# National Academies workshop:
# Mirror Image Biology
*September 29, 2025*

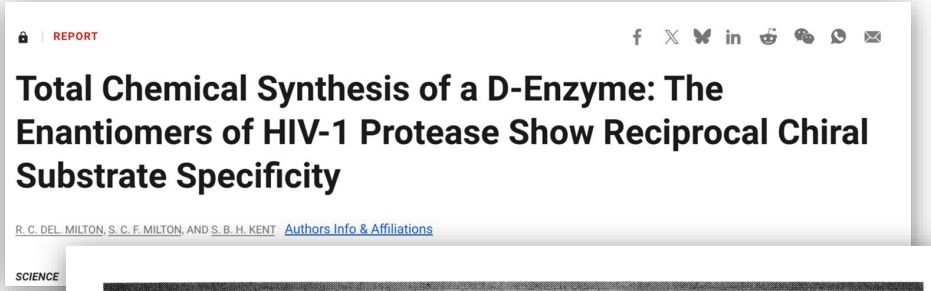
## Opening remarks

James Smith, DPhil

*Mirror Biology Dialogues Fund*
*J. Craig Venter Institute*

# Past conversations on mirror life

- 1848. Louis Pasteur discovered homochirality of life
- 1992. Science letter: mirror life “would have built-in immunity to attack from ‘normal’ life” and that “synthesizers of life… need to consider these matters in detail before getting started.”
- 2010. WIRED article: “mirror life wouldn’t have any predators or diseases to limit its reproduction. They would have to keep an eye on that.”



REPORT

**Total Chemical Synthesis of a D-Enzyme: The Enantiomers of HIV-1 Protease Show Reciprocal Chiral Substrate Specificity**

R. C. DEL. MILTON, S. C. F. MILTON, AND S. B. H. KENT Authors Info & Affiliations

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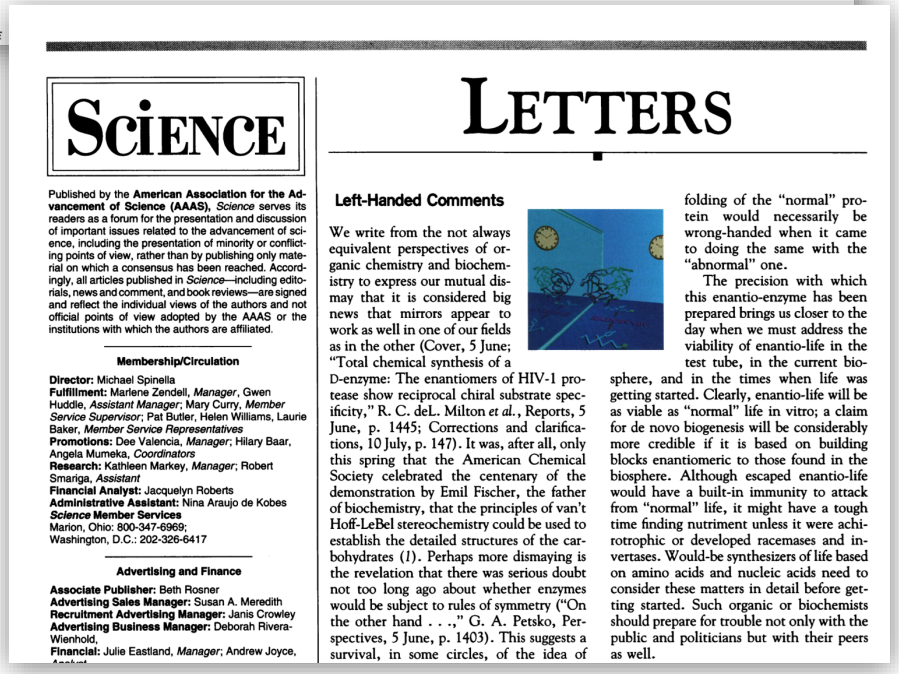

