chiral
∴ has no optical activity
Like a racemic mixture
within one molecule!



*Aside: in 5.9, see "erythro" vs. "threo" to describe isomers with >1 C**
If can rotate to have similar groups on same side of chain: erythro
If config. Makes similar groups remain on opposite sides: threo
BUT YOU ARE NOT STRICTLY RESPONSIBLE FOR THIS!

2,3-dichlorobutane: 2 stereocentres ⇨ max. 2^2 stereoisomers, but actually only 3 different cmpds since 1 is a meso cmpd



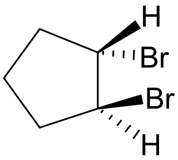
(2R,3R)-2,3-dichlorobutane

(2S,3S)-2,3-dichlorobutane

A meso compound
(2S,3R)-2,3-dichlorobutane
or (2R,3S)-2,3-dichlorobutane
Must have a unique name.
Which name is correct?

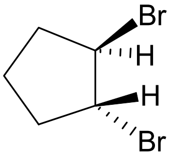
When naming meso compounds, the stereocenter with the lower number is designated as having the R configuration

Disubstituted cycloalkanes: many have a meso diastereomer



(1S,2S)-1,2-dibromocyclopentane

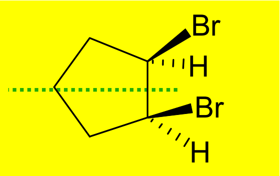
enantiomers



(1R,2R)-1,2-dibromocyclopentane

diastereomers

diastereomers



(1R,2S)-1,2-dibromocyclopentane
a meso compound

NOTE: convince yourself of this:

- all symmetrically disubstituted cyclopentanes have meso isomers
  → both 1,2- and 1,3-substituted
  BUT…
- not the case for all disubstitution patterns of cycloalkanes!
  → don't always have asymmetric Cs!

ASSIGNED READINGS

BEFORE NEXT LECTURE:

Read:	Ch.5 up to 5.11
Practice:	drawing & naming stereoisomers