the curve of ejection fraction versus velocity and so makes a big difference: Chen and Ahrens found that "almost all atmosphere" is lost at 8 km s^{-1}, but Genda and Abe find that less than 30% of the atmosphere is lost at 6 km s^{-1}.

Why is this result important? Although no one has yet found a convincing and general explanation for how the terrestrial planets acquired their atmospheres, the present abundances, particularly of Earth's heavy noble gases (neon, argon, xenon and krypton), seem hard to reconcile with a nearly complete loss of atmosphere after the Earth was assembled[6]. The abundances of these gases and their isotopes in the present atmospheres of Earth, Mars and Venus (insofar as we know them) differ substantially from their abundances either in the Sun's atmosphere or in meteorites. These differences have led atmospheric scientists to postulate a wide variety of mechanisms by which such gases may be acquired, partially lost and isotopically fractionated[7]. But the mechanical ejection of gases that was previously imagined for the giant impact is no help at all with this problem: in the impact scenario, the gases are ejected wholesale, without separation or fractionation.

If Earth's primordial atmosphere had been completely lost in the impact, then a new inventory of gases would have had to have been acquired later. It is unclear where such a secondary atmosphere would come from. It seems nearly certain that it would have a very different composition from that of either Earth's original atmosphere or the original atmospheres of the other planets. Total atmospheric loss thus adds a major wild card to the already highly uncertain mix of constraints on atmospheric evolution.

By showing that total atmospheric loss in a giant impact is unlikely, Genda and Abe[1] have permitted us to think what once seemed unthinkable: in spite of the violence of the Moon-forming giant impact, our primordial atmosphere may have survived all of the vicissitudes of Earth's turbulent birth. Going even further, the authors argue that much of the Mars-size impactor's atmosphere would also have survived, merging with Earth's own gas envelope.

Much remains to be done before we can understand how Earth's atmosphere evolved to its present state. Genda and Abe's computation could be augmented by a better equation of state for atmospheric gases at the high temperatures reached in the shock propagating upwards from the surface. A better understanding of how the solid Earth would respond to the shock of a giant impact would inspire more confidence in the correctness of the surface boundary conditions. And we are still a long way from understanding the processes that affect the composition of the atmosphere. Nevertheless, Genda and Abe's paper represents a major step forward in sorting out the history of the air we breathe. ■

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Evolutionary biology

Polygamy and parenting

Mark Pagel

In most animal groups, females put more effort into rearing children, and males compete for female attention. But what about seahorses and pipefish, in which males invest the most in offspring?

Modern men who think that they can attract women by being good with children may wish to read a study by Wilson and colleagues[1] that has just appeared in the journal *Evolution*. In seahorses and pipefish at least, females compete for males only when they — the females — have the time to, and not, it seems, according to the effort the males put into looking after offspring.

Evolutionary theory suggests that the relative amount of effort, or 'investment', that males and females put into rearing their offspring determines which sex competes for the other[2]. In most animal species, females contribute substantially more to the offspring than males, and it is the males that compete for mates. This leads to a form of biological evolution called sexual selection, in which traits are favoured that make males good at competing with other males (such as big antlers or sharp teeth) or more attractive to discerning females (such as colourful tails or complex songs and displays).

Pipefish and seahorses of the family Syngnathidae (Fig. 1) have some rather different habits, however. Many species appear to be monogamous (a rarity in nature), and all male syngnathids have some form of specialized egg-brooding structure located on the abdomen or tail, into which females deposit their eggs during mating. The males' brood pouches vary in complexity among species, from simple sticky patches to complex uterus-like structures with placenta-like features for nourishing the eggs: a mere transvestite seems unadventurous by comparison. By adopting these normally female traits and habits, males can be sure of their paternity of the fertilized eggs. But they achieve this by investing considerably more parental effort than females — and, it is assumed[3], increasingly so as the brood pouch gets more complex.

R. KUITER

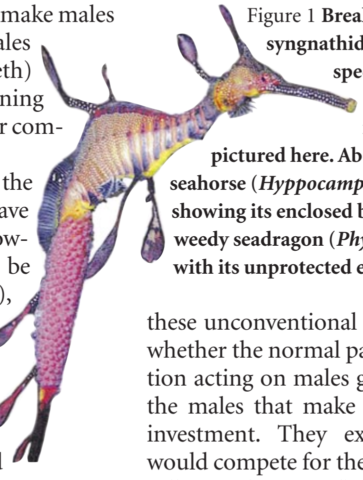

Figure 1 **Breaking the mould: syngnathid species. Males of these species put more effort than females into rearing offspring, as pictured here. Above, the pot-bellied seahorse (*Hyppocampus abdominalis*), showing its enclosed brood pouch. Left, the weedy seadragon (*Phyllopteryx taeniolatus*), with its unprotected egg-compartments.**

Wilson and colleagues[1] took advantage of these unconventional animals to investigate whether the normal patterns of sexual selection acting on males get reversed when it is the males that make most of the parental investment. They expected that females would compete for the males (a pattern they call sex-role reversal) in the species with the most complex brood pouches. But they don't. Instead, sex-role reversal in syngnathids tends to arise in those species with polygamous mating systems — those in which both males and females can have multiple mating partners. More tellingly, it is often the females of these species, and not the males, that attempt to have more than one partner, a mating system known as polyandry. So it appears that, in seahorses, natural selection for sexually exuberant female mating habits drives sexual selection for female–female competition, independently of males' paternal investment. Selection for female polygamy also favours other traits that are normally associated with sexual selection in males of different animal groups: some female seahorses are vividly coloured.

