



There Are Only Two Sexes and There Can Never Be More

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Introduction

There are only two sexes and there can never be more. This is not a matter of cultural convention, social belief, or political preference. Sex is not defined by one's identity, social role, or even their chromosomes or genitalia. In biological science, sex is defined by the gamete morph an organism produces: females produce large gametes (eggs/ova); males produce small gametes (sperm) (Parker et al., 1972; Togashi & Cox, 2011). This definition applies at the level of evolved phenotype. Individuals who are infertile, prepubescent, or post-reproductive, are still categorized as male or female because they belong to a phenotype that, under typical development, produces a specific gamete morph.

The existence of two sexes is itself defined by anisogamy: the condition in which reproduction involves two distinct gamete morphs—large and small. This condition evolved through natural selection acting on gamete size, favoring divergence into these complementary morphs. Once established, anisogamy marked the origin of female and male as biological sexes.

Here, I examine the evolutionary origins and persistence of the two-sex system (anisogamy). I do not address gender identity or social roles. The focus is on the evolutionary biological forces that generated—and continue to maintain—two, and only two, sexes.

The mathematics and logic underlying anisogamy's evolution have been formalized and developed in evolutionary game-theoretic models for over 50 years, most notably by Parker and colleagues. All converge on the same result: a third sex is evolutionarily impossible. This is a rigorously derived conclusion of extensive modeling of anisogamy, gamete competition, fusion dynamics, and survival trade-offs (e.g., Bulmer & Parker, 2002; Lehtonen, 2021; Lehtonen &

Parker, 2014, 2019; Parker, 1978, 1982; Parker et al., 1972; Togashi & Cox, 2011) supported by empirical evidence across multiple taxa (e.g., da Silva & Drysdale, 2018; Hanschen et al., 2018; Randerson & Hurst, 2001; Togashi et al., 2021).

Although the logic underpinning the two-sex system is well understood within biology, it remains widely misunderstood elsewhere. The distinction between sex and gender is frequently blurred in public discourse, policy, and even academic writing. As a result, empirical claims about sex are often misinterpreted as ideological positions.

This commentary is not an ideological or political statement nor a novel scientific proposal. It is a restatement of the well-supported conclusion of decades of theoretical and empirical work that bears directly on the first question posed by this journal's call for commentary (Zucker, 2025): "How many sexes are there?"

The conclusion is grounded in detailed formal mathematical models (see, for example, Lehtonen, 2021; Togashi & Cox, 2011). However, the goal here is conceptual clarity, not technical exposition. The core logic is accessible, and worth communicating clearly beyond biology, to researchers in psychology, anthropology, sociology, and other fields grappling with questions of sex, identity, and human variation.

Clarifying the evolutionary basis of two sexes is not merely academic. In an era when sex and gender are frequently conflated and politically co-opted, the distinction has urgent consequences for science, medicine, education, law, and public discourse. Recent policy shifts in the USA, including the defunding of LGBTQ+ and sex-related research, highlight the costs of confusion and conflation. Amidst this climate, it is all the more important to communicate clearly what sex is, biologically, and why there can only be only two. This commentary is offered in the hope that a clearer understanding of biological sex can contribute to more grounded and constructive discussions across disciplines and domains.

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What Sex Is Not

Many common misconceptions conflate sex with secondary traits, developmental anomalies, or mating systems that do not involve gamete dimorphism. It is therefore worth beginning by being explicit about what sex is not.

“Hermaphrodites” are not a third sex. They are organisms that produce both large and small gametes (eggs and sperm), each in a functional form (Wake, 2018). Hermaphrodites therefore embody both sexes, not a new one. Functional hermaphroditism can be synchronous or sequential. It occurs naturally in some fishes and frogs, but has never been observed in humans or any other mammal. Extremely rare cases where a human develops both ovarian and testicular tissue do not qualify: these individuals do not produce both gamete morphs, and they also lack two fully integrated reproductive systems. Since sex is defined by the gamete morph an individual produces, no human has ever been both female and male.