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# LETTERS

## Left-Handed Comments



We write from the not always equivalent perspectives of organic chemistry and biochemistry to express our mutual dismay that it is considered big news that mirrors appear to work as well in one of our fields as in the other (Cover, 5 June; “Total chemical synthesis of a D-enzyme: The enantiomers of HIV-1 protease show reciprocal chiral substrate specificity,” R. C. deL. Milton *et al.*, Reports, 5 June, p. 1445; Corrections and clarifications, 10 July, p. 147). It was, after all, only this spring that the American Chemical Society celebrated the centenary of the demonstration by Emil Fischer, the father of biochemistry, that the principles of van't Hoff-LeBel stereochemistry could be used to establish the detailed structures of the carbohydrates (*1*). Perhaps more dismaying is the revelation that there was serious doubt not too long ago about whether enzymes would be subject to rules of symmetry (“On the other hand . . .,” G. A. Petsko, Perspectives, 5 June, p. 1403). This suggests a survival, in some circles, of the idea of folding of the “normal” protein would necessarily be wrong-handed when it came to doing the same with the “abnormal” one.

The precision with which this enantio-enzyme has been prepared brings us closer to the day when we must address the viability of enantio-life in the test tube, in the current biosphere, and in the times when life was getting started. Clearly, enantio-life will be as viable as “normal” life in vitro; a claim for de novo biogenesis will be considerably more credible if it is based on building blocks enantiomeric to those found in the biosphere. Although escaped enantio-life would have a built-in immunity to attack from “normal” life, it might have a tough time finding nutriment unless it were achirotrophic or developed racemases and invertases. Would-be synthesizers of life based on amino acids and nucleic acids need to consider these matters in detail before getting started. Such organic or biochemists should prepare for trouble not only with the public and politicians but with their peers as well.

# 2024: Working group on mirror life

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**Jack Szostak**

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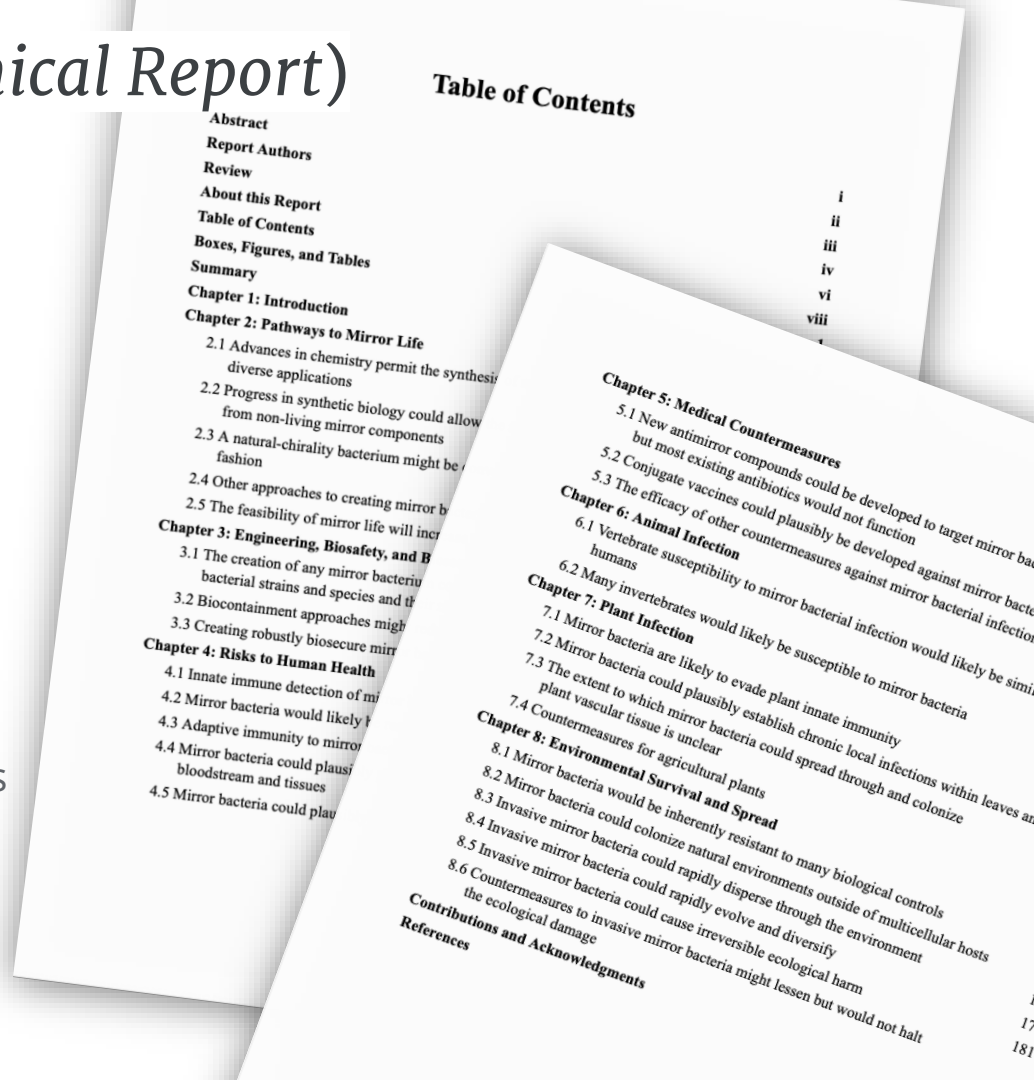
**Weiwen Zhang**, Tianjin University
**Xinguang Zhu**, CAS-MPG Partner Institute
**Maria Zuber**, Massachusetts Institute of Technology *

