Chirality, Life, and Magnetic Field

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Chirality: from cosmic dimensions, such as spiral galaxies to the nanoscale

A supermassive ***black hole*** lies at the center of the galaxy, surrounded by swirling arms that contain gas, dust, and starbursts.

The spiral shape of the galaxy can be explained by a theory, where the ***magnetic fields that align*** the dust, gas, and stars in the arms of the galaxy are being compressed by gravity.

Credit: NASA/SOFIA; NASA/JPL-Caltech/Roma Tre Univ.

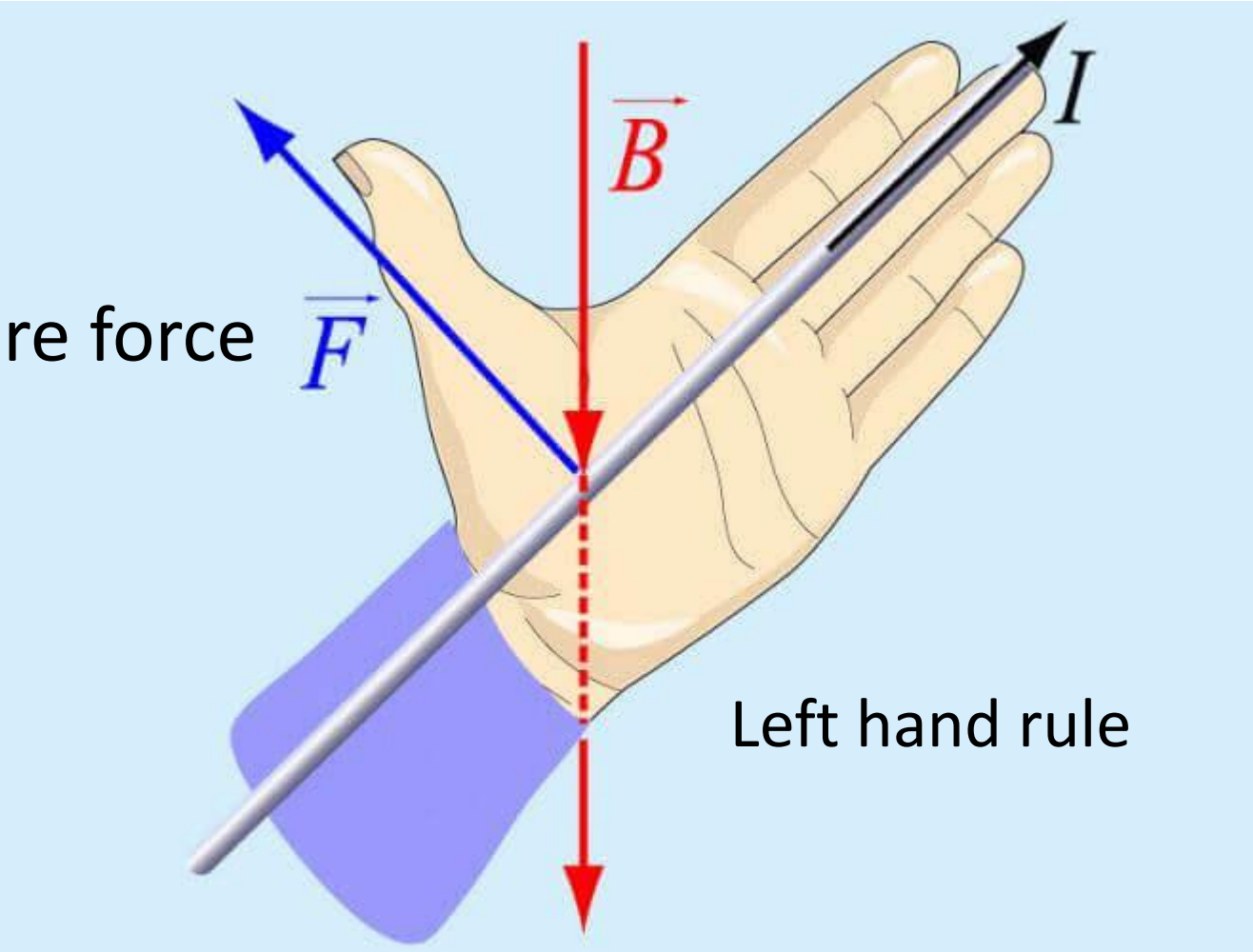
Why Do Spiral Staircases Go Anti-Clockwise?

Historically they have been built this way because they were in castles and defended buildings.
Most people are right handed; therefore an attacking swordsman coming up the stairs would be at a disadvantage as his right hand is restricted (he can't stab or swing his sword around the central pillar).

You have met an alien

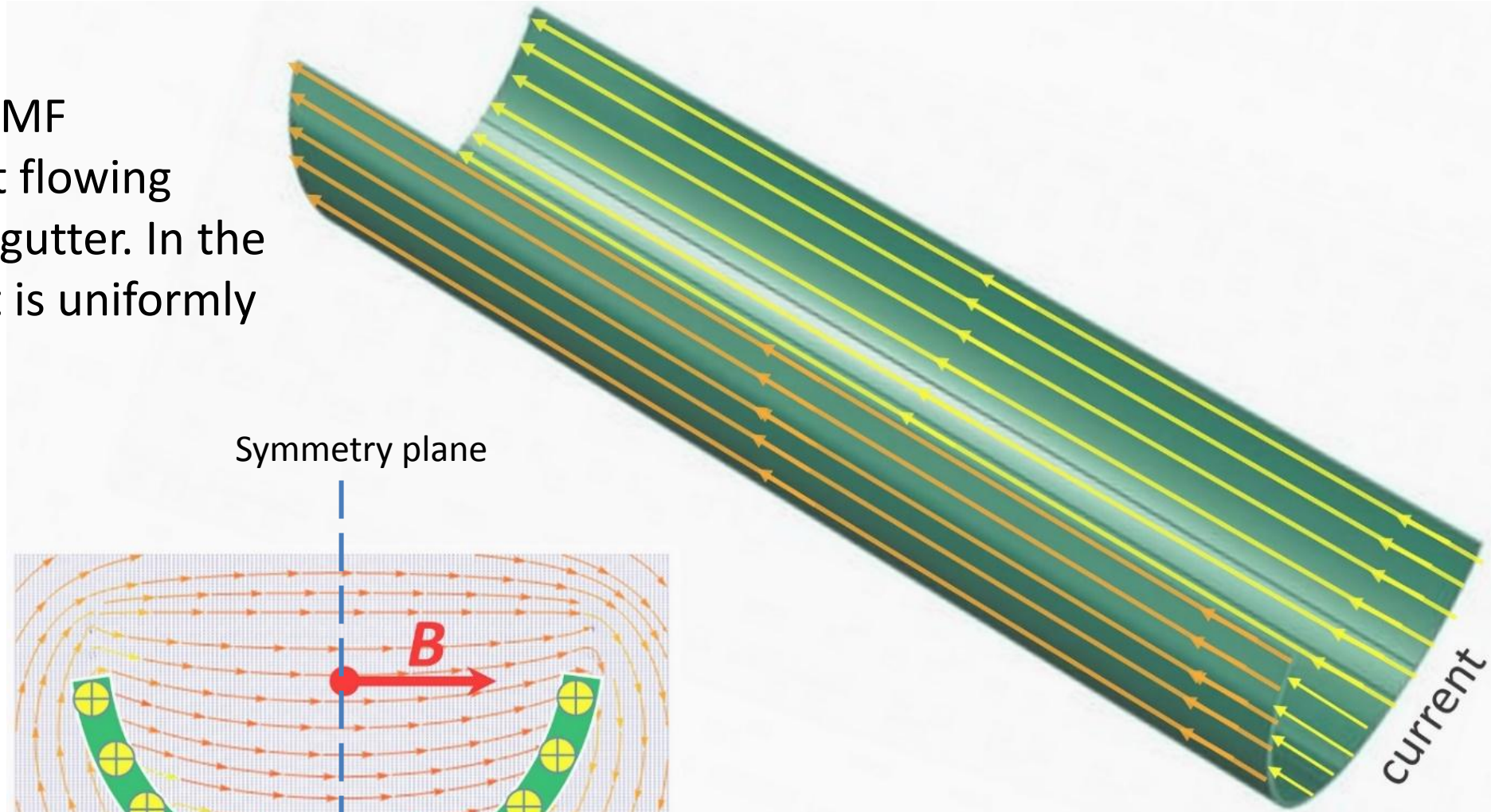
How would you explain to him where the left side is and where the right side is?

