

Life Ascending

The Ten Great Inventions of Evolution

Chapter 5: Sex

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About

Dr Nick Lane is a British biochemist and writer. He was awarded the first Provost's Venture Research Prize in the Department of Genetics, Evolution and Environment at **University College London**, where he is now a Reader in Evolutionary Biochemistry. Dr Lane's research deals with evolutionary biochemistry and bioenergetics, focusing on the origin of life and the evolution of complex cells. Dr Lane was a founding member of the UCL Consortium for Mitochondrial Research, and is leading the UCL Research Frontiers Origins of Life programme. He was awarded the 2011 BMC Research Award for Genetics, Genomics, Bioinformatics and Evolution, and the 2015 Biochemical Society Award for his sustained and diverse contribution to the molecular life sciences and the public understanding of science.



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The Irish playwright George Bernard Shaw is a powerful magnet for anecdotes and apocrypha. One such story tells of Shaw being propositioned by a beautiful actress at a party. 'We should have a child together,' the actress declares, 'for it would be blessed with my beauty and your brains.' 'Ah,' replies the cagey Shaw, 'but what if it had my beauty and your brains?'

Shaw had a point: sex is the most peculiar randomiser of successful genes known. Perhaps only the randomising power of sex is able to throw up a Shaw or a beautiful actress in the first place; but no sooner has sex engineered a winning combination of genes than it dissolves them again. An infamous, albeit mostly harmless, organisation, known as the 'Nobel sperm bank', fell into exactly that trap. The biochemist George Wald, on being invited to contribute his prize-winning sperm, declined on the grounds that it was not his sperm they needed but that of people like his father, a poor immigrant tailor, whose loins were unsuspected as the fount of genius. 'What have my sperm given the world?' asked the laureate. 'Two guitarists!' Genius, or intelligence in general, is certainly heritable (which is to say, genes influence rather than determine the outcome), but sex makes it all an unpredictable lottery.

Most of us sense that the magic of sex (as a form of reproduction) lies in exactly this ability to generate variation, to pull a unique being from a hat every time. But when scrutinised with the care of a mathematical geneticist, it is far from obvious that variety for variety's sake is a good thing. Why break up a winning combination; why not just clone it? Cloning a Mozart or a GBS might strike most people as playing God, a dangerous manifestation of humanity's self-inflated conceit, but this is not what the geneticists have in mind. Their point is rather more mundane – the endless variety spun

out by sex can lead directly to misery, disease and death, when a plain clone would not. Cloning, by preserving gene combinations fired in the crucible of selection, is often the best bet.

To give a single example, consider sickle-cell anaemia. This is a grave genetic disease, where red blood cells twist into a rigid sickle shape, which can't squeeze through fine capillaries. It is caused by inheriting two 'bad' copies of a gene. Why didn't natural selection eliminate the bad gene, you may ask? Because a single copy of the 'bad' gene is actually beneficial. If we inherit one 'good' and one 'bad' copy from our parents, not only do we not suffer sickle-cell anaemia, but we're also less likely to get malaria, another disease that affects the red cells. A single 'bad' copy of the sickle-cell gene alters the membrane of the red cells, blocking the entry of malarial parasites, without turning the cells into a hazardous sickle shape. Only cloning (that is to say, asexual reproduction) can pass on this beneficial 'mixed' genotype every time. Sex shuffles the genes inexorably. Assuming both parents have this mixed genotype, about half of any children do inherit the mixed genotype, but a quarter receive two 'bad' copies of the gene, giving them sickle-cell anaemia, while another quarter end up with two 'good' copies of the gene, putting them at high risk of malaria, at least if they live anywhere in the great swathes of the planet inhabited by the mosquito (which transmits the disease). In other words, greater variety puts no less than half the population at risk of serious disease. Sex can blight lives directly.

And that's far from the only disadvantage to sex. Indeed the list of drawbacks ought to put any sane person off the idea for good. Jared Diamond once wrote a book with the title 'Why is Sex Fun?' but oddly omitted to offer an answer. He must have thought it obvious: if sex were not fun, nobody in their right mind would get up to it. And where would we all be then?

Let's imagine that Shaw threw caution to the wind and gambled his luck on a child with brains and beauty. We'll imagine, too, unfairly but illustratively, that the apocryphal actress lived up to the allegorical reputation of her profession. She probably had venereal

disease, let's say syphilis. Their meeting took place before the advent of antibiotics, before syphilis had lost much of its dread among those impoverished soldiers, musicians and artists who frequented equally impoverished ladies of the night. In that age, the dreadful demise into insanity of figures like Nietzsche, Schumann and Schubert made the punishment for sexual misdemeanour all too real. And in those days, the touted cures, like arsenic and mercury, were nearly as bad. A night in the arms of Venus, it was said, led to a lifetime on Mercury.

