The story of mirror life: From intriguing idea to unprecedented threat

Grave warnings have been issued about the dangers of creating life forms using mirror-image molecules. How worried should we be?

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In the coming decades, we might figure out how to make an entirely new kind of life: a mirror cell, in which every molecule is the mirror image of those found in normal cells. Such reversed cells have probably never existed on our planet in its 4.5-billion-year history. Yet we could one day make them – perhaps as a way to make new drugs, or simply out of pure scientific curiosity about the origins and evolution of life.

But should we? According to a coalition of synthetic biologists and biosafety specialists, the answer is a resounding "no". Mirror life, they argue, would pose "unprecedented risks" to the health of every living organism on the planet. If it got out, we might never be able to recapture it, leading to "pervasive lethal infections".

It's an apocalyptic-sounding threat, but would it really be as dangerous as the team argues if we managed to create these new life forms? And although mirror life could be decades away, could there be things we can do now to reduce the risk?

Many of the essential molecules of life can exist in two mirrored forms, like a person's left and right hands. While these "chiral" molecules are difficult to distinguish from each other, their distinct shapes cause them to behave differently. No matter how much you rotate a left-handed molecule, you will never get it to match a right-handed one.

In all living organisms on Earth, DNA is right-handed and proteins are left-handed. This arrangement seems to have been adopted very early in the history of life, and happened because living systems need consistent chirality to work effectively. The molecules in our cells must fit together neatly, sometimes as precisely as a key in a lock, so a jumble of left- and right-handed molecules would gum up the works.

Nobody knows why life chose this particular pattern of handedness. It may have been an arbitrary choice that became fixed over the course of evolution: a frozen accident. If that's true, life elsewhere in the universe might use molecules with opposite handedness to life on Earth. Alternatively, there may be some subtle advantage to right-handed DNA and left-handed proteins, which enabled this form of life to outcompete its mirror image.

To explore these questions, biochemists have developed ways to make mirror molecules. Entire right-handed proteins have been constructed, as have left-handed nucleic acids – the building blocks of DNA – and, once assembled, the mirror molecules are perfectly functional. In a 2016 study, Ting Zhu, now at Westlake University in Hangzhou, China, and his colleagues created a mirror DNA strand that could be copied by a mirror enzyme.

Separately, synthetic biologists have been modifying living cells in ever more ambitious ways. As early as 2010, researchers led by Craig Venter at the J. Craig Venter Institute in La Jolla, California, removed all the DNA from a bacterial cell, then replaced it with a genome they had synthesised themselves. Subsequent studies have given cells heavily edited genomes, simpler than those found in nature. Ultimately, this could enable researchers to build an entirely synthetic cell: that is, assemble a living cell from scratch, using synthesised chemicals.

Synthetic cells

"The core of biochemistry for 50 years has been reconstituting activities that go on in cells," says Jack Szostak at the University of Chicago. "The ultimate of that would be to reconstitute the whole cell."

This means, argues Szostak, we are approaching a convergence point. As we get better at making mirror molecules and figure out how to build synthetic cells, there will come a point when we are able to construct a mirror cell: one where the DNA, proteins and other chiral molecules all have the opposite handedness to existing life.

“It’s probably quite some ways off,” says Szostak. Estimates vary between 10 and 50 years, depending on how many of the steps prove to be easy or difficult. “If there are only a few hard parts, who knows?”

That’s why Szostak and 37 co-authors, including Venter, teamed up to consider the potential benefits and risks of creating mirror life. Their conclusion, published in *Science* in December 2024, is that “mirror bacteria and other mirror organisms should not be created” due to the dire risks they pose.

In theory, many types of mirror life could be constructed. However, most would be either harmless or enormously difficult to make.

For instance, it should be possible to make a mirror virus, because viruses are much smaller and simpler than cells: just a piece of nucleic acid surrounded by a protein shell. However, viruses can only reproduce by infecting cells and taking over their machinery – and because chiral molecules like DNA are involved throughout, this infection “should be totally impossible”, says Szostak. “A mirror virus can only grow in a mirror cell.”

