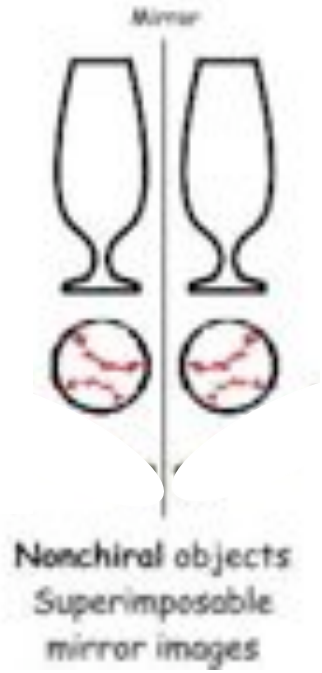
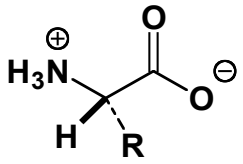
ANOTHER CHARACTERISTIC FEATURE OF LIFE: MOLECULAR ASYMMETRY

CHIRALITY IN BIOMOLECULES

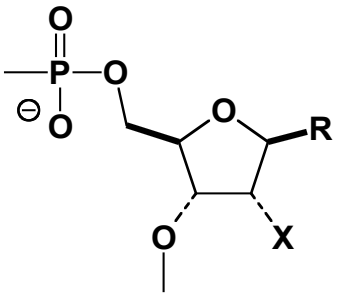
SYMMETRY AND ASYMMETRY IN NATURE

Chirality

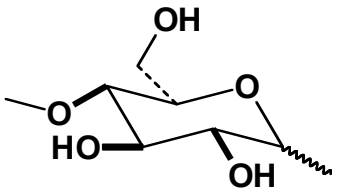




aminoacid



nucleic acid



sugar

Chirality criteria

Operationally:

1. Build (or imagine) the mirror image of the object.
2. If the object and its mirror image are superimposeable, then the object is not chiral.

OPERATIONAL CRITERIUM:

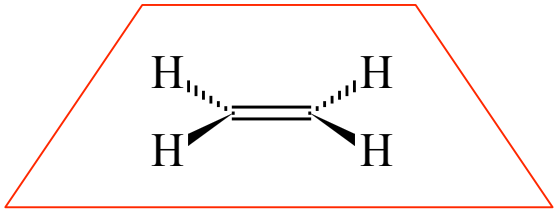
Chiral objects are not superimposeable to their mirror images.

Theoretically (*Group Theory applied to chemical compounds*):

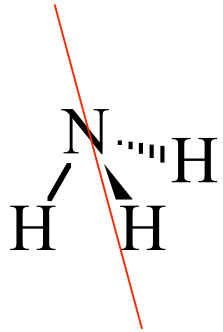
1. Chirality derives from the lack of some symmetry elements.
2. Axis of rotation are possible in chiral objects. Other symmetry elements (such as plane of symmetry, inversion center and axis of roto-reflection are not possible)

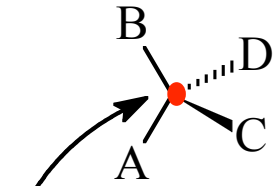
Symmetry and Asymmetry Elements

plane of reflection
(mirror)



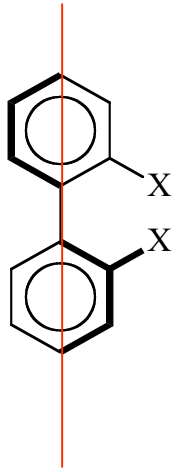
axis of rotation
(two-fold, three-fold, ...)



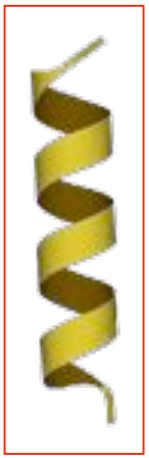


chiral center
(atom)