Disorders of sexual development (DSDs) are atypical developmental outcomes caused by chromosomal or genetic anomalies. Though some DSDs involve ambiguous or mixed reproductive anatomy, there is no documented case of a human producing both sperm and eggs in a functional capacity. These individuals do not meet the biological definition of hermaphroditism (Wake, 2018) nor do they constitute a third sex. All known DSDs and sex-chromosome anomalies are sex-specific variations of female or male development: they do not create new reproductive categories but reflect developmental atypicality within the two existing sexes.

Mating types in microbes, often incorrectly referred to as “sexes,” are simply compatibility systems that regulate fusion between gametes of the same size (Yadav et al., 2023). Sexes, as defined in biology, are determined by divergence into large and small gametes, without which there are no sexes at all. Because microbes do not produce size-differentiated gametes, they do not possess biological sexes.

These cases do not challenge the biological understanding of the sex-binary once properly understood.

Before Two Sexes: Isogamous Ancestry

To understand how the sex-binary evolved, we must begin with a world where gametes were morphologically identical—where no sexes existed.

Sexual reproduction is an ancient attribute of eukaryotic life, likely present in the last eukaryotic common ancestor that lived approximately 1.5–2 billion years ago in aquatic environments (Parfrey et al., 2011; Speijer et al., 2015). The ancestral sexual population was isogamous: individuals produced morphologically equivalent gametes of the same

size, with no differentiation into females or males (Lehtonen et al., 2016b). This isogamy is the ancestral state from which anisogamy—the evolution of morphologically distinct gamete morphs—arose (Lehtonen et al., 2016b; Togashi & Cox, 2011).

Grounded in this well-supported evolutionary history, seminal models of the isogamy–anisogamy transition rest on the assumption that, in the ancestral isogamous population, individuals released gametes into the surrounding water, with zygote (the first cell of a new offspring) formation occurring through random collision and fusion of gametes (Lehtonen & Parker, 2014; Parker et al., 1972). Although individuals in this ancestral population produced gametes of identical sizes, models assume that, over time, random mutations occasionally introduced subtle, heritable variation in gamete size. Since organisms have fixed resource budgets at any given time, individuals carrying such mutations were subject to a trade-off between gamete size and number: genotypes producing larger gametes yielded fewer overall, whereas those producing smaller gametes yielded more. These alternatives represent different evolutionary strategies.

Because zygotes relied entirely on the resources contained within the gametes that formed them, their initial survival depended on the total amount of provisioning they received. In the models, this provisioning is assumed to scale with the combined size of the two fusing gametes. Larger zygotes (formed from larger gametes) contained more provisions and are therefore assumed to have had higher viability (Parker et al., 1972).

In the ancestral population producing similarly sized gametes, very small zygotes would not survive well. This generated selection favoring larger gametes that increased zygote viability. However, beyond a certain point, the relationship between zygote size and zygote survival followed a pattern of diminishing returns, with each further increase in size yielding progressively smaller fitness gains (Lessells et al., 2009) (Fig. 1). This meant that, although extremely small gametes were clearly disadvantageous, ever-larger gametes also faced diminishing payoffs, setting an upper limit on gamete size.

Once sufficient numbers of large gametes were present in the environment, a mutant strategy producing small gametes could become established. This was possible because large gametes could fuse with either other large gametes or small gametes, yielding zygotes with at least some viable provisioning. In contrast, small–small fusions produced zygotes with negligible viability. Because even partially provisioned zygotes (from large–small fusions) had decent survival, small gamete producers could exploit the presence of large gametes while avoiding the costs of provisioning. Together, these dynamics created strong selection pressure for small gametes to fuse with large ones. By contrast, selection pressure for large gametes to avoid small ones was much weaker, because large–small fusions still produced viable zygotes.