In contrast, mirror animals and plants would be enormously hard to construct, because they are made up of larger and more complex eukaryotic cells. “That seems much harder and much further away,” says Szostak.

That’s why Szostak and his colleagues focused on the creation of a mirror bacterium: a single-celled organism, of a type that dates back billions of years to the earliest life on Earth. A mirror bacterium, they say, is something we should not make – for our own safety.

Invasive bacteria

Not that Szostak believed that when he first started thinking about mirror life. Pathogenic bacteria that can cause diseases have specialised equipment to evade their host’s immune systems and attack its tissues. Much of this equipment relies on chiral molecules. “When I first started getting involved in this, my initial reaction, like I think almost everybody, is that to be a pathogen is a highly evolved state,” says Szostak. “You might think, well, there’s no way that a mirror bacterium could be a pathogen.”

However, he and his colleagues concluded that a mirror bacterium need not be a specialised pathogen to cause serious harm.

The immune system recognises bacteria by locking onto telltale molecules on their outer walls, and those molecules are all chiral. As a result, a mirror bacterium would probably go undetected by our immune system and wouldn’t be cleared out of our bodies.

The bacterium would then have to locate food. Some nutrients found in our bodies, like the amino acid glycine, are non-chiral, so the mirror bacterium could feed on them. “The concentrations are lower and the nutritional value is probably not as good as something like glucose,” says Szostak. This might mean the mirror cells grow only slowly. However, “the fact that they’re not being killed off means that they could potentially grow without limit”.

Furthermore, the mirror bacterium wouldn’t be confined to a single type of host – unlike pathogenic bacteria, which tend to infect a limited number of species. In theory, mirror bacteria could grow in any living organism, in any ecosystem. Szostak and his colleagues write: “We cannot rule out a scenario in which a mirror bacterium acts as an invasive species across many ecosystems, causing pervasive lethal infections in a substantial fraction of plant and animal species, including humans.”

As a result, mirror bacteria would act as pathogens with an “unusually broad host range”, says Filippa Lentzos at King’s College London.

In all living organisms on Earth, DNA is right-handed. Yet all proteins are in a left-handed form

Vladislav Kochelaevskiy/Alamy

The worry is that a mirror bacterium might escape from the lab where it was created and wreak havoc. Laboratories can be designed to be highly secure, but accidents can and do happen. And there is an even more dramatic scenario: mirror bacteria could be weaponised by a rogue government or terrorists.

Once mirror bacteria were out in the wild, they would be very difficult to control. In theory, we might synthesise mirror antibiotics to kill them, but these wouldn't be a cure-all. "You could protect a small number of people or animals, but there's no way to deploy something like that on a global scale," says Szostak.

Risks of mirror life

That's the case for the prosecution. However, specialists in biosafety and biosecurity contacted by *New Scientist* expressed conflicting views about mirror life. Because mirror bacteria do not yet exist, there is great uncertainty about the risks they pose.

The first disagreement is about whether it is worth having the discussion at all, when mirror life may be decades away.

"No one in the world has come close to creating a cell from scratch," says Markus Schmidt at Biofaction, a research and science communication company in Vienna, Austria. Rapid progress in synthetic biology notwithstanding, our inability to make synthetic cells "tells us that we actually do not really understand very well how the cell works". Consequently, Schmidt says "we are very, very far away" from building a mirror bacterium. There are far more pressing biological challenges, he says.

In contrast, Lentzos says raising the issue early is "exemplary". She points out that scientists developing new technologies have tended to only engage the public once they are ready to take them to market – by which stage people have attached their careers to the technique and large quantities of money are involved. "You're at the very end of it, and then nothing's going to change, whatever people say," she says. Better to raise the concerns "really far upstream", she argues. "To me, this is a textbook case of responsible science in action."