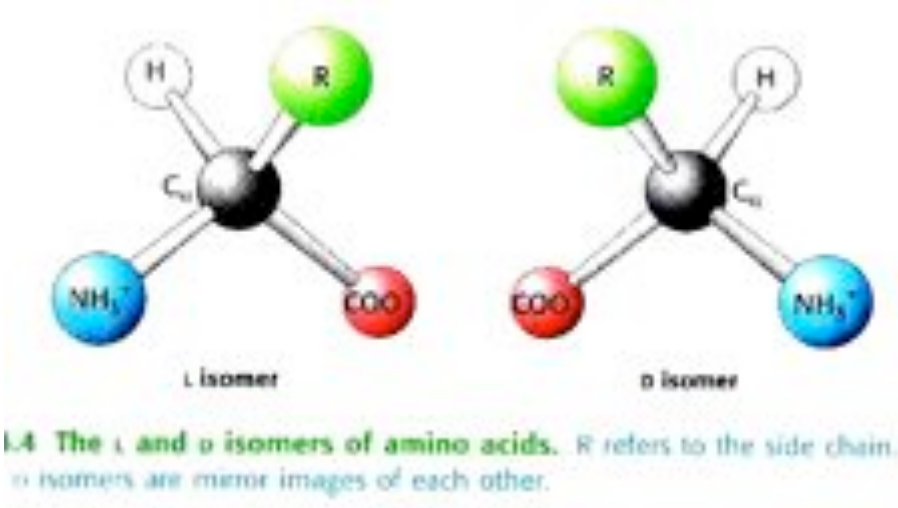
chiral axis



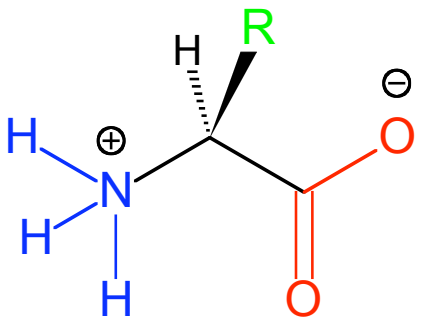
helix

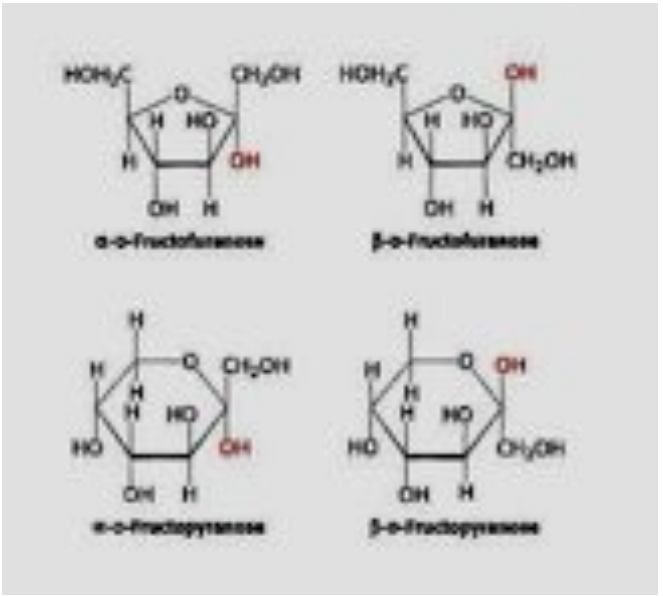


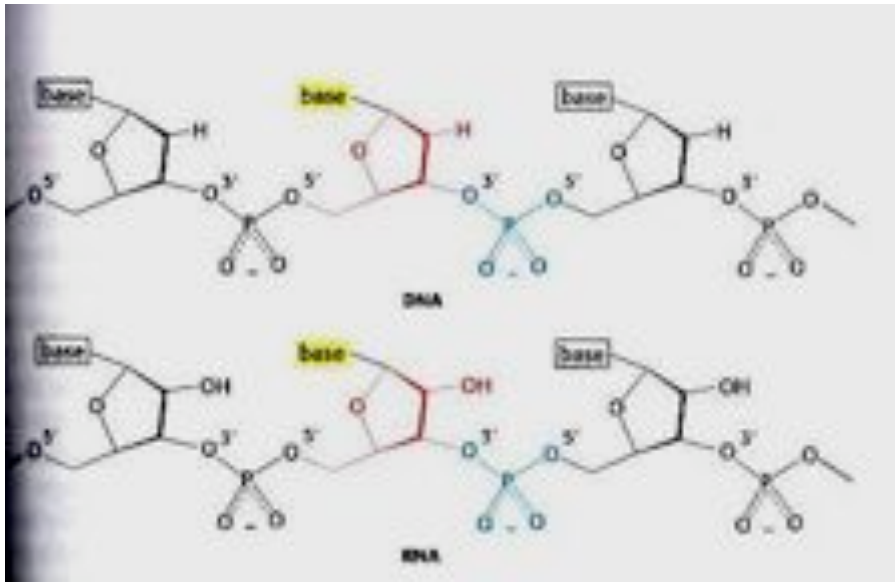
Aminoacids and sugars are chiral



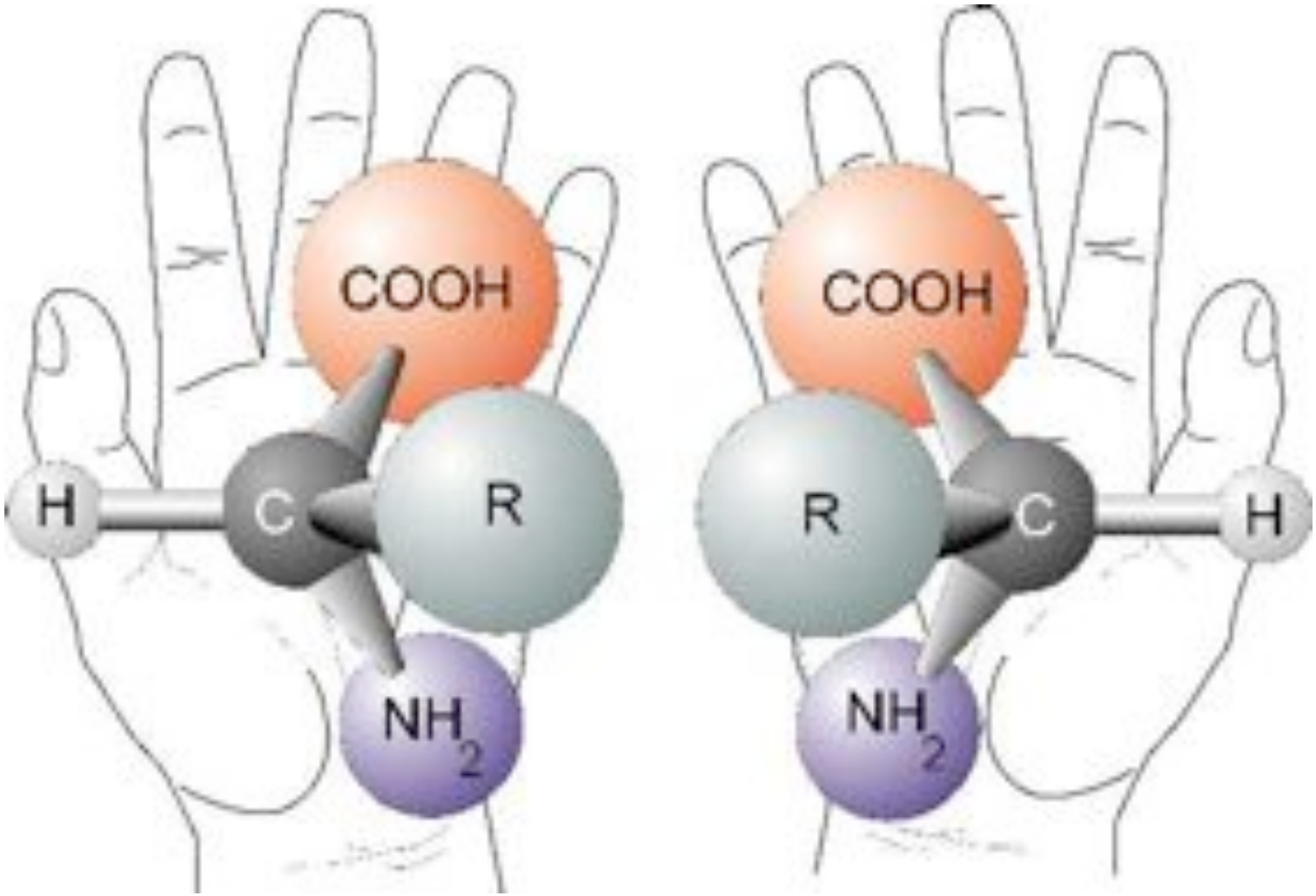
L.4 The L and D isomers of amino acids. R refers to the side chain. D isomers are mirror images of each other.