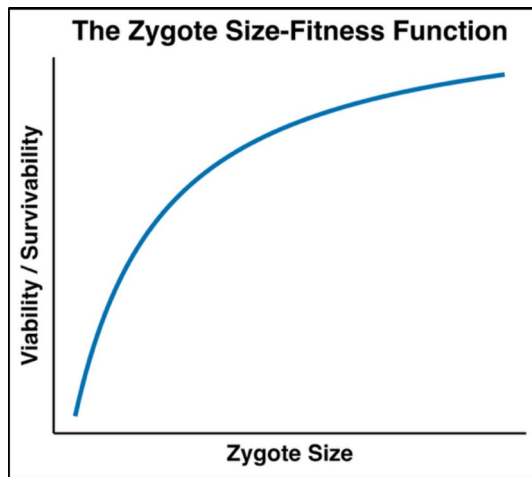


Fig. 1 Illustration of the association between zygote size and zygote viability. Zygote survivability increases with size, but with diminishing returns; beyond a certain point, further investment in zygote size yields progressively smaller fitness gains

This selection asymmetry allowed small gametes to persist, ultimately setting the stage for a stable evolutionary split between large and small gametes.

Gamete Fusion Trade-Offs Led to Two Sexes

Consider the ancestral population previously described. Individuals release gametes of a single size into an aquatic environment, but gamete size varies between individuals. Due to the size-number trade-off, smaller gametes are produced in far greater numbers than larger ones. Gametes fuse at random, so reproductive success depends on the likelihood that a gamete fuses, and on the morph of the gamete it fuses with.

A producer of large gametes has high per-zygote fitness: large gametes contribute heavily to provisioning, making the resulting zygotes highly viable. But this strategy carries two risks. First, large gametes are relatively rare, so fusions with other large gametes are very unlikely. Second, the more common outcome—fusions with small gametes—yield zygotes that are only partially provisioned. Despite this reduction in viability, however, large–small fusions are still functional, and vastly more probable than large–large fusions. The success of the large gamete strategy depends on the presence of abundant small gametes. Without them, large gametes would rarely fuse at all. In the mixed system, however, producing large gametes reliably leads to zygotes with decent survival prospects. Large–small fusions are not optimal, but they are good enough and frequent enough to make the large gamete strategy sustainable.

A producer of small gametes, by contrast, relies on quantity. Small gametes are cheap and produced in great numbers. As a result, they fuse often, but mostly with other small gametes, because this is the most common morph in the environment. These small–small fusions are essentially worthless, yielding negligibly viable zygotes. The small gamete strategy is wasteful, but it persists because of scale. When small gametes are produced in vast quantities, even a tiny fraction that successfully fuse with large gametes can yield enough viable zygotes to make the strategy worthwhile. In effect, small gamete producers rely on sheer numbers to push a few fusions over the viability threshold, making the occasional large–small pairing the entire basis of their reproductive success.

But what about producers of intermediate-sized gametes? One might expect that this “third gamete morph” could do well, but this strategy fails on three fronts. Intermediates are not cheap enough to be produced in competitively high numbers, so they lack the fusion rates of small gametes. Nor do they provision zygotes well enough to compete with the higher viability seen in fusions involving large gametes. Worse still, intermediates are most likely to fuse with small gametes or other intermediates—combinations that yield relatively underprovisioned zygotes with low survival. Fusion with large gametes could offer a partial rescue. But large gametes are rare, and are more likely to fuse with the abundant small gametes than with intermediates. Intermediate–large fusions are thus much rarer than large–small fusions, offering little compensatory benefit. Together, this triple disadvantage severely undermines the success of the intermediate strategy.

Intermediates are thus caught in an evolutionary dead end: too costly to produce in numbers required to outcompete small gametes, too poorly provisioned to match the zygote viability of large gametes, and too unlikely to fuse with large gametes at rates that compensate for these disadvantages. Their reproductive payoffs remain consistently poor and fusion dynamics ensure these failures compound across generations. It is mathematically impossible for intermediates to persist. Therefore, disruptive selection—a form of natural selection that favors individuals at both ends of a trait value distribution while disfavoring individuals with intermediate values (Fig. 2)—eliminates producers of intermediate-sized gametes. This divide underlies the evolution of two distinct and stable gamete morphs (egg and sperm), and thus of two sexes: female and male.