Ampere force



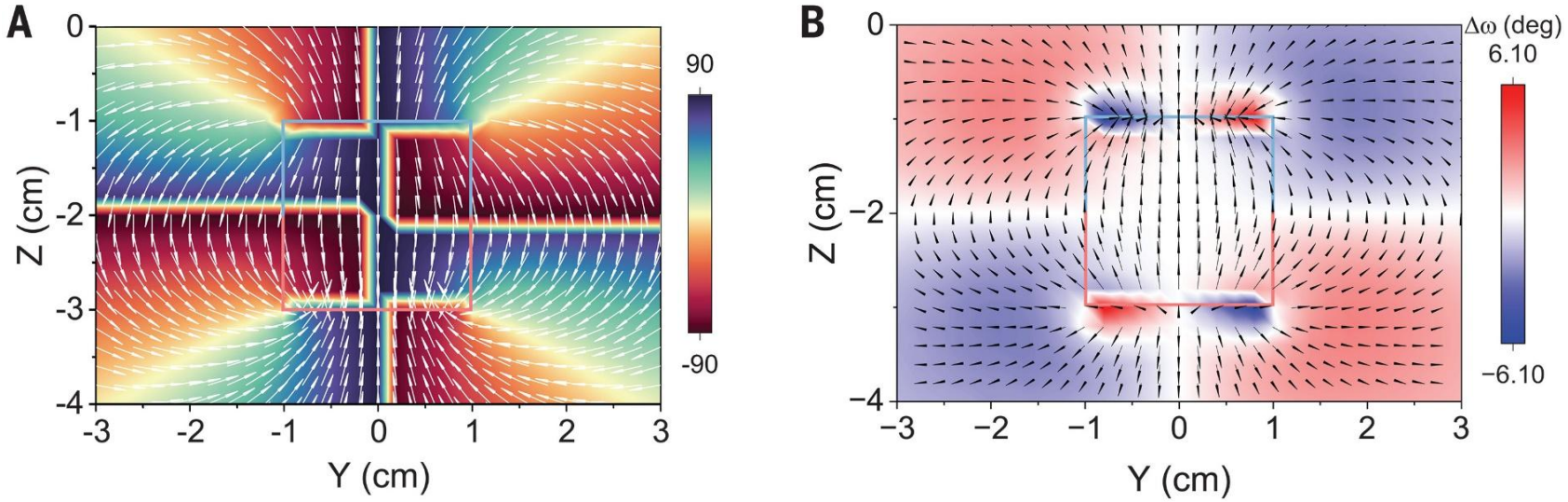
“Breaking the mirror” with a magnetic field

Left-Right asymmetry of MF generated by the current flowing along a thin wall infinite gutter. In the gutter’s wall, the current is uniformly distributed.



V. Zablotskii, T. Polyakova, A. Dejneka BioEssays, 2018, https://doi.org/10.1002/bies.201800017

The quadrupole field chirality of permanent magnet



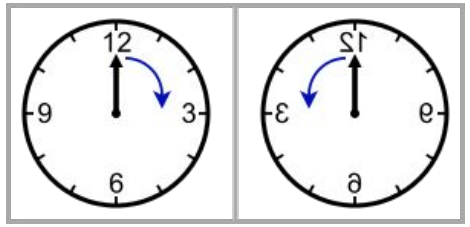
Normalized magnetic field (white arrows) and field-vector azimuth (color maps) of a permanent magnet (highlighted in the middle square). (B) The field rotating vectors (black arrows) and field angle changes (color map) of the magnetic field along the x axis. Positive rotation angles (Δω) represent clockwise left-handed rotation of the magnetic field, and negative rotation angles represent counterclockwise right-handed field rotation.

Applying the chiral quadrupole field generated by permanent magnets to dispersed magnetic nanoparticles creates long-range chiral superstructures that adopt the field chirality.

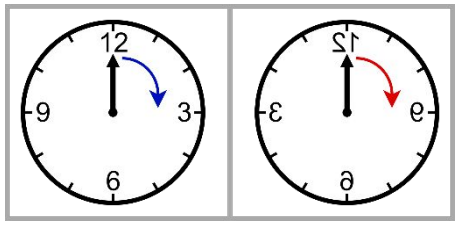
Zhiwei Li et al. , Science380,1384-1390(2023).DOI:10.1126/science.adg2657