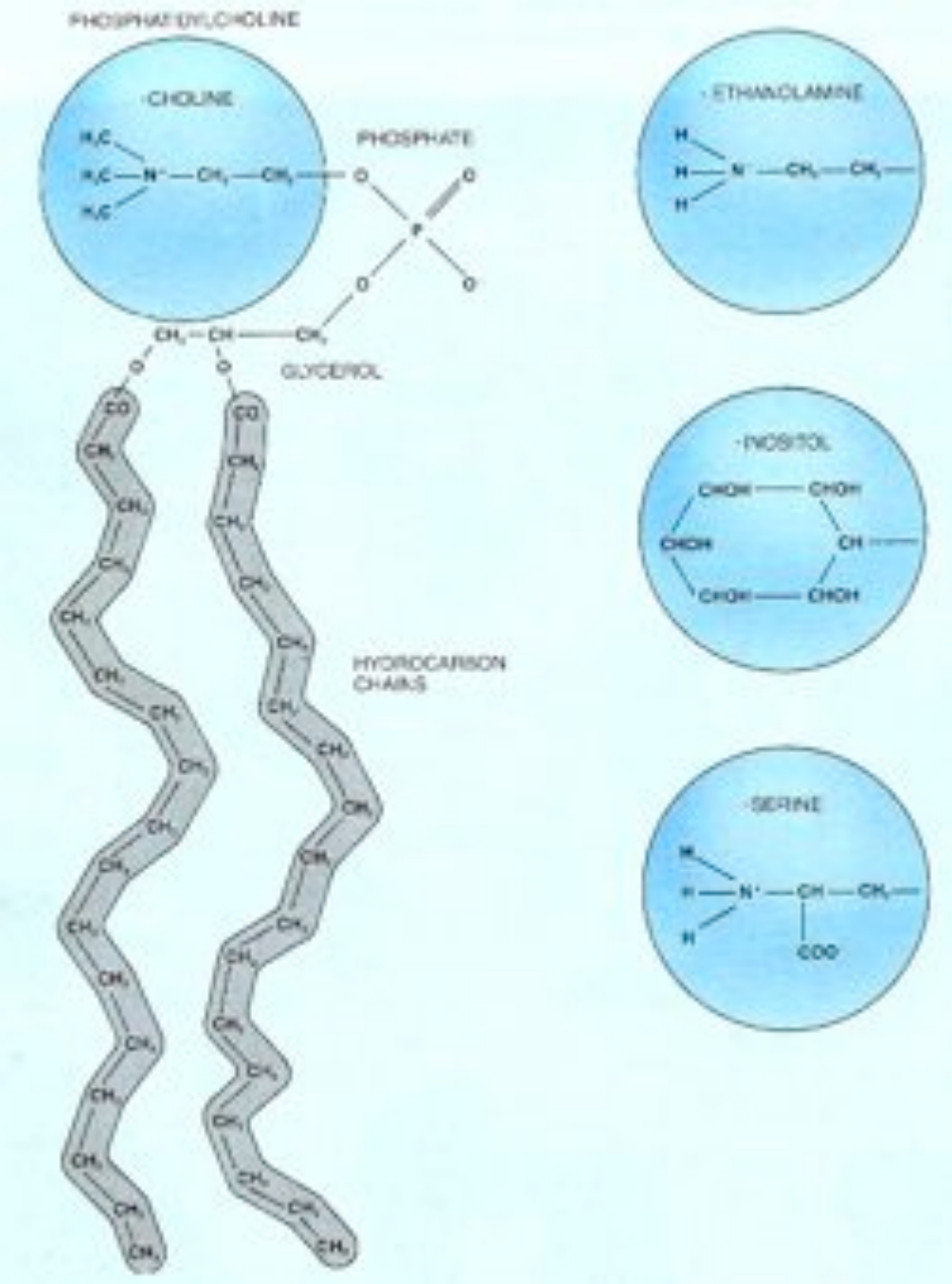






Peptides, proteins, nucleotides, nucleic acids, sugars, polysaccarides and glycerophospholipid (from glycerol, which is pro-chiral) are intrinsecally chiral due to their primary structure.


COOH
H
C
R
NH2
COOH
R
C
H
NH2



PHOSPHOLIPID MOLECULE is the primary structural element in all cell membranes. Four main kinds of phospholipid are found in animal-cell-membranes. The one shown at the left in the diagram is phosphatidylcholine, but the other tree differ from it and from one another only in the chemical structure of their head groups, which are diagrammed here as colored spheres. The electric charge in each head group makes the group hydrophilic. The head group is connected to a glycerol group, and two hydrocarbon chains are attached in turn o glycerol. The hydrocarbon chains are oily and therefore hydrophobic.