The Maintenance of Two Sexes: No More to Come and No Going Back

Once anisogamy evolves, the two-sex system becomes fixed because it constitutes an evolutionarily stable strategy (ESS)—a concept from evolutionary game theory. An ESS is a strategy that, once widespread in a population, cannot

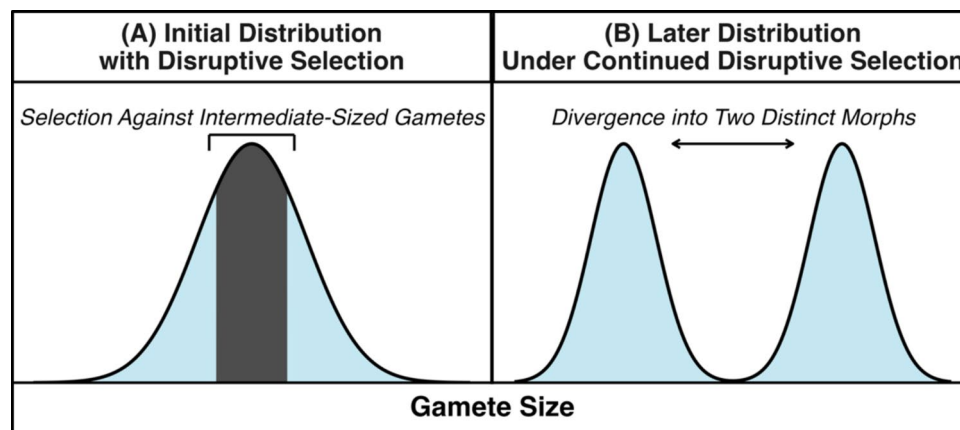


Fig. 2 Evolution of two distinct gamete morphs through disruptive selection on gamete size. Panel **A** shows an ancestral population with some heritable variation in gamete size due to mutations. Disruptive selection eliminates intermediate-sized gametes (dark gray), favoring both very small and very large gametes (light blue). Panel **B** shows

the resulting divergence into two discrete gamete morphs. Over subsequent generations, sperm size becomes tightly constrained around a small-size optimum, and egg size around a large-size optimum, with minimal variation in each morph within a given species (Color figure online)

be invaded or displaced by any alternative (Maynard Smith & Price, 1973). In the case of anisogamy, deviations such as producing slightly smaller eggs or slightly larger sperm fail because they have lower reproductive success relative to established strategies. Smaller eggs reduce zygote viability; larger sperm reduce the number of gametes and thus fusion success. Because no alternative strategy yields higher fitness, the two-sex system resists invasion. Accordingly, evolutionary models consistently show that anisogamy resists invasion across a wide range of ecological and selective conditions (Lehtonen & Kokko, 2011; Parker, 1982; Parker et al., 1972).

Birkhead and Parker (1997) illustrate this resistance with the following example. A cow's egg is approximately 20,000 times larger than a bull's sperm. Even if a mutant bull doubled the size of its sperm, each sperm would contribute only 0.005% more provisioning to a resulting zygote—a negligible benefit. But doubling sperm size would halve the number produced, significantly reducing the bull's chances in sperm competition, where multiple males compete to fertilize the same eggs. As Parker (1982) showed, even a very small probability of sperm competition is enough to make this trade-off selectively unfavorable. This logic holds even in mating systems where fertilization is internal and sperm competition is rare.