The difference between left and right in weak interactions: parity violation

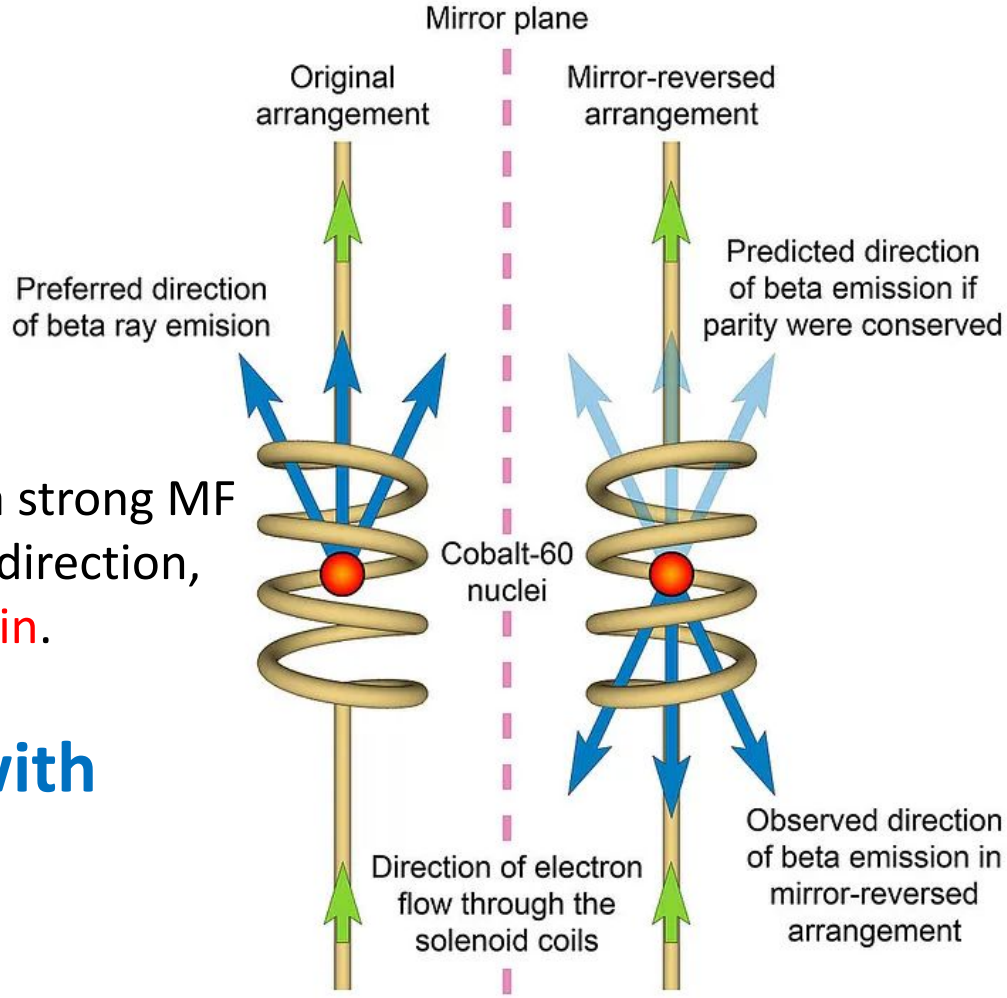
Our world and one built like its mirror image would behave in the same way, with the only difference that left and right would be reversed (for example, a clock which spins clockwise would spin counterclockwise if a mirrored version of it were built). E. Wigner, 1927.



P-symmetry



P-asymmetry



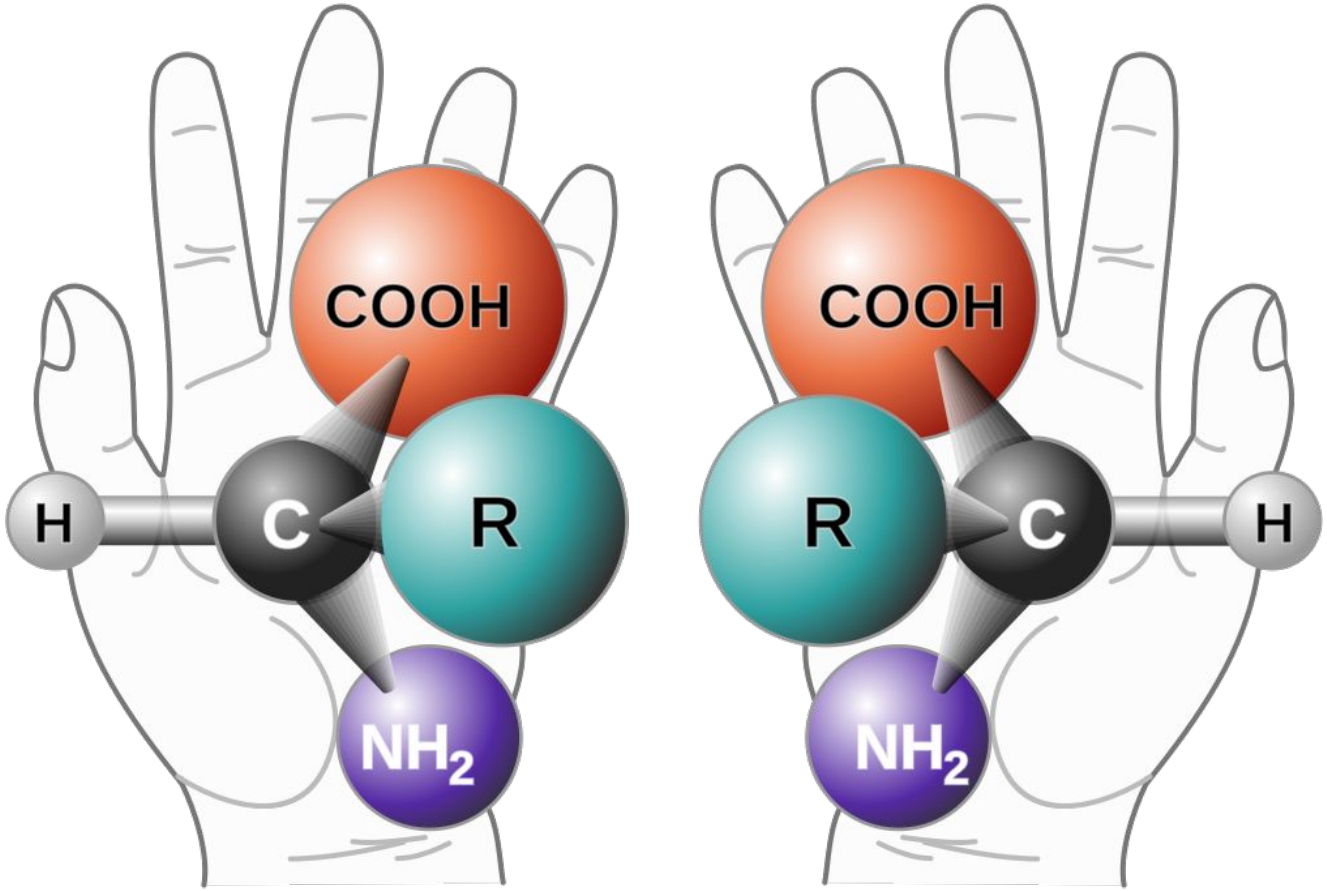
Chien-Shiung Wu designed the experiment and led the team that carried out the test of the conservation of parity in 1956.

