Distinguishing Left from Right: Homochirality in Life

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  - Chiral bio-molecules
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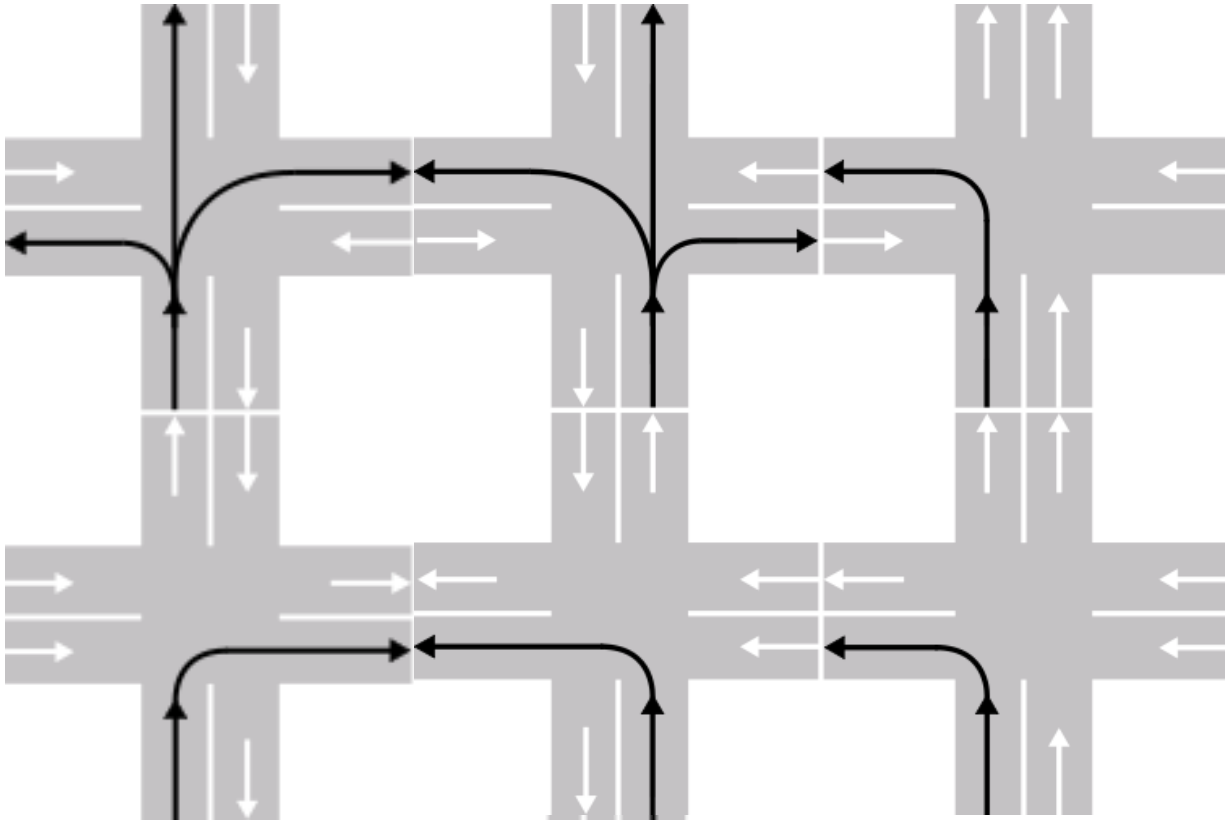
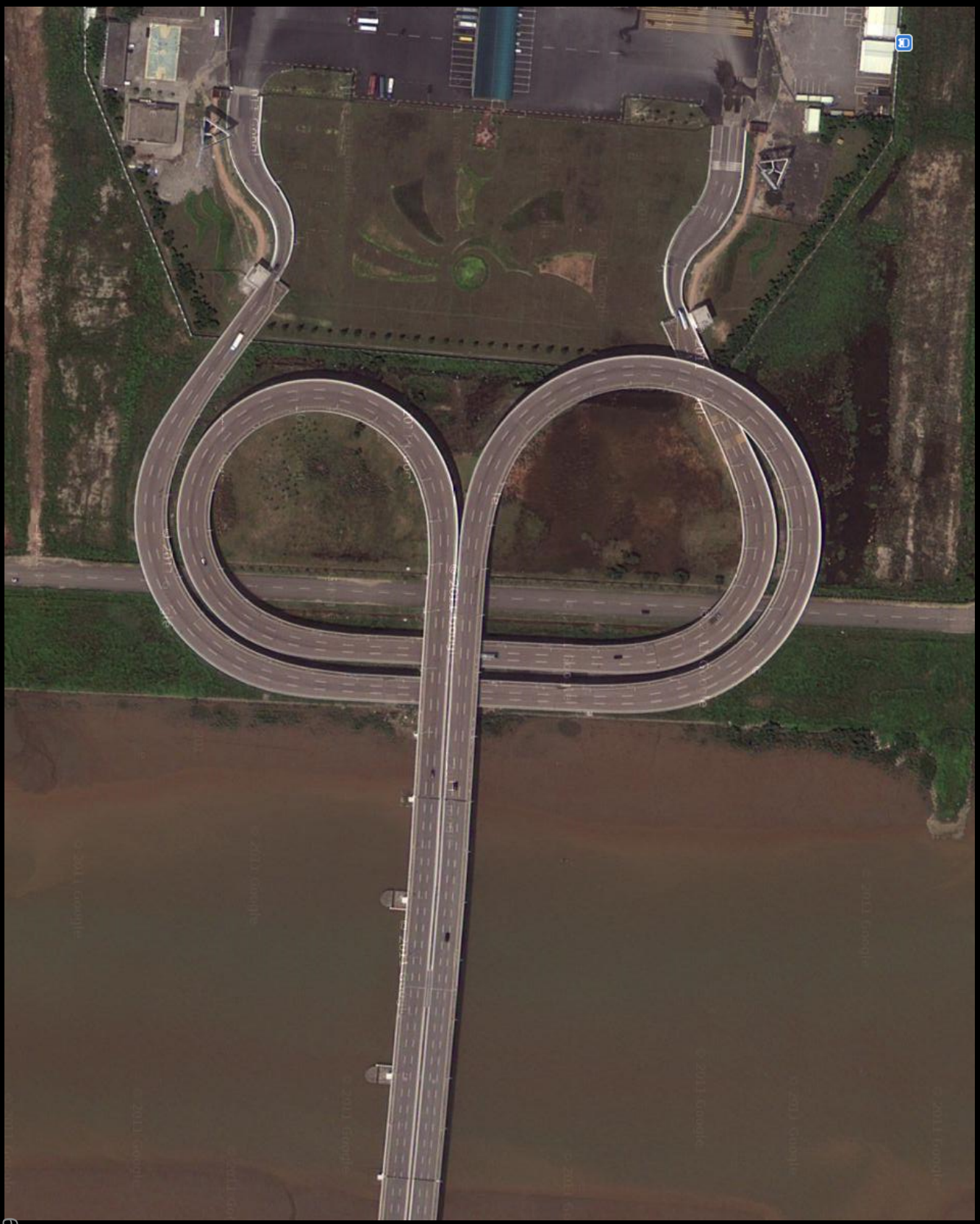
- Implications for the origin of life