Contrary to expectations, then, the assiduousness of syngnathid males does not predict sex-role reversal. But why? The answer is probably that about half of the species with complex brood pouches are monogamous, and that complicates any attempt at prediction, because females of monogamous species are generally just too busy to compete for other matings. Far from being the expression of undying mutual commitment and affection heralded by church and state, monogamy, if it even exists[4], is a sort of evolutionary last resort: it arises only when both partners' full efforts are required to raise offspring successfully. Under these circumstances, both partners will be selected to evolve whatever adaptations will improve the offspring's survival. This may explain why the males of some seahorse species have evolved such elaborate brood pouches. It could also explain why female syngnathids are rarely sex-role-reversed in the monogamous species, even in those with the most complex brood pouches — these females are probably too encumbered helping to rear offspring to fight among themselves for males.

Is the picture that emerges from syngnathids — that sexual selection is determined not by relative amounts of parental effort, but rather by mating habits — likely to be general? The unusual propensity of seahorses and pipefish for monogamy may make their case exceptional. But it shows us that for relative degrees of parental investment to influence sexual selection, the sex that invests the least must have some flexibility in its mating habits. In support of this, some evidence from human groups suggests that as the strictures of monogamy are relaxed, men will take advantage of women who invest in children at high levels, by proportionately reducing their own contribution[5]. This, then, may become the incipient state of sexual selection for male–male competition (and likewise perhaps for female–female competition in the polygamous seahorses).

Finally, what are we to make of seahorse and pipefish males, especially those in the sex-role-reversed species: in what sense are they 'male'? Evolutionary biology prosaically defines maleness and femaleness by the size of one's gametes. Females make the large, well-provisioned and energetically costly gametes called eggs, and males make the tiny, unprovisioned sperm. Given that male syngnathids have found themselves in most other respects in the role of females, and vice versa, what prevents them from being not just sex-role-reversed but instead fully sex-reversed, with 'males' evolving egg-like gametes and 'females' evolving sperm-like sex cells? Were females to make smaller eggs, they could produce more gametes in total to assist them in their efforts to mate with many males. Males in turn might be selected to increase the size of their sperm to ensure that the fertilized eggs were still well provisioned. The syngnathid sexual circle would then be complete, as girls became boys and boys became girls.

Has this ever happened? Whatever the answer, the inverted world of seahorses shows that simple gamete-based definitions of 'male' and 'female' can be misleading if taken to indicate a typical sex-role. Indeed, the genetic sex-determining architecture is intriguingly variable in animals[6]. Maybe seahorses, with their occasional sex-role reversal and would-be-female males, show us one reason why. ■

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Condensed-matter physics

Really cool molecules

Paul S. Julienne

Ultracold molecules have been made by applying a changing magnetic field to a quantum gas of 'fermionic' atoms. This raises the prospect of creating novel superfluids and molecular Bose–Einstein condensates.

At the quantum level, any particle can also be considered to be a wave, its momentum corresponding to a wavelength. In ultracold atomic gases, at temperatures much lower than a millionth of a degree above absolute zero, the wavelength of the atoms becomes larger than the mean distance between them, giving rise to some remarkable quantum mechanical properties that are at the forefront of contemporary physics research[1]. The properties of such cold quantum gases depend on whether the atoms are bosons or fermions. Bosonic atoms have integer values of the quantum number known as spin, and can form a Bose–Einstein condensate in which the trapped atoms occupy the single ground state of the system. Fermionic atoms, on the other hand, have half-integer spin values and each identical fermion must occupy a different quantum level. But if two fermions paired up to make a bosonic molecule, an exotic kind of superfluidity — flow without resistance — could be the result[2–4]. On page 47 of this issue, Regal *et al.*[5] describe an important step in this direction.

Their experiment began with a quantum gas of fermionic potassium atoms, a mixture of equal numbers of atoms with spin quantum numbers $-9/2$ and $-5/2$. The different spin states are necessary for the fermions to undergo collisions with each other with low collision energy. To create molecules from these atoms, Regal *et al.* took advantage of a special molecular state known as a Feshbach resonance, which may be thought of as a weakly bound pair of atoms. The energy of such a state can be tuned, using a magnetic field, to lie close to that of two separated atoms. By ramping the magnetic field so that the energy of the resonance state moved from being above to being below the energy of two separated atoms, colliding pairs of atoms were induced to form a lower-energy molecule that is bound with respect to the separated atoms (Fig. 1). Regal *et al.* were able to convert up to half of the atoms to diatomic molecules.

Producing a molecular gas in this ultracold regime has proved to be a challenge. There have been several proposals to make molecules, and possibly a molecular Bose–Einstein condensate, by combining bosonic atoms in a Bose–Einstein condensate using a molecular resonance state[6–10]. Experiments have come tantalizingly close. Wynar *et al.*[11] were the first to infer the formation of molecules nearly at rest, by observing the loss of condensed rubidium-87 atoms as they were photoassociated into molecules using a two-colour pulse of light. Donley *et al.*[12] have also given evidence for coherent atom–molecule interconversion[13,14] in experiments with a rubidium-85 condensate that involved manipulating the energy of a Feshbach-resonance state using a sequence of magnetic-field pulses. However, neither experiment could detect any molecules directly: the imaging methods used for atoms do not work for molecules, because they have very different light-scattering properties.

Part of the beauty of the new work by Regal *et al.*[5] is that they have conclusively demonstrated the presence of cold molecules. They exposed the molecules to a radio-frequency electromagnetic field of the right frequency to make them fall apart into single atoms with