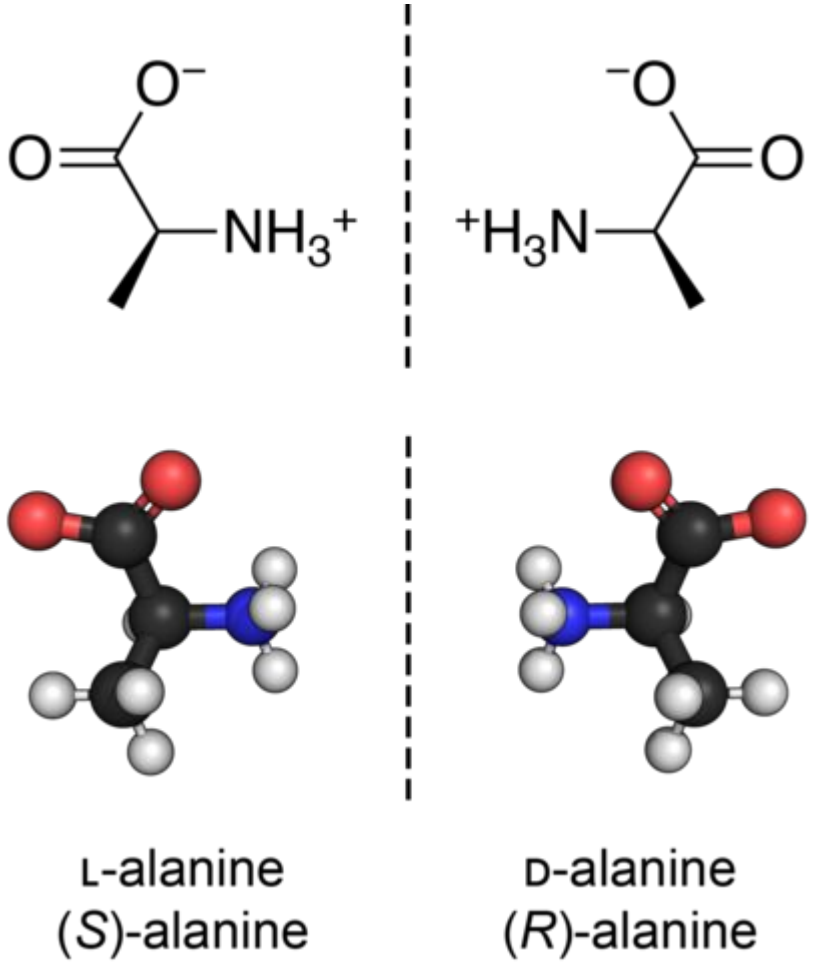
Wu observed that during Co nuclei decay in a strong MF most of the electrons favored a very specific direction, specifically opposite to that of the nuclear spin.
Parity violation was established.

So, our world is asymmetrical with respect to Left and Right (weak interactions).

The results greatly surprised the physics community.

Two enantiomers of amino acids that are chiral. L-alanine and R-alanine used in the biosynthesis of proteins





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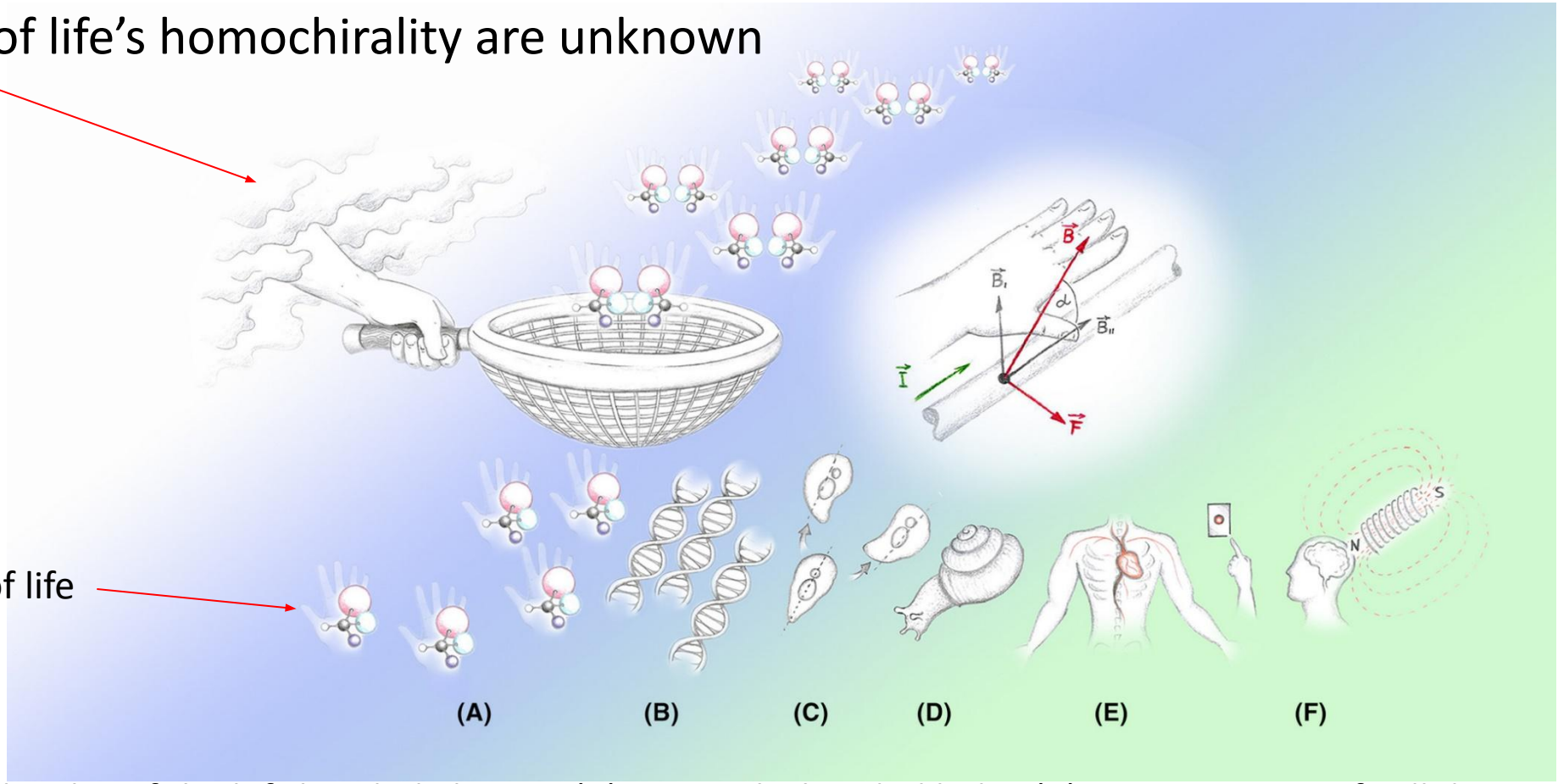
https://en.wikipedia.org/wiki/Chirality_%28chemistry%29

Chirality Selection for Life

The origins of life's homochirality are unknown

Building blocks of life



(A) homochiral molecules of the left-handed alanine, (B) DNA right-handed helix, (C) LR asymmetry of cell division, (D) right (typical) form of the snail *Fruticicola lantzi* which is more viable than the inverse form, (E) LR asymmetry of human body and (F) LR inversion in the human brain under influence of a magnetic field. All amino acids are present in all proteins only in the left configuration. It has been proposed that the amino acids (in particular, left-handed alanine) chiral selection takes place in strong **Magnetic Fields** generated by neutron stars.

X. Yang, et al., FASEB BioAdvances, v. 2, 4, 254, 2020.

Chirality is a signature of life as we know it.

Did you know?

The right-coiled (typical) form of the snail *Fruticicola lantzi* is more likely to survive than its left-coiled mirror twin. But why?