The two enantiomers are called

R and S

According to the theory of Khan, Ingold e Prelog

Or, more commonly,

L and D

According to the old nomenclature

STEREO- ISOMERS, OPTICAL ISOMERS,

R----R **S----S**

R----S **S----R**

R

-

R---R---R **R—R—R**

R---S---S **R---R---S**

ENANTIOMERS

R---R R----S

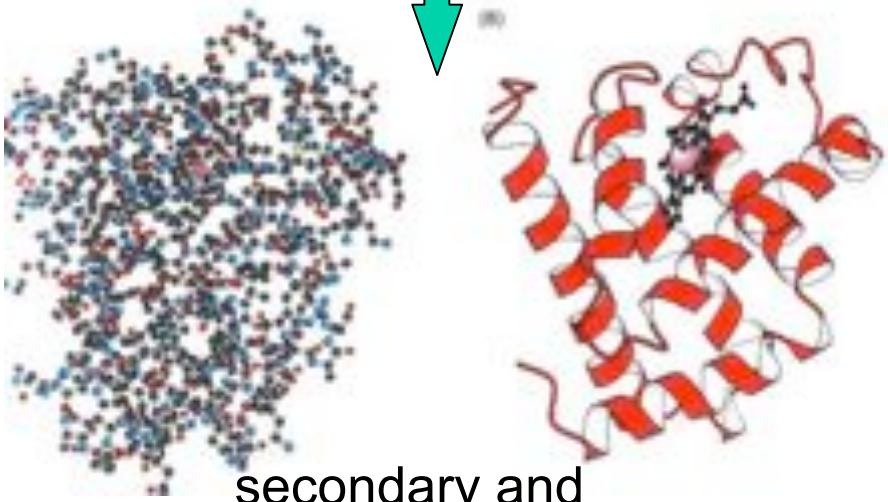
R---R---R R—S---R

S---S---R S---R---S

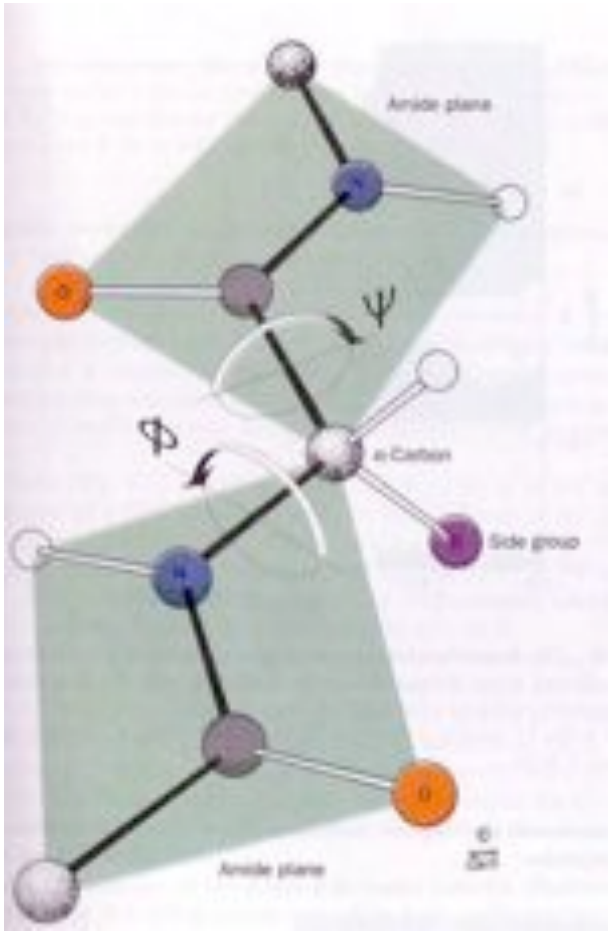
DIASTEREOMERS

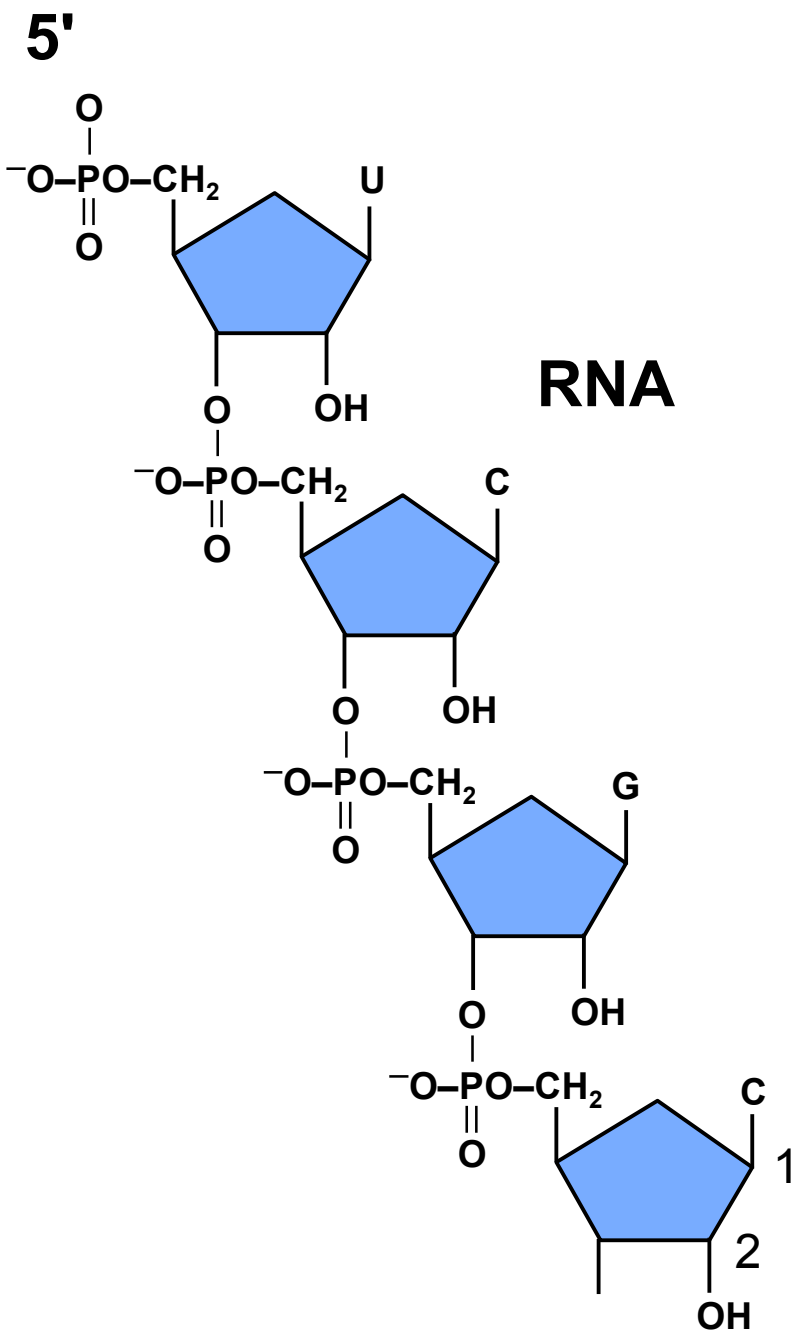