Chirality

Chiral traffic

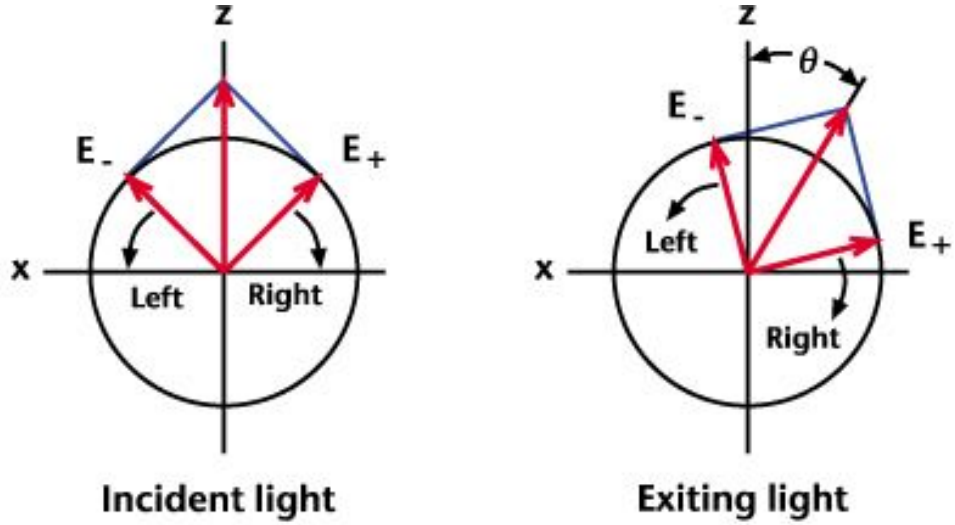




Chiral molecules

Jean-Baptiste Biot (1815):

There are organic solutions that are optically active!