Scientists still don't have a clear answer. This mysterious asymmetry—why one side thrives while the other struggles—remains one of biology's fascinating puzzles.

Want to dive deeper into the strange world of left-right asymmetry and broken symmetry in nature?
Check out the book "Shadowless Squids", available on Amazon or through Routledge.

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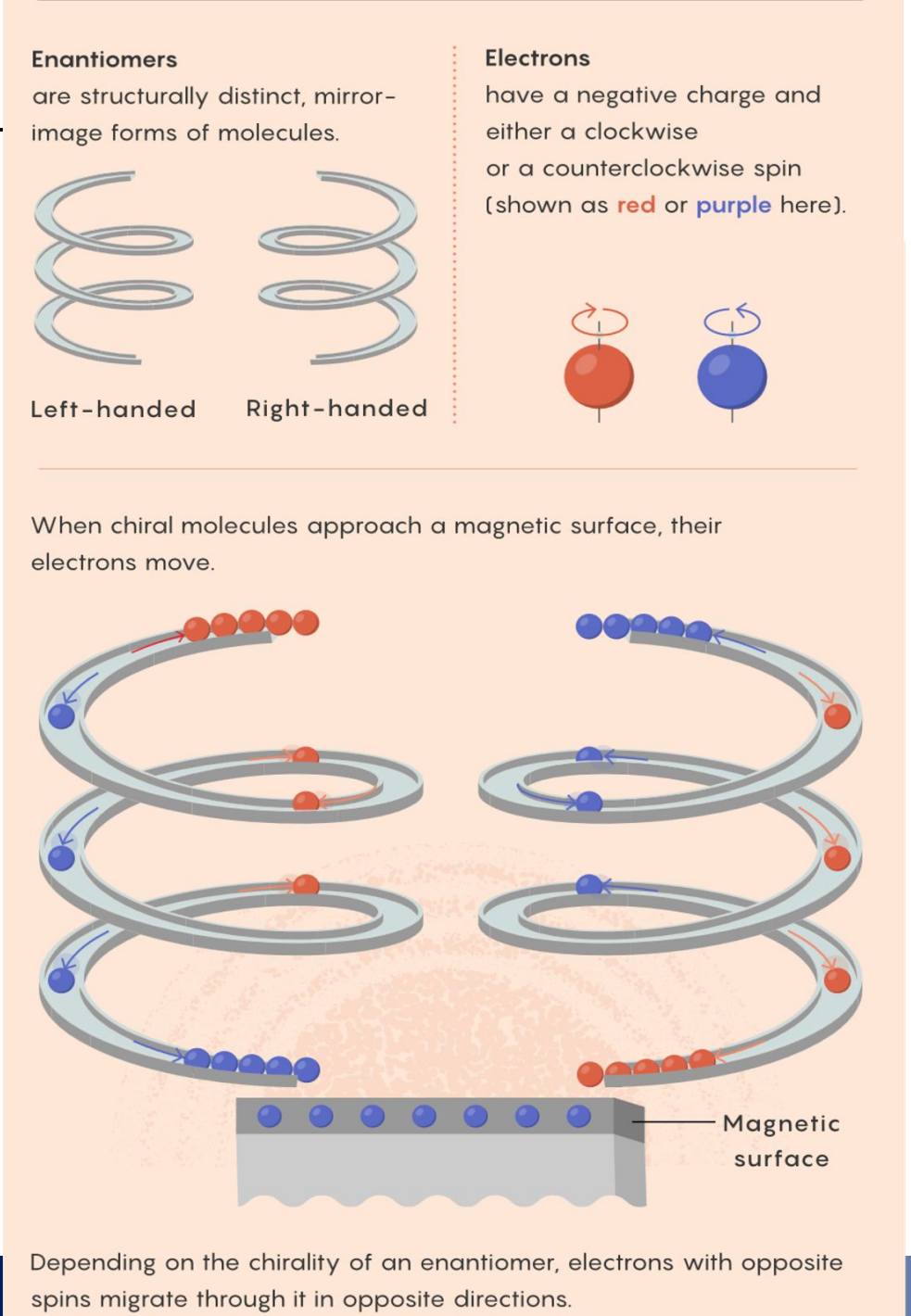
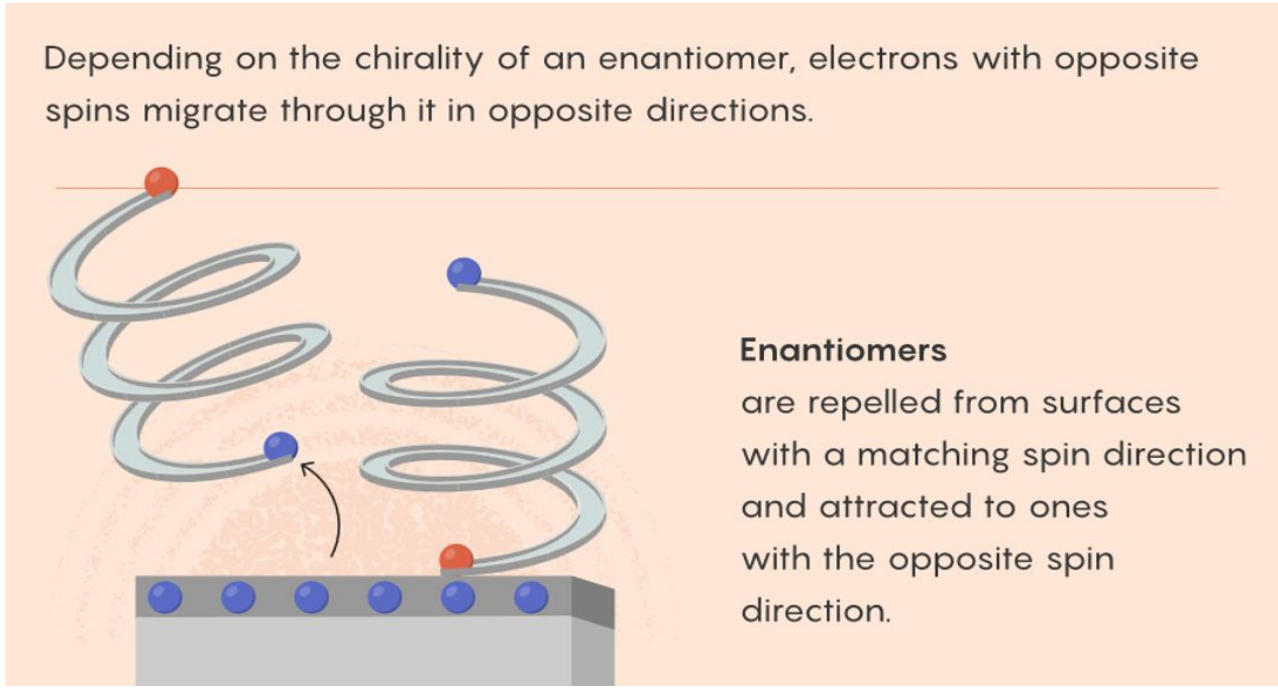
V. V. Kasimov, Biologicheskaya izomeriya (Biological Isomerism), Nauka, L., 1973