Polypeptide chain folding

full-extended polypeptide chain

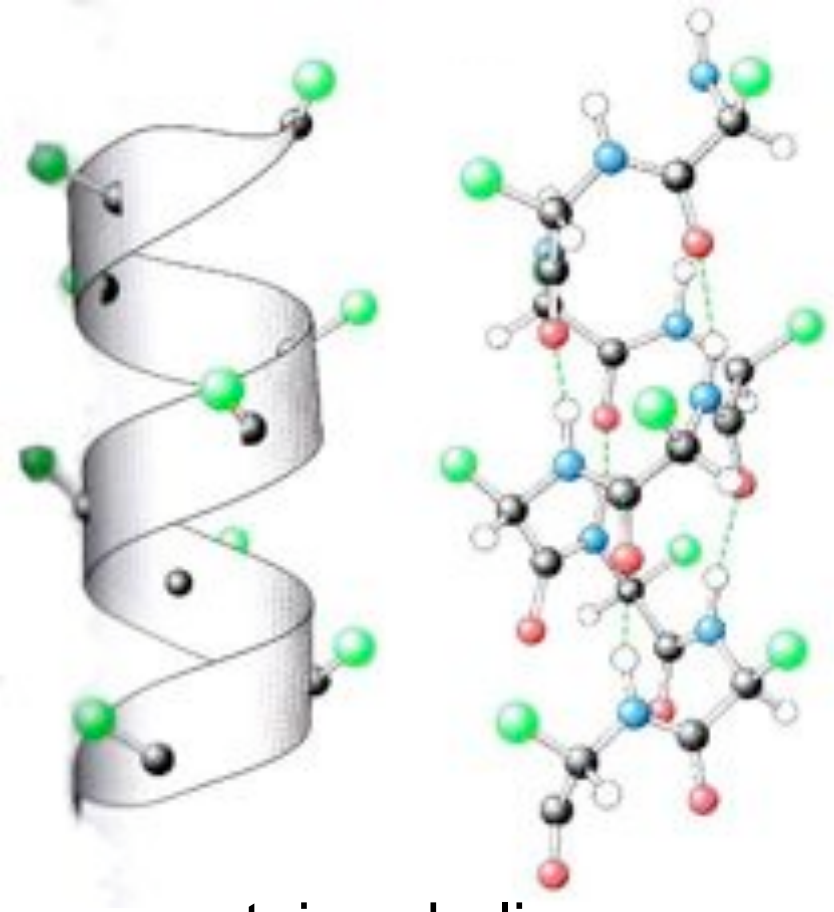


secondary and
tertiary structure

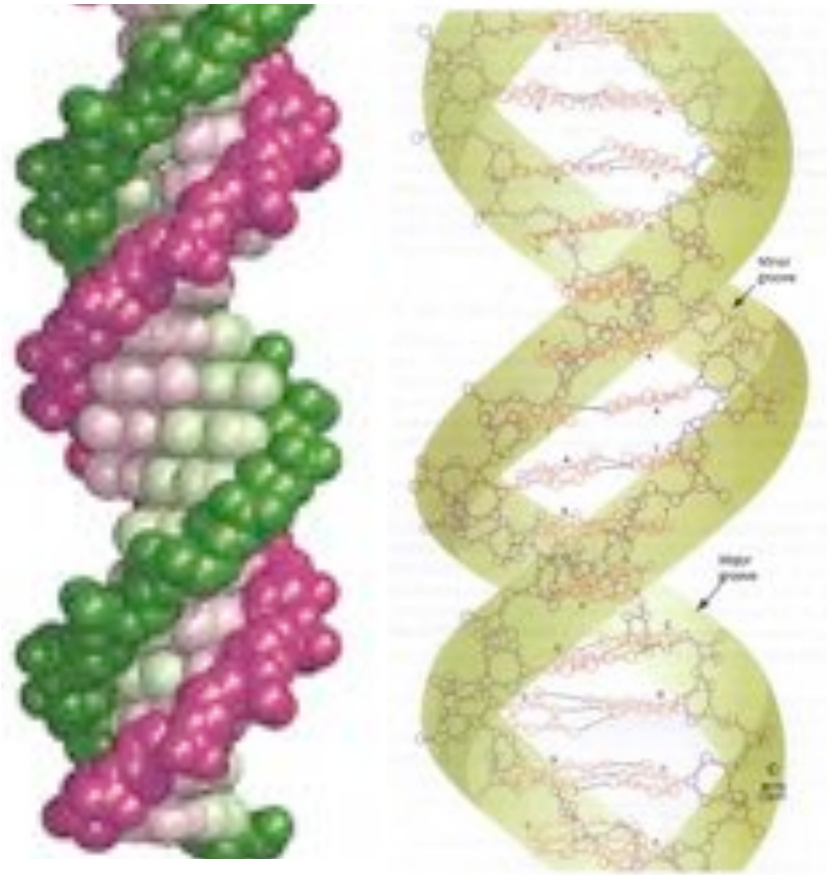



5'
O
⁻O–PO–CH2
O
U
O
OH
RNA
⁻O–PO–CH2
O
C
O
OH
⁻O–PO–CH2
O
G
O
OH
⁻O–PO–CH2
O
C
1
2
OH

Secondary structure chirality

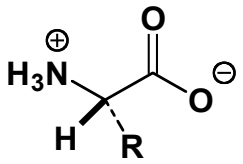


protein a-helix
(right-handed)

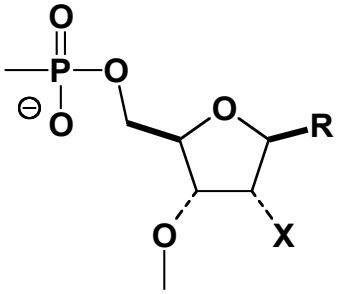


double stranded DNA helix,
B-form (right-handed)