Syphilis, of course, is just one of many unpleasant or deadly venereal diseases, like AIDS, the incidence of which is now soaring across much of the world. The rise of AIDS in sub-Saharan Africa is shocking and scandalous. As I write, some 24 million Africans are infected with HIV, a prevalence of about 6 per cent among young adults. The worst affected countries have a prevalence of well over 10 per cent, with a related decline in mean lifespan of more than a decade. While the crisis is certainly compounded by inadequate medicine, poverty and co-morbid diseases like tuberculosis, unprotected sex is still the biggest part of the problem. But whatever the cause, the sheer scale of the problem does give a sense of the occupational folly of sex.

But let's go back to Shaw. Unguarded sex with the actress could have produced a child with all the worst traits of its parents, and rendered Shaw himself diseased and insane. But he had some advantages too, unlike all too many of the rest of us. When propositioned by the actress, he was already rich and famous: a magnet not just for anecdotes but, in the modern idiom, for babes. At least by acquiescing to sex he had a chance that some of his genes would flow on down the river of time. He would not have had to endure the wretchedness and torment suffered by so many in the search for the right partner or any mate at all.

I don't want to get into the highly charged politics of sex. It seems obvious that there is a cost to finding a partner, and so a cost to passing on one's genes. I don't mean a financial cost – though that is felt keenly enough by anyone picking up the tab on a first date or staggering away from a divorce settlement – but the cost in unrequited time and

emotion, made plain from any lonelyhearts column or the proliferation of internet-dating pages. Yet the real cost, the biological cost, is hard to fathom in human societies, for it is buried under layers of culture and etiquette. If you doubt that there is a serious biological cost, just think of the peacock's tail. Those magnificent plumes, the emblem of male fertility and fitness, are undoubtedly a hazard to survival, as are the colourful courtship displays of plenty of other birds. Perhaps the most striking example of all is the hummingbird. Glorious as they may be, the 3,400 species of hummingbird embody the cost of finding a mate, not for the hummingbird (hard enough, no doubt) but for flowering plants.

Rooted to the spot, plants are the most implausible of sexual organisms, yet the overwhelming majority of them are exactly that; only dandelions, along with a handful of other species, cock a snook at sex. The rest find a way, the most spectacular being the exquisite beauty of flowering plants, which swept through the world some 80 million years ago, turning the dull green forests into the magical painted glades we know today. Although they first evolved in the late Jurassic, perhaps 160 million years ago, their global takeover was long delayed, and ultimately tied to the rise of insect pollinators like bees. Flowers are pure cost to a plant. They must attract pollinators with their flamboyant colours and shapes; produce sweet nectar to make such visits worthwhile (nectar is a quarter sugar by weight); and distribute themselves with finesse – not too close (or inbreeding makes sex pointless) and not too far (or the pollinators will never make it to fertilise a partner). Having settled on a pollinator of choice, the flower and pollinator evolve in tandem, each imposing costs and benefits on the other. And no cost is more extreme than that paid by a tiny hummingbird for the static sex life of plants.

The hummingbird must be tiny, for no larger bird could hover motionless over the deep throat of a flower, its wings humming at 50 beats a second. The combination of tiny size and colossal metabolic rate needed to hover at all means that hummingbirds must refuel almost incessantly. They extract more than half their own weight in nectar every day, visiting hundreds of flowers. If forced to stop feeding for long (more than a couple of hours), they fall unconscious into a coma-like torpor: their heart rate and breathing

plunge to a fraction of that in normal sleep, while their core temperature goes into free fall. They have been seduced by the enchanted potions of plants into a life of bondage, moving relentlessly from flower to flower, distributing pollen, or collapsing in a coma and quite possibly dying.

If all that were not bad enough, there is a yet deeper enigma to sex. The cost of finding a partner is as nothing compared to the cost of having a partner at all: the infamous twofold cost of sex. The irate feminist, railing at the very existence of men, has a most reasonable point. On the face of it, men are a heavy cost indeed, and a woman who solved the problem of virgin birth would be a worthy madonna. While a few men seek to justify their existence by assuming the burden of childcare, or material provisioning, the same is not true of many lower creatures, human or otherwise, where the males quite literally just fuck off. Even so, the impregnated female gives birth to sons and daughters in equal measure. Fifty per cent of her efforts are wasted on bringing ungrateful males into the world, where they simply perpetuate the problem. Any female, in any species without paternal provision, who could do away with males forever, would double her reproductive success. A race of cloning females ought to double in numbers every generation, wiping their sexual relatives from the population in a matter of a few generations. From a purely arithmetical perspective, a single cloning female could swamp a population of a million sexually reproducing individuals in just fifty generations!