The effects of the Left-Right asymmetry manifest themselves in a wide variety of vital functions of organisms and human right down to the sphere of the psyche. For example, visual perception of Raphael's Sistine Madonna changes significantly on reflection in a mirror:
https://scholar.google.com/scholar_lookup?hl=en&publication_year=1974&author=R+Arnheim&title=Art+and+visual+perception

Magnetism May Have Given Life Its Molecular Asymmetry

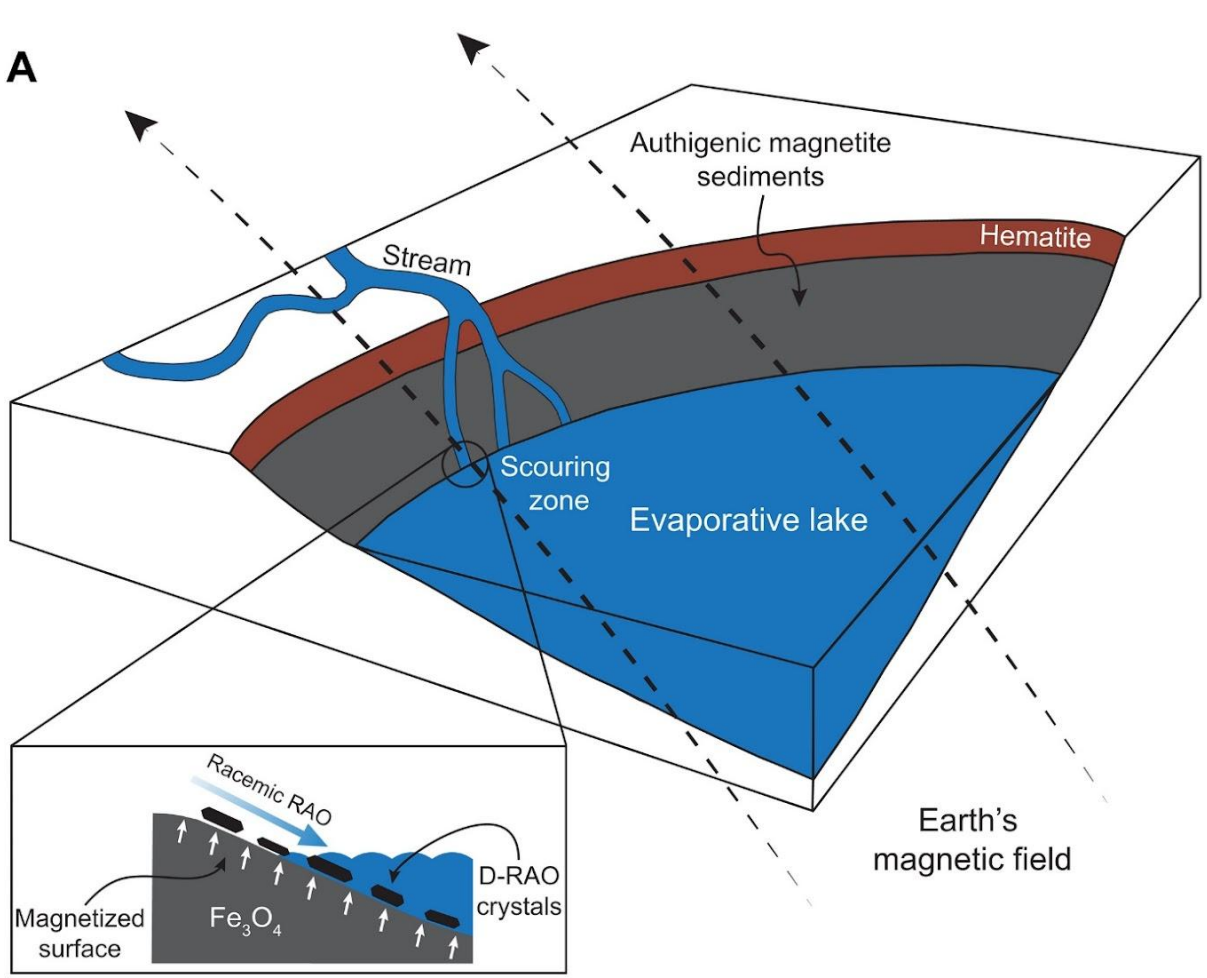
Mechanism: The preferred “handedness” of biomolecules could have emerged from biased interactions between electrons and magnetic surfaces.

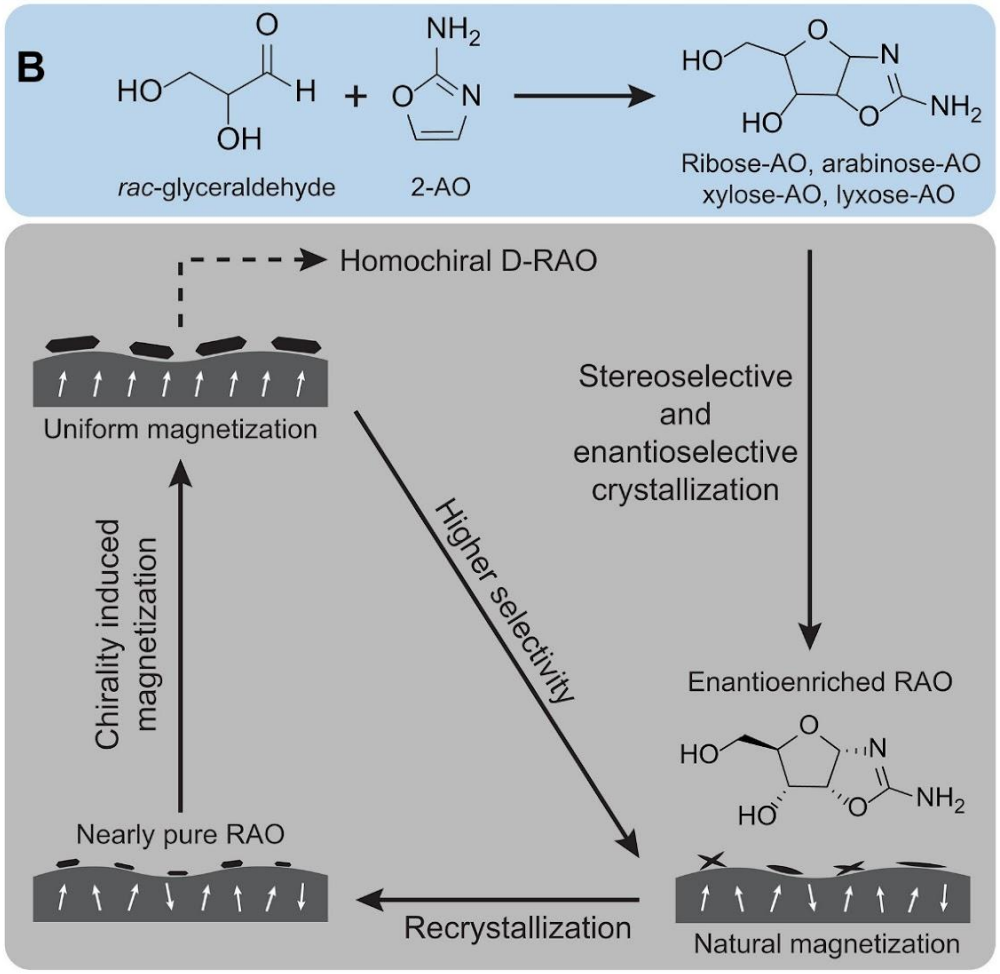




https://www.quantamagazine.org/magnetism-may-have-given-life-its-molecular-asymmetry-20230906/