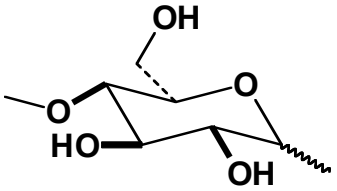
Microscopic systems are asymmetric



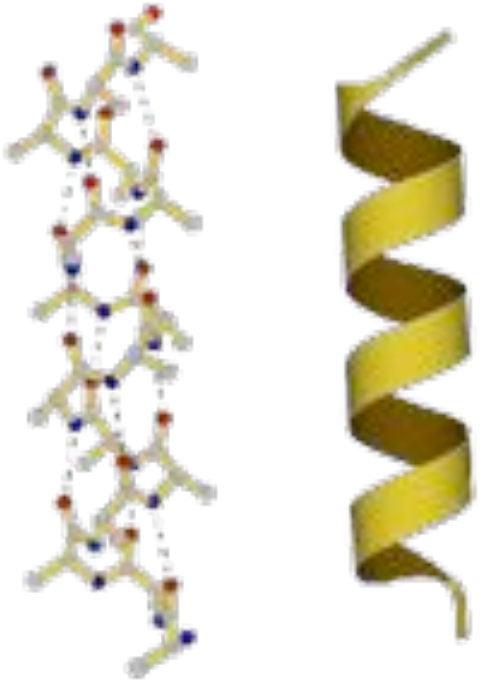
L-aminoacid



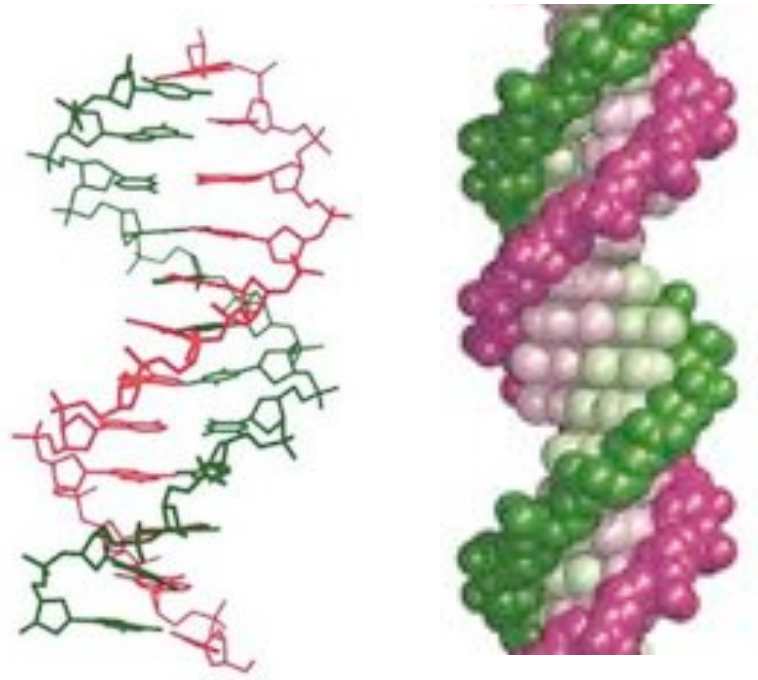
(deoxy)ribonucleic acid



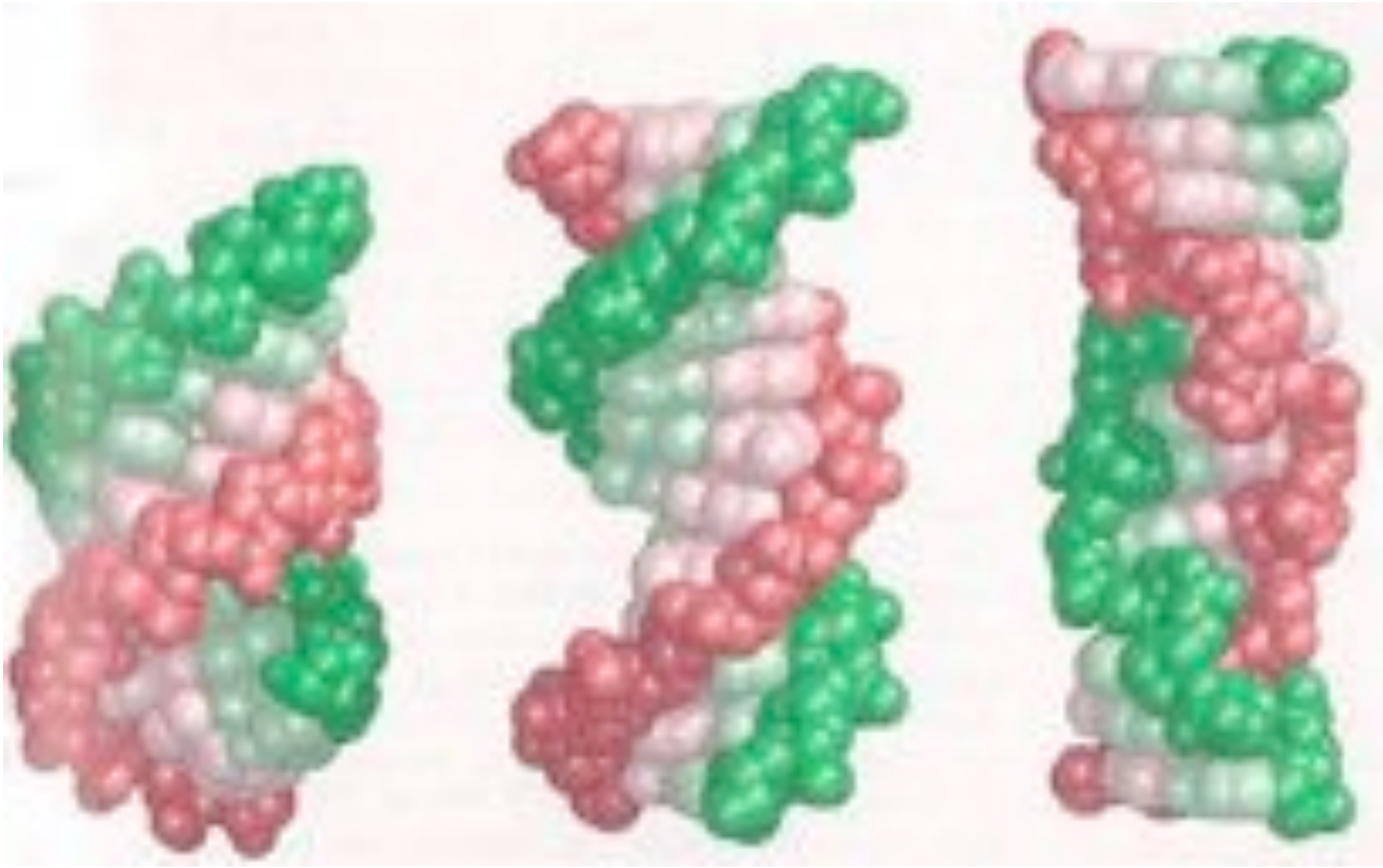
sugar



polypeptide chain in a-helix conformation