Fusion dynamics further reinforce the stability of the two-sex system (Birkhead & Parker, 1997). In isogamous systems, gametes fuse at random. But once gamete dimorphism arises, only fusions between dimorphic gametes reliably produce zygotes that can persist under selection. Small–small fusions fail to support development, and large–large fusions occur too rarely to compete with large–small fusions. As small gametes become more numerous, they saturate the gametic environment and

rapidly fertilize the scarce large gametes, leaving almost no opportunity for large–large fusions to occur. Even though such fusions would yield viable zygotes, they are simply outcompeted in the race to fertilization. The two gamete strategies thus become mutually dependent: large gametes rely on small ones for frequent fertilization, and small gametes depend on large ones to produce viable zygotes.

Together, these dynamics create strong selection for disassortative fusion. Through the evolution of molecular recognition mechanisms and gamete behaviors, small gametes become specialized in targeting large ones, and large gametes evolve to resist fusion with each other. This disassortative fusion increases fertilization efficiency, reduces waste, and consolidates the two-sex system (Birkhead & Parker, 1997; Lehtonen & Parker, 2014). Once gametes are physiologically committed to fusions with their opposite-sized counterpart, the system becomes evolutionarily closed. Any additional gamete morph would have no compatible fusion partner, making it reproductively nonviable.

Reversion to isogamy is not possible either. The evolved asymmetry in size, function, and fusion behavior is stabilized by the same selective pressures that drove its emergence. The result is not merely a constraint but an inescapable outcome of anisogamy. No third gamete, and therefore no third sex, can evolve, and the two that do exist cannot be undone.

After Two Sexes: An Inevitable Cascade of Change

The evolution of gamete dimorphism did not only create two sexes, it also reshaped the trajectory of life on Earth. Once gametes diverged into large and small morphs, they were subject to fundamentally different selection pressures. Large gametes were costly to produce and limited in number, favoring selective fertilization and efficient use. Small gametes were cheap and numerous, favoring high output and maximized contact with fusion partners. These asymmetries gave rise to broader strategies: choosiness and investment among large gamete producers, and competition and mating effort among small gamete producers. Over time, these selection pressures shaped the evolution of mating behaviors, reproductive strategies, and widespread sex-differences in physiology and behavior.

As Lehtonen (2021) wrote, the transition from isogamy to anisogamy is “one of the most consequential in evolutionary history,” with effects that extend far beyond reproduction. Much of the biological diversity observed today, including differences in morphology, behavior, and social structure, ultimately stems from this initial split in gamete strategy (Lehtonen et al., 2016a; Parker, 2014; Trivers, 1972). From this divergence, a vast landscape of biological complexity and, in Darwin’s (1859) words, “endless forms most beautiful,” have followed.

Conclusion

The two-sex system is not arbitrary, fragile, or open to expansion. It is an evolutionarily stable outcome of natural selection acting on gamete size, fusion patterns, and reproductive efficiency. Evolutionary game-theoretic models consistently show that, once anisogamy evolves, no alternative gamete strategy can emerge or persist. This conclusion does not depend on narrow or unrealistic assumptions. The foundational model of Parker et al. (1972) has proven remarkably robust to variation in mating systems, fusion rules, and survival functions (Lehtonen, 2021; Lehtonen & Parker, 2019; Togashi & Cox, 2011), and empirical comparative studies increasingly support its predictions (e.g., da Silva & Drysdale, 2018; Hanschen et al., 2018; Randerson & Hurst, 2001; Togashi et al., 2021). Anisogamy has evolved independently in multiple lineages (Kirk, 2006; Lehtonen & Parker, 2014), yet, in every case, it has converged on a binary sex system. This recurring outcome provides additional compelling empirical validation of the evolutionary game-theoretic conclusion that only two gamete strategies—and therefore two sexes—can stably coexist.

As an anisogamous species, humans are governed by the same evolutionary forces that shape sex across the rest of the living world. The existence of only two sexes is not a cultural construct, but a biologically constrained inevitability of anisogamous reproduction. As such, there are only two sexes, and there can never be more.

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Conflict of interest The author has no conflict of interest to declare.

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