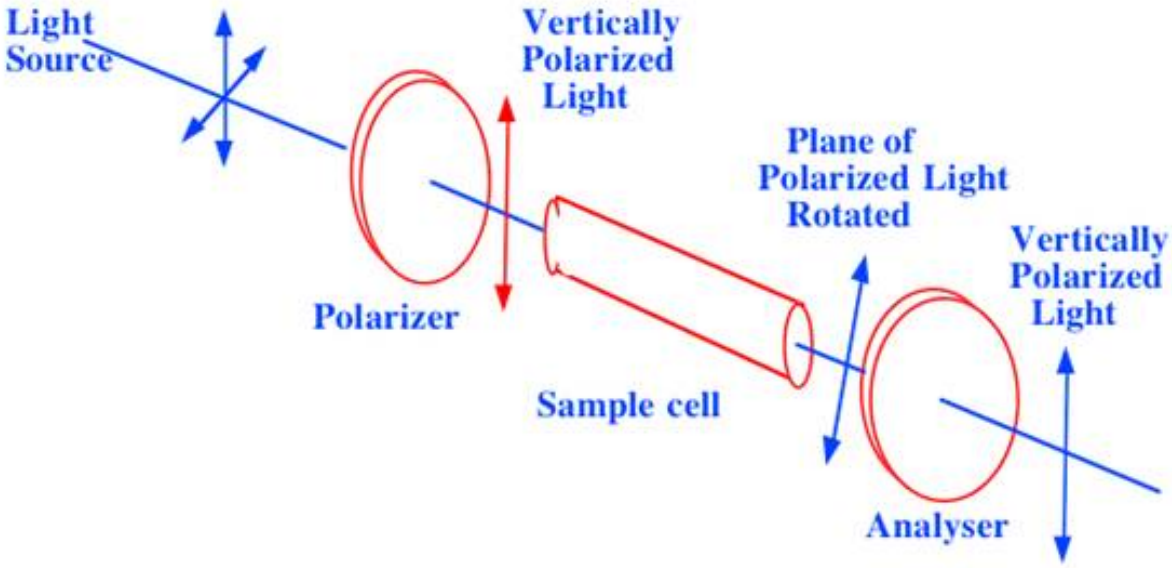


Clockwise:

Dextrorotating

Anticlockwise:

Levorotating



Puzzle:

Biological solutions optically active, while the same substance produced synthetically is optically *inactive*.

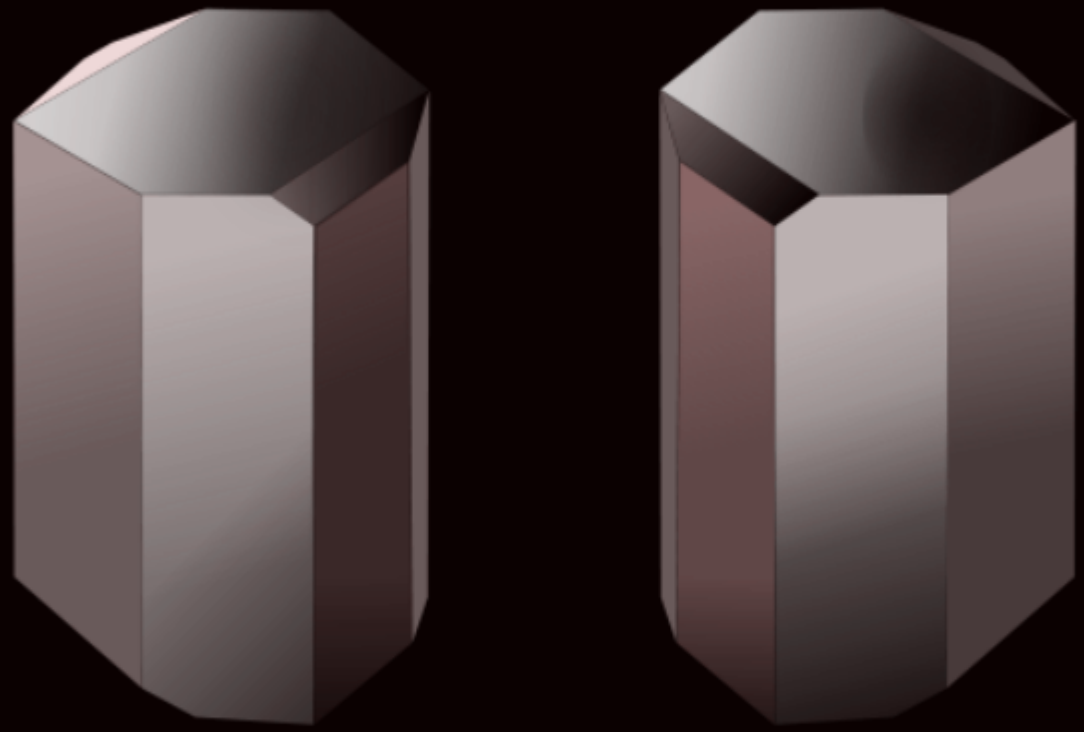
?!