B-DNA double helix

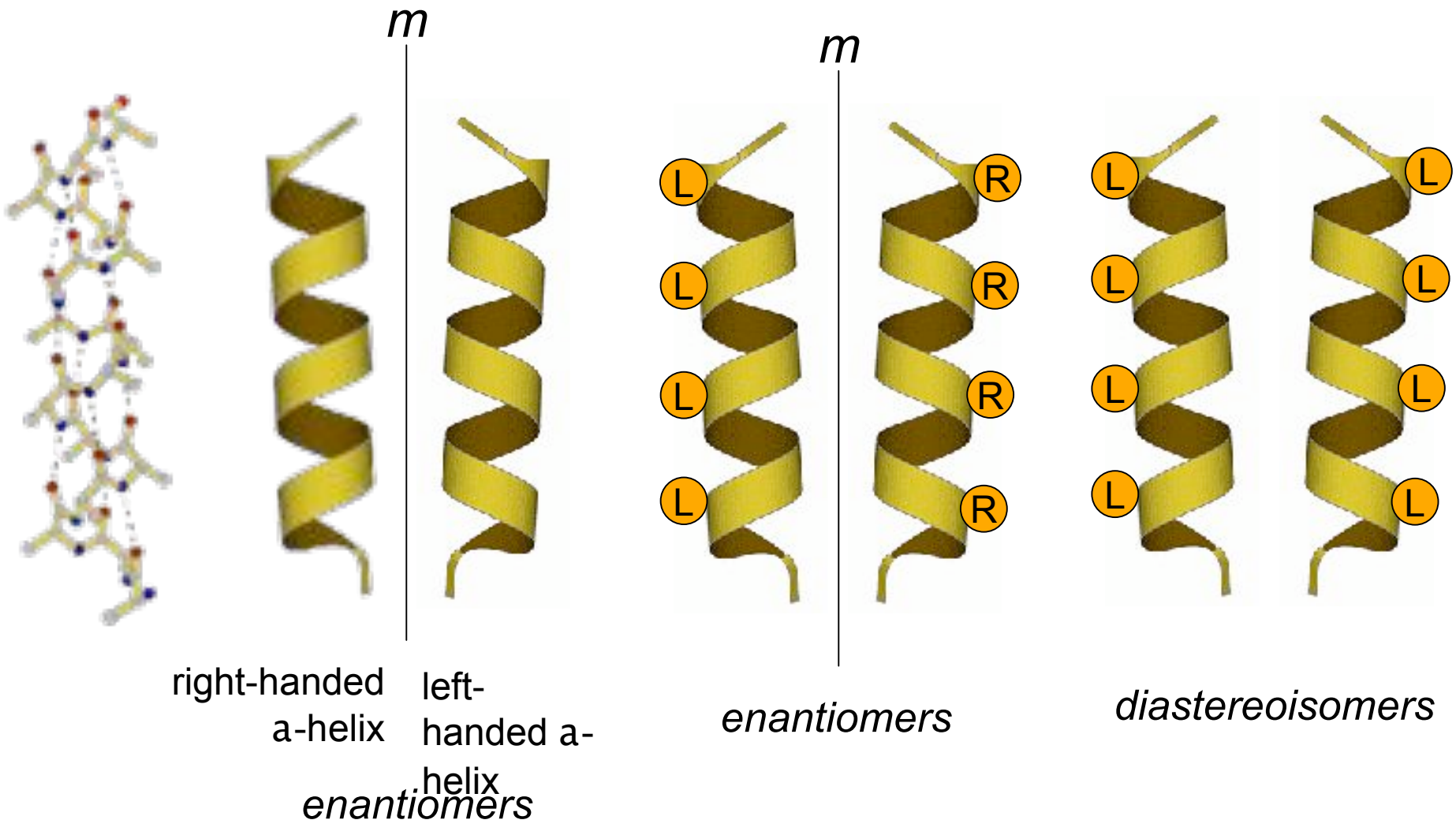


A-DNA B-DNA Z-DNA

Helices and chirality

Note that the handness is retained when the helices are turned upside down.

Enantiomers and Diasteroisomers



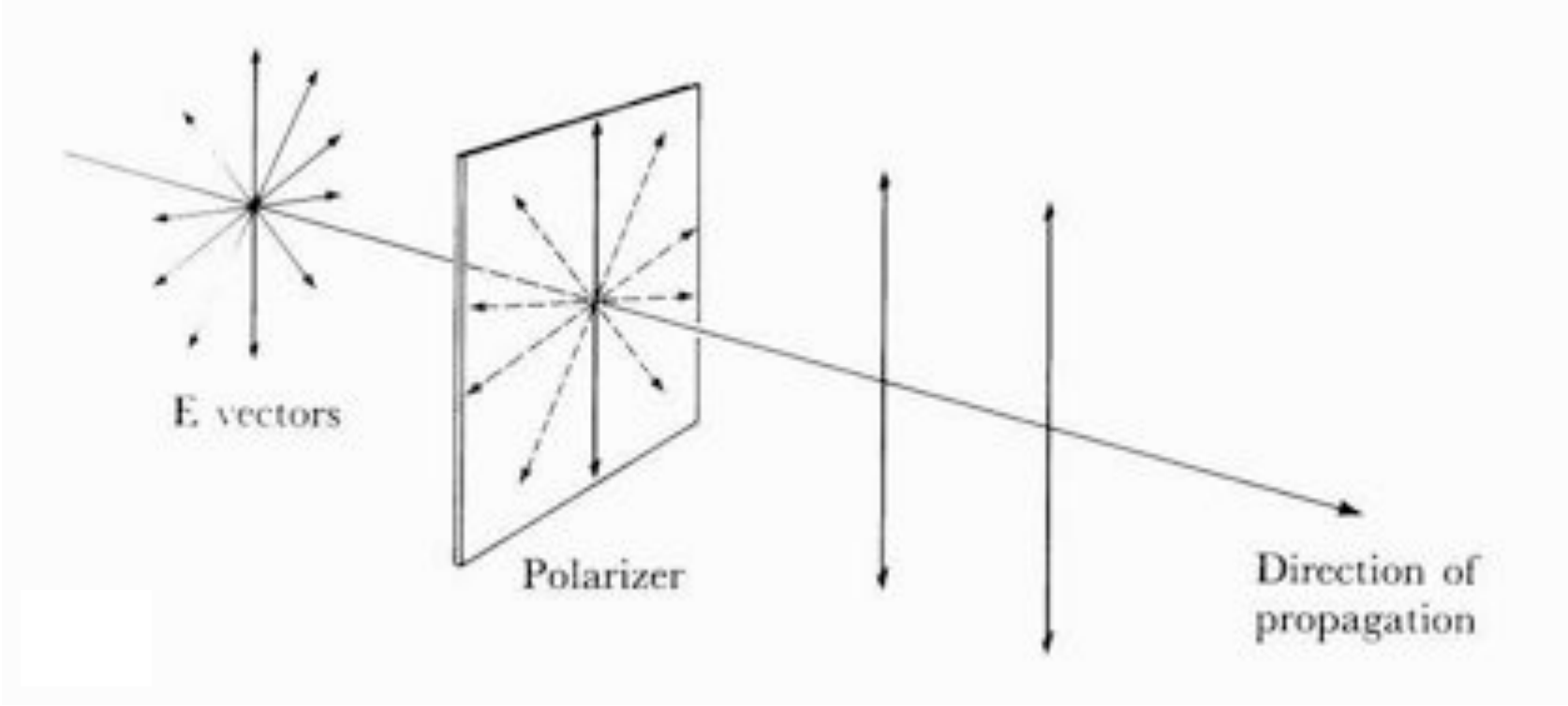
The two enantiomers differ only in one respect:

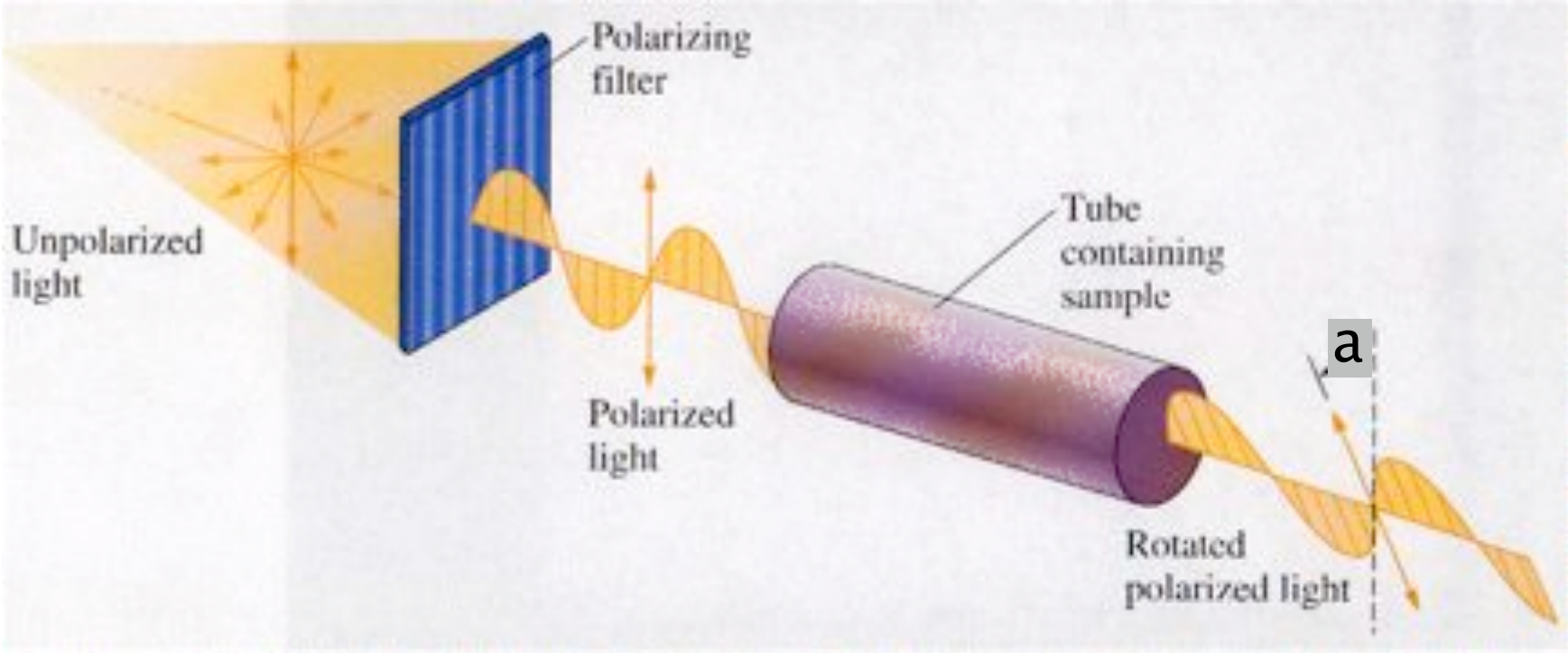
The interaction with polarized light.

This phenomenon gives rise to

Optical activity

Plane-polarized light





$$\alpha_\lambda = \frac{180}{\lambda}\alpha\left(n_L - n_R\right)$$

$$\left[\alpha\right]_\lambda = \frac{\alpha_\lambda}{d \cdot c}$$

specific rotation
d in dm; *c* in g/mL

$$\left[M\right]_\lambda = \left[\alpha\right]_\lambda \cdot \frac{M}{100}$$

molar rotation

The essential point:
The two enantiomers have the same energey and the same physical properties

All normal chemical synthesis in the laboratory gives a racemate, namely a 50:50 mixture of the two enantiomers.

(Only starting from asymmetric compounds can you get an asymmetric product)

1. **What is then the origin of chirality in nature?**

2. **What is chirality good for, in nature?**

Most probably
another example of contingency :

The chirality of the molecules of life

Aminoacids, sugars,
other simple molecules are „asymmetric“
or „chiral“

What is chirality?...

WHAT IS THE ORIGIN OF CHIRALITY?

CONTINGENCY (CHANCE)

OR

DETERMINISM (ONE OF THE TWO FORMS BEING MORE STABLE?)

TAKE A PEPTIDE WITH 10 AMINO-ACIDS

ASSUME THAT BOTH D AND L FORMS
ARE ALLOWED

HOW MANY STEREOISOMERS ARE POSSIBLE?

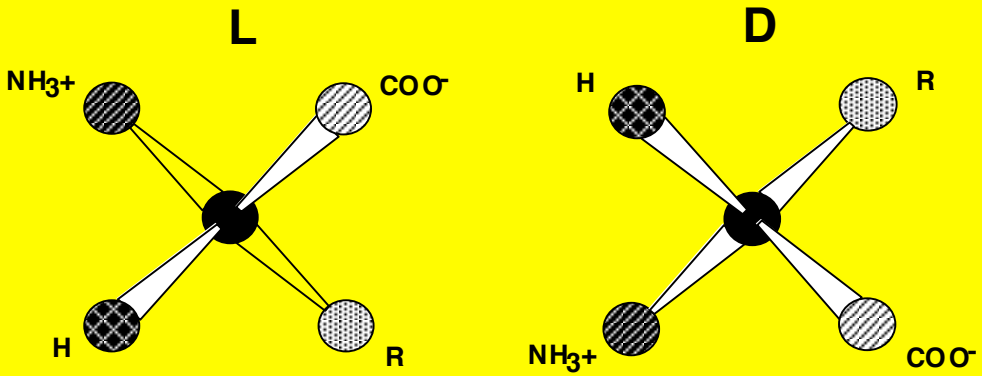
AND FOR A CHAIN WITH 50 AMINO-ACIDS?

FOR A CHAIN WITH 50 **racemic** AMINO ACIDS,
THE POSSIBLE NUMBER IS

2 To the power of 50
Many many billions.....

What is the number when only one form is allowed?

Thins number is : **ONE!!**



Asymmetry as a powerful ordering factor

Hormone with 10 residues

$N = 2 \times 2 \times 2 \times 2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2^{10} = 10^{3}$

if L and D isomers had the same probability.
But since only L-isomers are allowed, N = 1

For a chain with 50 residues (Insulin ...)

$N = 2^{50} \backsimeq 10^{15}$ → 1 !

only L-residues

L - Asp -	L - PheOMe		Aspartame (sweet)
L	D	}	bitter
D	L		
D	D		

RELATION BETWEEN MOLECULAR ASYMMETRY

AND
MACROSCOPIC SYMMETRY


Farfalla - Agosto 2003
Dolomiti
Foto di Nicola Cesarini
www.paleofox.com

Macroscopic systems are highly symmetric