Think of this at the level of cells. In clonal reproduction, or virgin birth, one cell divides in two. Sexual reproduction is actually the reverse. One cell (the sperm) fuses with another (the egg) to form a single cell (the fertilised egg). Two cells thus give rise to one: it is replication backwards. The twofold cost of sex manifests itself in gene numbers. Each sex cell, the sperm and the egg, passes on only 50 per cent of the genes of its parent to the next generation. The full quota of genes is re-established when the two sex cells fuse. In this context, an individual that finds a way to pass on 100 per cent of its genes to all its offspring, by cloning, has an inbuilt twofold advantage. Because each clone passes on twice as many genes as a sexual organism, the clone's genes should spread swiftly throughout the population, eventually replacing the genes for sexual reproduction.

It gets worse. Passing on only half your genes to the next generation opens the door to all sorts of other dubious shenanigans with selfish genes. In sex, at least in principle, all genes have a probability of exactly 50 per cent of being passed on to the next generation. In practice, this creates an opportunity for the cheats to do better: to act in their own selfish interests and get passed on to more than 50 per cent of the offspring. This is not just a theoretical possibility that doesn't actually happen. There are many examples of conflict between genes, between parasitic genes that break the law and the law-abiding majority that gang up to stop them. There are parasitic genes that kill the sperm, or even entire offspring that don't inherit them; genes that sterilise males; genes that inactivate their opposite numbers from the other parent; and jumping genes that proliferate throughout the genome. Many genomes, including our own, are stuffed with the relics of jumping genes that once replicated all over the genome, as we saw in Chapter 4. The human genome is a graveyard of dead jumping genes, literally half composed of their decaying corpses. Other genomes are even worse. An unbelievable 98 per cent of the wheat genome is made up of dead jumping genes. In contrast, most organisms that clone themselves have leaner genomes and apparently don't fall prey to parasitic genes in anything like the same way.

All in all, the odds seem massively loaded against sex as a mode of reproduction. An inventive biologist may conceive of peculiar circumstances in which sex could prove beneficial, but most of us, on the face of it, would feel compelled to dismiss sex as an outlandish curiosity. It suffers a notorious twofold cost compared with virgin birth; it propagates selfish genetic parasites that can cripple whole genomes; it places a burden on finding a mate; it transmits the most horrible venereal diseases; and it systematically demolishes all the most successful gene combinations.

And yet despite all that, sex is tantalisingly close to universal among all forms of complex life. Virtually all eukaryotic organisms (those built from cells with a nucleus; see Chapter 4) indulge in sex at some point in their lifecycle, and the large majority of plants and animals are obligately sexual, which is to say that we can only reproduce ourselves by sex. This is no quirk. Asexual species, which propagate clonally, are certainly rare, but

some, like dandelions, dance under our noses. The surprising fact is that almost all these clones are relatively recent species, typically arising thousands rather than millions of years ago. They are the smallest twigs on the tree of life, and they are doomed. Many species revert to cloning, but they hardly ever reach a mature age in the lifespan of a species: they die out without issue. Only a handful of ancient clones are known, species that evolved tens of millions of years ago and gave rise to large groups of related species. Those that did so, such as the bdelloid rotifers, have become biological celebrities, chaste exceptions in a world obsessed with sex, passing like monks through a red-light district.

If sex is an occupational folly, an existential absurdity, then not having sex is even worse, for it leads in most cases to extinction, a non-existential absurdity. And so there must be big advantages to sex, advantages that overwhelm the foolhardiness of doing so. The advantages are surprisingly hard to gauge and made the evolution of sex the 'queen' of evolutionary problems through much of the twentieth century. It may be that, without sex, large complex forms of life are simply not possible at all: we would all disintegrate in a matter of generations, doomed to decay like the degenerate Y chromosome. Either way, sex makes the difference between a silent and introspective planet, full of dour self-replicating things (I'm reminded of the Ancient Mariner's 'thousand thousand slimy things'), and the explosion of pleasure and glory all around us. A world without sex is a world without the songs of men and women or birds or frogs, without the flamboyant colours of flowers, without gladiatorial contests, poetry, love or rapture. A world without much interest. Sex surely stands proud as one of the greatest inventions of life; but why on earth, how on earth, did it evolve?

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