Chiral molecules

Louis Pasteur (1848):

biological tartaric acid is *homochiral*, while synthetically produced tartaric acid is *racemic*.

Potassium bitartrate



Dextro

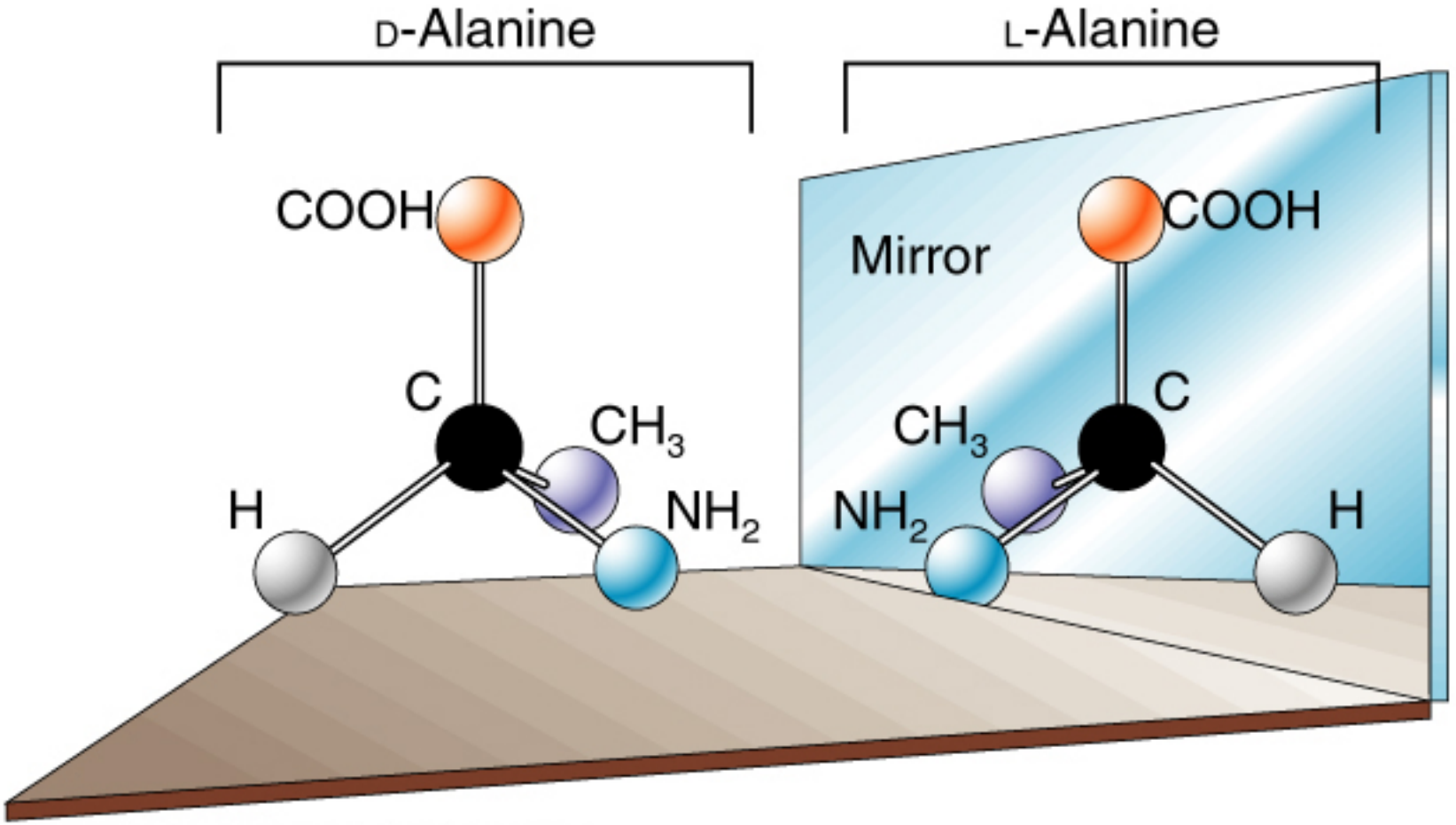
Levo

Tartaric acid

- Biological:
  Dextrotartaric acid or *L-(+)-tartaric acid*
- Synthetic: mixed with