Origin of biological homochirality by crystallization of an RNA precursor on a magnetic surface





An evaporative lake with magnetic sediments can accommodate spin-selective processes between an RNA precursor and a magnetized surface. Ribo-aminooxazoline (RAO) as a key compound to resolve the origin of homochirality due to its centrality in the synthesis of nucleotides and crystallization properties. **The Earth's magnetic field plays a key role in this process!**

S. Furkan Ozturk et al. , Sci. Adv.9,eadg8274(2023). DOI:10.1126/sciadv.adg8274

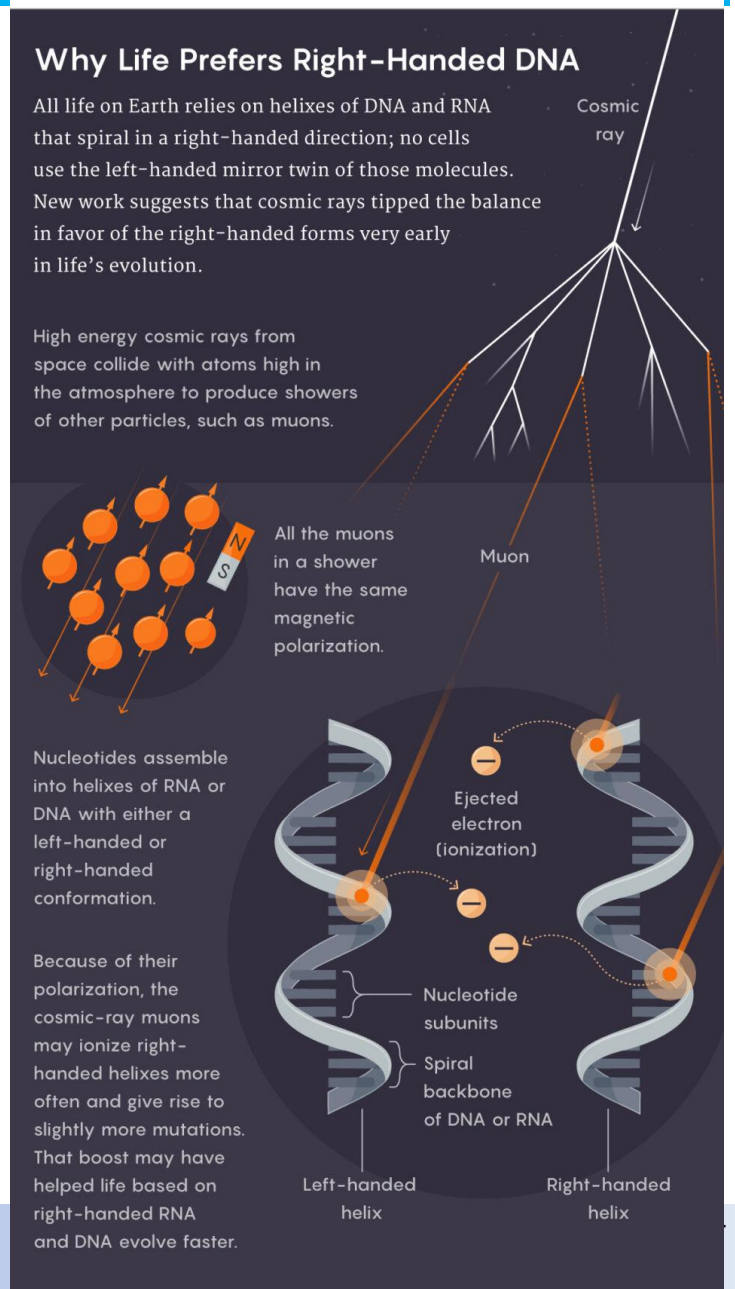
Cosmic Rays May Explain Life's Bias for Right-Handed DNA

The preferred chirality for "live" amino acids is almost exclusively left-handed.

Careful analysis of meteorites has found that certain "live" amino acids outnumber "evil" ones by 20% or more, a surplus they may have passed on to Earth. The excess molecules could be the lucky survivors of billions of years of exposure to circularly polarized light, a collection of beams all spiraling in the same direction that, experiments have shown, can destroy one type of amino acid slightly more thoroughly than the other.

Noemie Globus and Roger D. Blandford 2020 ApJL 895 L11
DOI 10.3847/2041-8213/ab8dc6

https://www.quantamagazine.org/cosmic-rays-may-explain-lifes-bias-for-right-handed-dna-20200629/



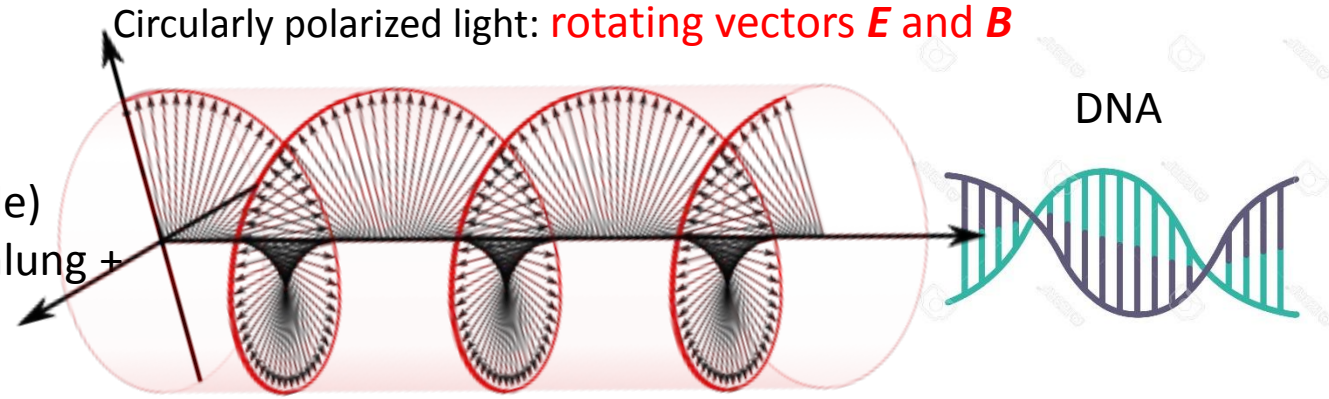
Circularly polarized light may have given chiral purity of life