** National Academy of Sciences/Medicine member*

# 2024: Analysis (see *Technical Report*)

- “Mirror bacteria” could plausibly be created in 10-30 years
- Plausibly unprecedented risks to humans, animals, plants, and ecosystems
  - Immune evasion allowing systemic lethal infections in many species
  - Evasion of predation allowing environmental spread
- Growth on achiral nutrients or with engineering for common chiral nutrients



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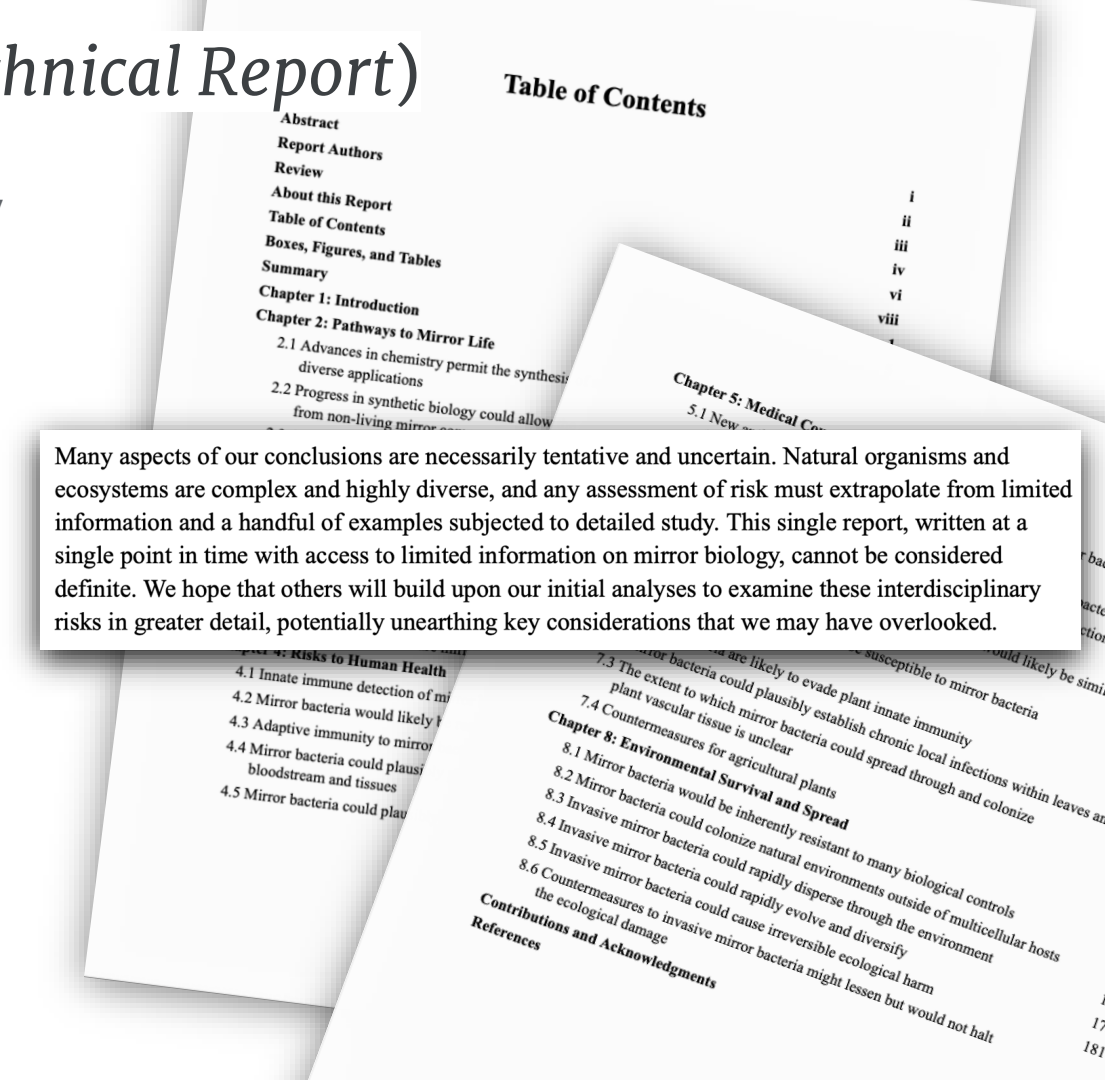
# 2024: Analysis (see *Technical Report*)