  Levotartaric acid or *D-(-)-tartaric acid*

Two molecules that are each other's mirror image are called *enantiomers*.

Enantiomers



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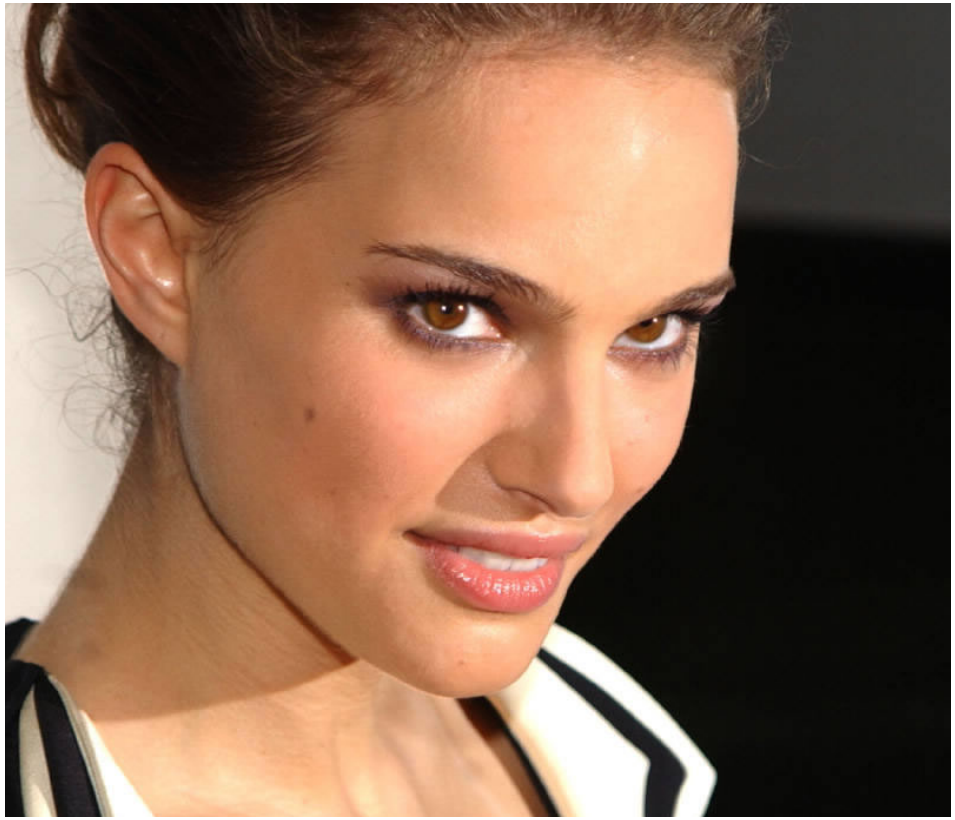
Molecular life

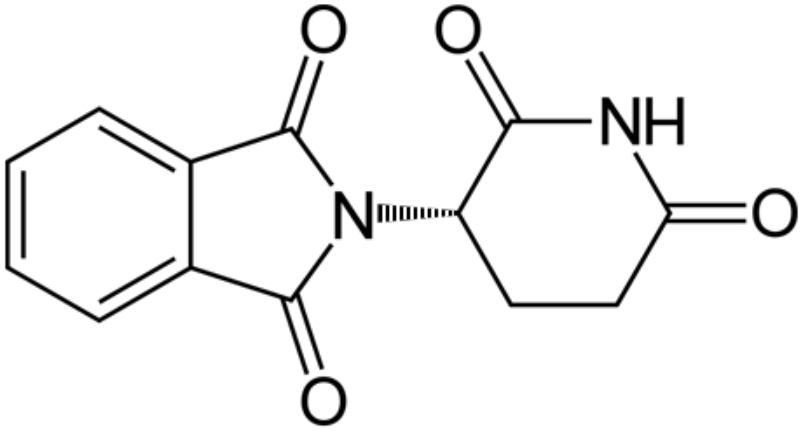
Alike as two peas?