The second question is whether mirror bacteria would really be able to make a living in our bodies, or anywhere outside a controlled laboratory. "Maybe they just die when they're in the environment," says Kathleen Vogel at Arizona State University.

It's true that organisms produced by synthetic biology tend to be rather fragile, compared with wild ones. "If somebody wanted to make a mirror bacterium, maybe just to show that they could, the first thing that was made would probably be quite crippled," says Szostak. Then again, a team skilled enough to make a mirror bacterium could probably also design it to be more resilient.

There are also many ways the mirror bacterium could be engineered to confine it. For instance, the cell could be designed to be entirely dependent on a single nutrient not found in nature. “When you don’t feed it, it’s not going to survive,” says Schmidt. Alternatively, the cells could be given a ticking clock, so that they self-destruct after a specified amount of time. They could even be engineered to work using a different genetic code, incompatible with that used by all existing organisms. By stacking up several such control mechanisms, the odds of the mirror cells roaming unchecked could be rendered infinitesimal.

Survival in the wild

In short, it isn’t inevitable that a mirror bacterium would survive in the wild, and a responsible creator could engineer the cell to make it less likely to cope.

However, that presumes the people creating the mirror bacterium have the best interests of humanity at heart. “It might be someone with more sinister intentions,” says Lentzos. In the most extreme scenario, someone might engineer mirror bacteria to be pathogenic – essentially, using them to commit mass murder.

We do have laws prohibiting such weapons. The Biological Weapons Convention of 1975 completely prohibits biological and toxin weapons. “The words ‘mirrored bacteria’ are not in that text,” says Lentzos. However, “the text of the convention is broad enough to cover that”.

The problem is enforcing the laws. “If you really start to think about somebody malicious doing this, that’s really, really hard to stop,” says Szostak.

However, Vogel says protection may come from the sheer difficulty of making such a weapon. “Solid empirical evidence tells you that creating a biological weapon to cause mass casualties is an extremely technically difficult thing to do,” she says. “Even states who had all of the resources, all of the expertise, all of the infrastructure, all of the equipment, struggled in their efforts.” This is again because living organisms are often very particular about the conditions in which they survive, and engineered organisms are especially fragile. “There are a lot of things that have to come into play for this to work,” says Vogel.

But just because it hasn’t happened yet doesn’t mean it never will.

Why make mirror microbes?

Despite all the dangers of mirror bacteria, as a society, we might want to take the risk of making them if they offer significant benefits. However, here there is consensus: the benefits are either small or non-existent.

“You could use mirror bacteria as a sort of biofactory to make mirror molecules,” says Szostak. Those mirror molecules can be genuinely useful, notably as long-lasting pharmaceuticals that don’t get degraded by our immune systems. “But I think that benefit is actually pretty small, because the technology for just chemically synthesising mirror molecules is already pretty good.”

The only other benefit is pure curiosity: what would a mirror cell be like? Would it behave any differently compared with its reverse twin?

Consequently, Lentzos says the risk-reward calculation is clear. “I agree with the conclusion that we should ban this kind of research,” she says. “You do need to weigh up the risks and potential benefits, and in this case the potential benefits are fairly limited, and the risks are very large.”

Keeping control

For Schmidt, the discussion of mirror life is part of a bigger issue: containment of synthetic and modified organisms of all kinds. He says that many of the purported risks of mirror life could also apply to other kinds of synthetic and modified cells. “If you make something different, you run into the same concerns as with mirror life.”

Synthetic biology is proceeding at a rapid pace, with all kinds of modified biomolecules and organisms being developed every year. Yet there is not enough effort being put into developing containment systems, says Schmidt. He wants to see lots more attention and investment directed to biosafety, with the aim of developing a suite of methods to restrain synthetic and modified organisms, either physically or otherwise.

Mirror bacteria, in this view, are just one of many kinds of synthetic organisms we will build over the coming years – and they all need to be carefully managed. So the level of existential threat posed by these possible new forms of life is in our hands.