- Countermeasures feasible, but likely insufficient to prevent widespread harm
- Unique biosecurity challenges
- Limited potential benefits of mirror *life* (vs. mirror molecules for therapeutics)
- Detailed analysis in technical report. Call for more research to address outstanding questions.



# 2024: Working group recommendations (*Science*)

**Global conversation needed to chart a path forward**

Authors' starting point for discussion:

- Work on mirror biomolecules for therapeutics and synthetic cell work should continue
- Mirror bacteria should not be created, given current understanding
- Conduct research transparently to better understand risks from mirror bacteria without advancing toward their creation
- Consider governance of precursor technologies on way to mirror life

POLICY FORUM

BIOSECURITY

## Confronting risks of mirror life

Broad discussion is needed to chart a path forward

By Katarzyna P. Adamala, Deepa Agashe, Yasmine Belkaid, Daniela Matias de C. Bittencourt, Yizhi Cai, Matthew W. Chang, Irene A. Chen, George M. Church, Vaughn S. Cooper, Mark M. Davis, Neal K. Devaraj, Drew Endy, Kevin M. Esvelt, John I. Glass, Timothy W. Hand, Thomas V. Inglesby, Farren J. Isaacs, Wilmot G. James, Jonathan D. G. Jones, Michael S. Kay, Richard E. Lenski, Chenli Liu, Ruslan Medzhitov, Matthew L. Nicotra, Sebastian B. Oehm, Jaspreet Pannu, David A. Relman, Petra Schwille, James A. Smith, Hiroaki Suga, Jack W. Szostak, Nicholas J. Talbot, James M. Tiedje, J. Craig Venter, Gregory Winter, Weiwen Zhang, Xinguang Zhu, Maria T. Zuber

All known life is homochiral. DNA and RNA are made from "right-handed" nucleotides, and proteins are made from "left-handed" amino acids. Driven by curiosity and plausible applications, some researchers had begun work toward creating lifeforms composed entirely of mirror-image biological molecules. Such mirror organisms would constitute a radical departure from known life, and their creation warrants careful consideration. The capability to create mirror life is likely at least a decade away and would require large investments and major technical advances; we thus have an opportunity to consider and preempt risks before they are realized. Here, we draw on an in-depth analysis of current technical barriers, how they might be eroded by technological progress, and what we deem to be unprecedented and largely overlooked risks (*1*). We call for broader discussion among the global research community, policy-makers, [illegible] has not previously been completed. The need for such an analysis has grown with advances in key enabling technologies. To address this gap, a group with diverse expertise qualitatively assessed the feasibility and risks of creating mirror bacteria, considering factors including the nature, magnitude, and likelihood of potential harms; the ease of accidental or deliberate misuse; and the effectiveness of potential countermeasures. Our group includes expertise in synthetic biology; human, animal, and plant physiology and immunology; microbial ecology; evolutionary biology; planetary life detection; biosecurity; global health; and policy-making and includes researchers who have held the creation of mirror life as a long-term aspirational goal. The findings are summarized below and detailed in a separately released, in-depth technical report (a cross-referenced version of this article is provided in the supplementary materials) (*1*). We focus on

A chemical structure model o
occurring amino acid, L-tryptop
with its mirror image (*right*).