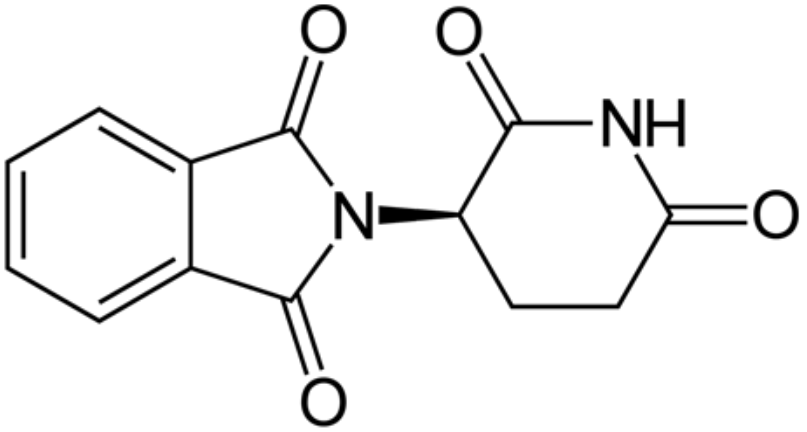


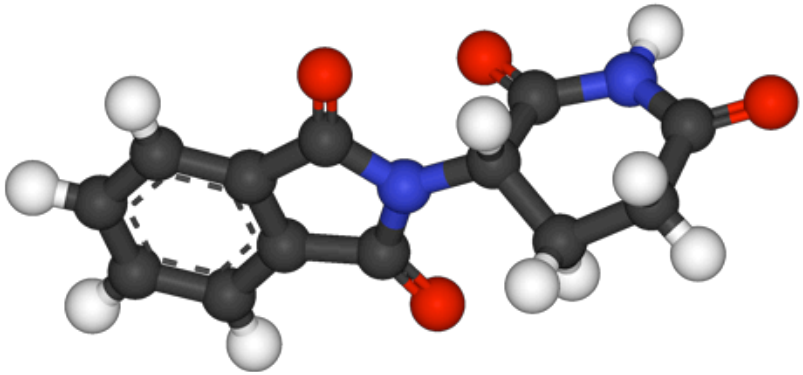
Molecular biology: homochiral!

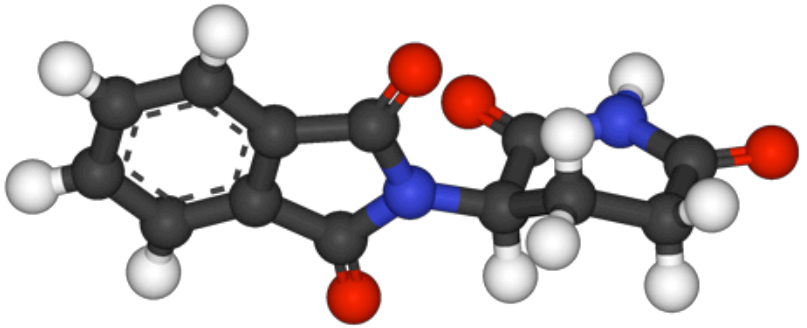
- All 22 *amino acids* important for humans are of L-form, except *glycine*, which is achiral
- Amino acids are *monomers* that *polymerise* to *peptides*, which are the building blocks of *proteins*.
- *Nucleotides* are monomers that polymerise to *nucleic acids*, such as RNA (*ribonucleic acid*) and DNA (*deoxyribonucleic acid*) that carry genetic information. Nucleotides are D-form.

Thalidomide









Origins of homochirality

Why homochiral?