Astronomical sources of circularly polarized light

- Plerion (Pulsar powered synchrotron nebula)

Crab nebula. Synchrotron <0.1% (visible)

- Pulsar (rotating neutron star) Crab pulsar ? <0.07% (visible)
- Magnetic white dwarf. PG 1031+234 Magneto-bremsstrahlung + Zeeman effect. 12% (visible)
- Polar (magnetic white dwarf binary). AM Her Cyclotron emission 50% (visible)
- **Reflection nebulae in Orion OMC-1 Scattering from 23% (IR) star formation regions aligned dust grains**



Mechanisms of homochirality: CPL carries an angular momentum + Effect of Sadovski

Reflection nebulae in some regions of massive star formation show large circular polarizations in the IR, and similar levels of polarization at UV wavelengths may well be present. Since this effect operates in regions where stars are forming and organic molecules are known to be present, it provides the most probable explanation for the enantiomeric excesses that are seen in meteorite amino acids. It is suggested that the α-methyl amino acids which are found to be enriched in the L-enantiomer in meteorites acted as a chiral initator for autocatalytic processes occurring during early stages of the origin of life.

Bailey, J. Astronomical Sources of Circularly Polarized Light and the Origin of Homochirality. Orig Life Evol Biosph 31, 167–183 (2001). https://doi.org/10.1023/A:1006751425919

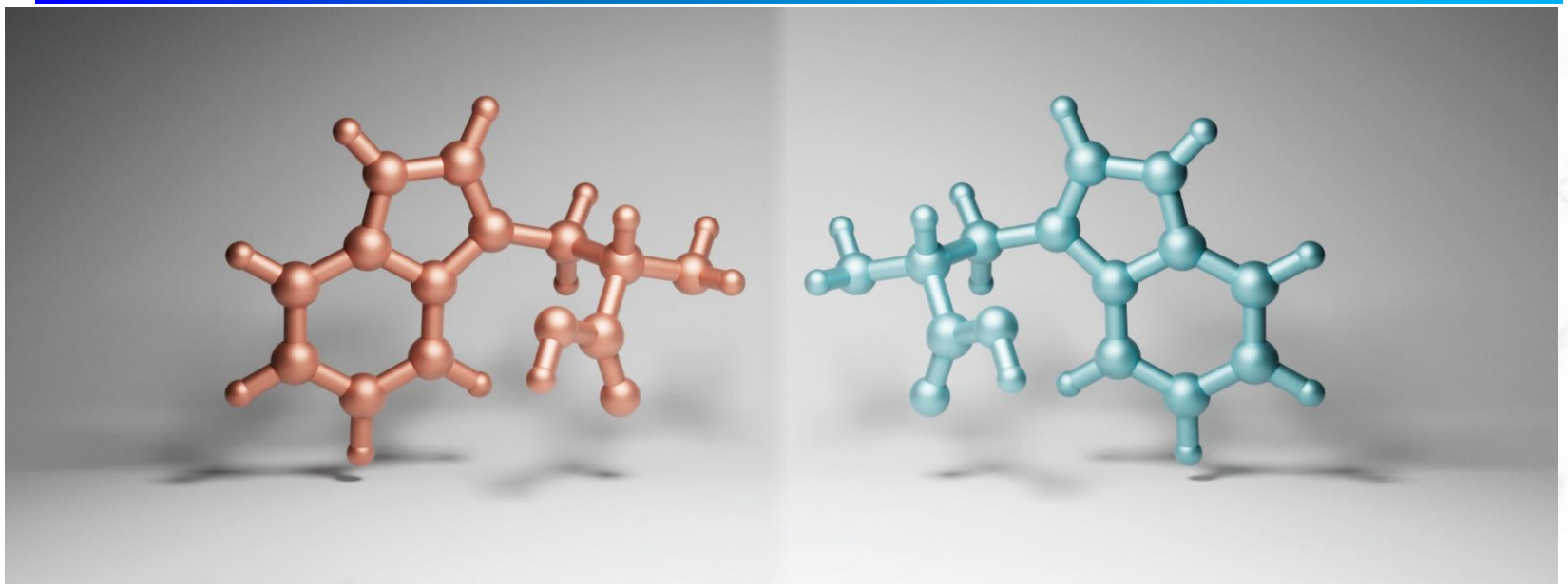
Toward Mirror Life

Although mirror life could be just as functional as natural chirality life, it cannot arise from existing life: Evolution proceeds in incremental steps and would be unable to invert the chirality of complex biomolecules such as DNA or proteins, let alone all biomolecules simultaneously. It is also exceedingly unlikely that we will encounter mirror life that has arisen independently.

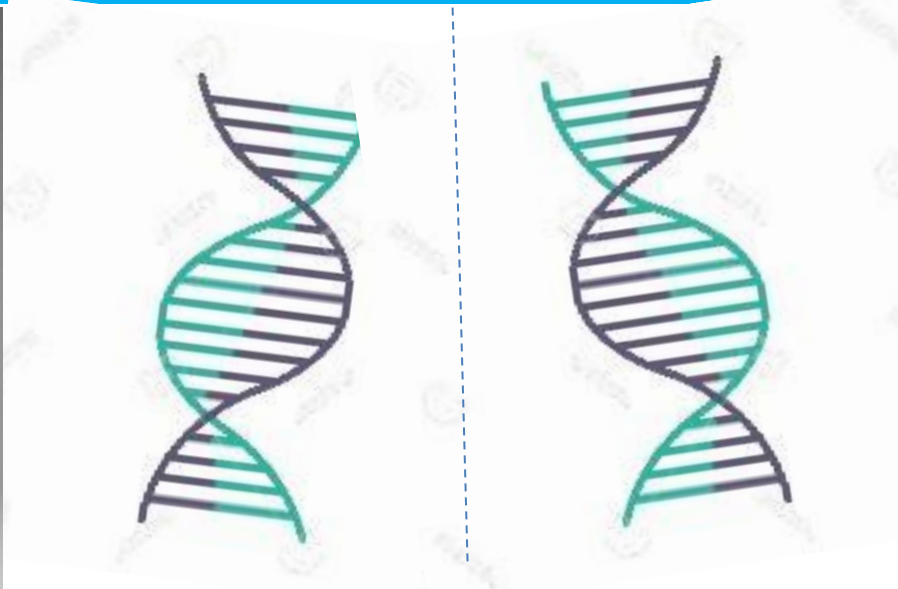
However, with scientific advances, a mirror organism might be created in a laboratory.

Katarzyna P. Adamala *et al.* , Confronting risks of mirror life. *Science* **386**,1351 (2024). DOI:10.1126/science.ads9158

Risks of Mirror Life



A chemical structure model of a naturally occurring amino acid, L-tryptophan **(left),** is shown with its mirror image **(right)**.



DNA is made from "right-handed" nucleotides **(left),** is shown with its mirror image **(right).**

Analysis suggests that **mirror bacteria would likely evade many immune mechanisms mediated by chiral molecules**, potentially causing lethal infection in humans, animals, and plants.

Thank you for your time