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the environment and thus wou
trinsically biocontained.

We call for additional scru
findings and further research
understanding of these risks.
the absence of compelling evid
assurance, our view is that mir

# Broadening discussion on mirror life













# Example: scientific discourse

FEB. 25, 2025

**Remember The Glycans: Consideration of Glycans in Evaluating the Threat of Mirror-Image Life Forms.**

RATMIR DERDA Department of Chemistry, University of Alberta, Edmonton, AB T6G 2G2, Canada

[...]

A recent analysis of the potential threat posed by mirror-image life forms (*1*) presented an important topic for the scientific community. Major concerns were raised by the authors, who argued that many aspects of the immune response to mirror bacteria could be deficient. However, there was limited consideration of the crucial roles of the third pillar of biomolecules, namely carbohydrates (comprising oligo- and polysaccharides, a.k.a. glycans), in con-

DEC. 23, 2024

**In response to "Confronting risks of mirror life".**

DAVID PERRIN Professor, UBC Chemistry Department

In the December 12th issue of *Science*, Adamala *et al*. in "Confronting risks of mirror life" raise the specter of "mirror-life" organisms—bacteria whose molecular components are the enantiomers of those found in natural life—warning of the "unprecedented risks" such organisms might pose to human health. Yet a number of critical aspects were not fully discussed. These include the immune system's capacity to respond, the complex nature of bac-

JAN. 24, 2025

**Response to Perrin**

JOHN GLASS J. Craig Venter Institute

SEBASTIAN OEHM University of Cambridge

JASPREET PANNU Stanford University

# Paris Conference on Risks from Mirror Life


Watch talks and read the report:
[parismirrorlife.org](parismirrorlife.org)

# Manchester Technical Workshop on Mirror Life

Technical expertise around precursor technologies

# Independent discussions and analyses

unesco
International
Bioethics Committee

**V.2.3 Impose Precautions on "Mirror" replicating cells**

201. Enact a precautionary global moratorium on creating mirror cells (living, dividing organisms made of DNA, proteins, sugars and lipids with reversed chirality). International authorities (e.g. via the UN Biological Weapons Convention) should explicitly include these in emerging biohazard oversight. Researchers should be encouraged to find alternative routes towards synthesis of beneficial mirror molecules and to further study the risks of mirror cells via simulations or non-living experiments.

ZKBS
Zentrale Kommission
für die **Biologische Sicherheit**

The ZKBS has examined the authors' arguments and shares their key assessments. In particular, the ZKBS recognizes the potential, albeit currently difficult to assess, danger posed by self-replicating mirror bacteria to humans, animals, plants, and the environment. The call for a broad scientifically and socially oriented debate is explicitly supported.

*translated using Google Translate

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Office for Science

Research and analysis
**Mirror life**
Updated 16 July 2025

would not be possible to use antibiotics on entire ecosystems that mirror bacteria might colonise.

27. 'Safety switches' or identification 'barcodes' could be incorporated into synthesised cells to mitigate the risk of uncontrolled release. However, malicious actors or natural evolution could possibly adapt cells to overcome such mitigations.

28. There should be a coalition among funders, researchers, governments and civil society to develop appropriate guidelines to manage the development of mirror molecules and prevent the development of replicating mirror organisms.

29. There should be collective international agreement to monitor research into self-replicating mirror cells and to develop appropriate mitigations on a case-by-case basis. Any such agreement could, of course, be ignored by bad actors.

# Concluding remarks

In supporting this workshop, we hope to:

1. Clarify relevant science/technology
2. Clarify potential risks and benefits
3. Identify strategies to mitigate risks while preserving beneficial research

**Contact: james.smith@mbdf.org**