- Energetically more efficient
- Prebiotic chiral evolution likely
- Amplification of initial imbalance (*enantiomeric excess*), due to:
  - Asymmetry of physical laws
  - Circularly polarised radiation preferentially destroying one enantiomer
  - Earth rotation
  - Statistical fluctuation
- Amplification model proposed by Frank (1953)

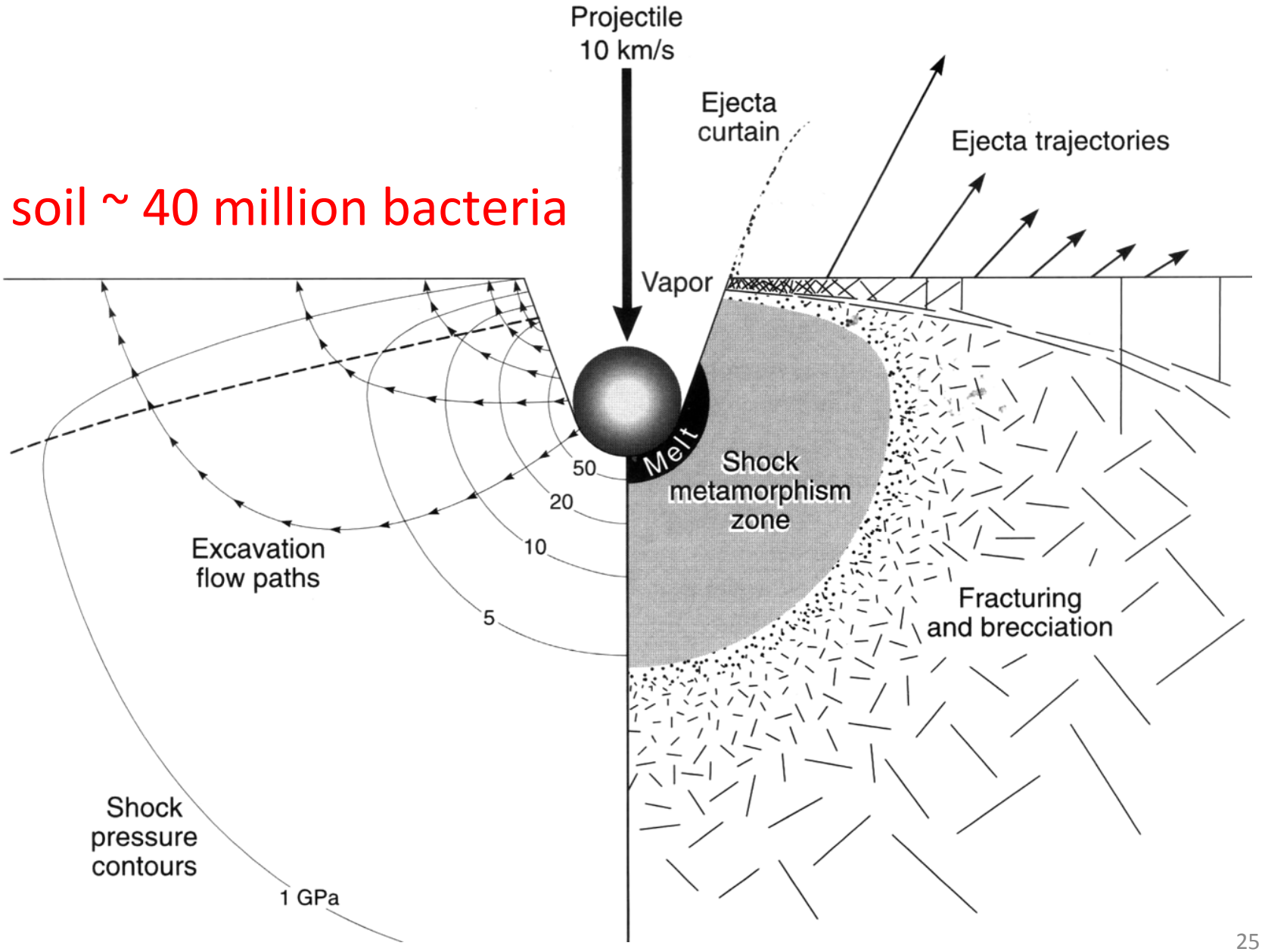
Where can life be found on Earth?

- At least:
  - Down to 3 km below surface, inside rock
  - Down to the deepest sea floors, at 10 km depth and 1000 atmosphere pressure
  - Up to 40 km height in Earth's atmosphere
  - Up to temperatures of 120°C
  - In the most frigid parts of Antarctica
  - In strongly acidic conditions (down to 1 pH)
- More or less everywhere we look!

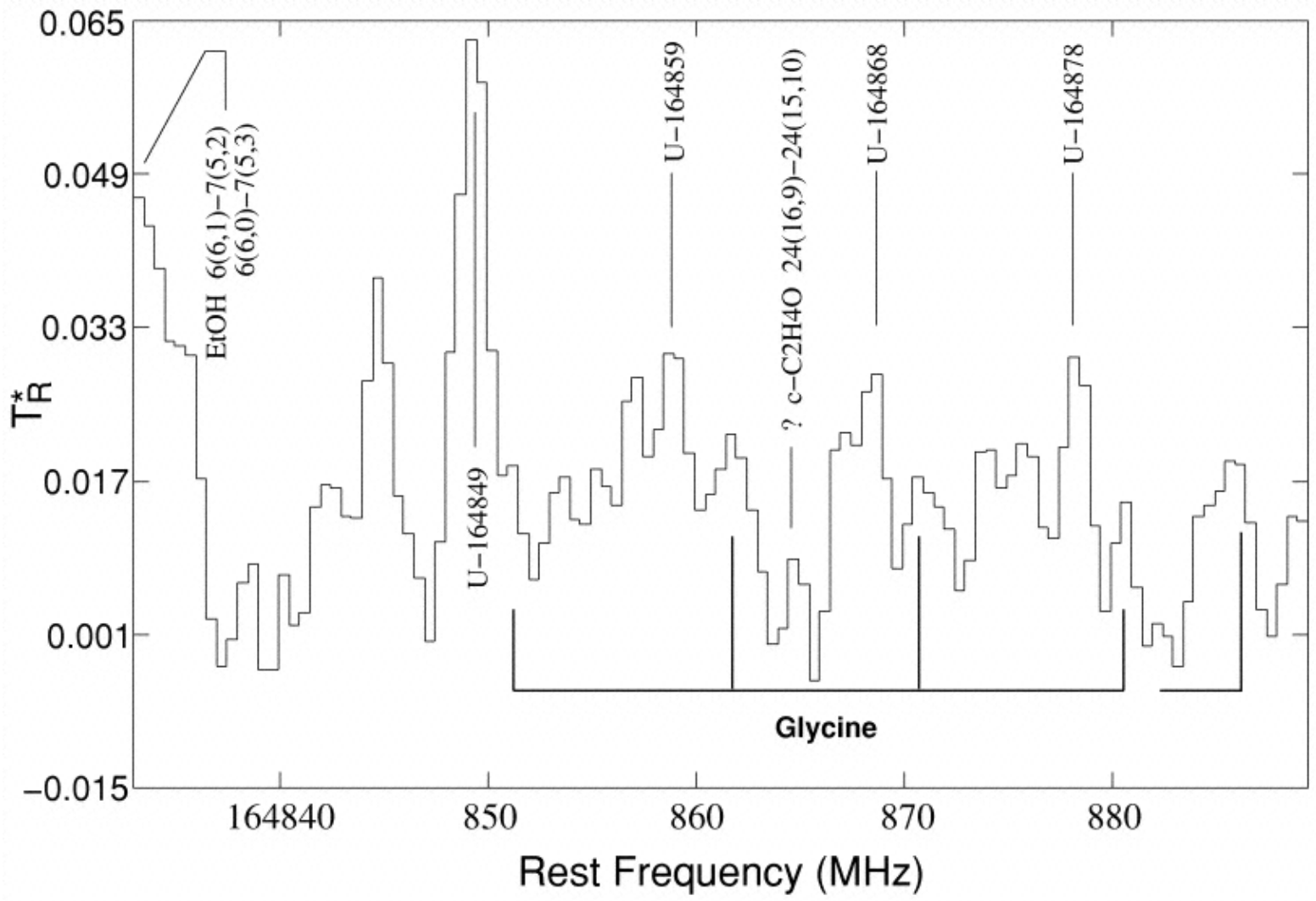
Life in the universe

- All life on Earth is too similar to not be related; either life originated once, or competing life were rapidly driven to extinction
- There is no known reason why the chirality of life as we know it could not be the opposite
- Half-life of DNA has been estimated to ~1 Myr – enough for life to potentially spread between planets (*interplanetary panspermia*), but difficult to reach even the nearest stars

1g soil ~ 40 million bacteria



Glycine in Orion



Kuan, Charnley, et al. 2003, ApJ 593:848

Summary

- Life is chiral; all biochemistry of life on Earth share the same chiralities.
- Homochirality can arise from the amplification of small enantiomeric excesses.
- Amino acids in space can potentially be detected over astronomical distances, but their chirality is likely too difficult within foreseeable future