because they contain chondrules — silicate spherules solidified from melt droplets formed by a mysterious heating event early in the history of the Solar System. The discovery of large amounts of volatile noble gases in these chondrules is unexpected because it is widely believed either that the gases never existed in the material that formed the chondrules or, if they were present, that they were driven out by the heating event. Although noble gases have not yet been found in chondrules in any other meteorites, this discovery may lead to new insight into the processes that formed our Solar System.

This is not the first time that rare gases have been used to probe the history of the Solar System. The addition of even a tiny amount of a noble gas to a solid causes a large fractional increase, making it easier to detect. So the noble gases provide an extremely sensitive record of processes that may be too subtle to detect by other means. For example, the extinct radioactive nuclide I-129, which existed for only a short time in the early Solar System, was found through the detection of its daughter product, Xe-129. Another example is that, when a rock is irradiated by cosmic rays, tiny amounts of magnesium and silicon are converted into Ne-21. So the accumulation of Ne-21 in a meteorite is a reliable measure of the time it took to travel from its parent asteroid to the impact with Earth. The detection of rare gases in chondrules is perhaps the most unexpected of these discoveries, and may eventually lead to a better understanding of the formation and evolution of chondrites.

The chondrules studied by Okazaki and co-workers[1] came from meteorite Yamato-791790 (hereafter referred to as Y-79), an enstatite chondrite found in Antarctica. The authors used pulses from a fine laser beam to heat small amounts of material — typically 0.7 micrograms — from different areas of Y-79. Rare gases released from each area were analysed in a mass spectrometer. Test areas inside the chondrules released about 80, 0.4 and 0.08 million atoms of Ar-36, Kr-84 and Xe-132, respectively. In contrast, the amount of rare gases released from the matrix between the chondrules was ten times lower and approaches the instrumental background levels. Together these data indicate that rare gases in Y-79 reside primarily in chondrules.

How do noble gases get into meteorites? One possible explanation comes from studies of samples from the Moon. Without the protection of either a magnetic field or an atmosphere, the surface of the Moon is constantly being bombarded by the solar wind. Travelling at a speed of around 500 km s^{-1}, this outflow of ionized gas from the Sun directly impinges upon the lunar surface, and the fast-moving particles penetrate into the solid before stopping within the first micrometre or so. Some of these ionized particles are noble gases. When lunar soil samples are heated in a laboratory vacuum, the implanted solar wind particles can diffuse back out and be measured. This is how the 'solar' pattern of rare gases was determined[2] (Fig. 1, overleaf). This pattern favours the lighter rare gases, so the abundances drop exponentially from helium to xenon.

Rare gases found in meteorites follow one of two patterns. One of them is reminiscent of that found in the Earth's atmosphere (Fig. 1), so it is termed 'planetary', even though its origin is still unknown. The other type closely follows the solar pattern determined from lunar soil samples, and so presumably came from a similar process of solar wind implantation, except that the exposure took place on the surface of asteroids instead of the Moon. Until now, most of the rare gas in meteorites was found in fine-grained fragments attributed to the ancient surface layer of asteroids.

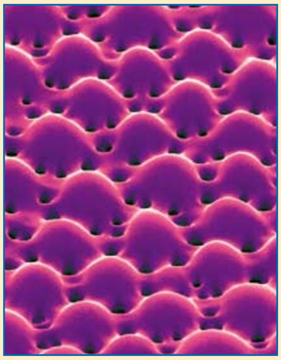
In the case of Y-79, the proportions of rare gases released from the chondrules were roughly 2,000:5:1 for Ar-36, Kr-84 and Xe-132. The pattern of high Ar:Xe but moderate Kr:Xe seems to indicate that the rare gases in Y-79 follow the solar pattern. This makes solar-wind implantation an attractive hypothesis. But no trace of helium or neon was detected in Y-79 and the argon seems to have been depleted relative to what might be expected for the solar pattern based on krypton and xenon alone (Fig. 1). There is, however, an apparent correlation between the missing gases and their masses. The lightest gases, helium and neon, are completely depleted, whereas argon is only partially

Optics

Armed for light sensing

Light is a primary driving force in nature, and most organisms have some type of light-detection system, often one that uses lenses. But it comes as a surprise to learn from Joanna Aizenberg and colleagues, writing elsewhere in this issue (*Nature* **412,** 819–822; 2001), that a species of brittlestar, *Ophiocoma wendtii*, possesses a remarkable microlens array. Brittlestars belong to the group of marine invertebrates known as echinoderms, and Aizenberg *et al.* find that the calcium carbonate (calcite) that makes up the external skeleton of *O. wendtii* also forms light-sensing arrays.

The arrays are found in the skeletal plates that protect the upper-arm joints on each of the brittlestar's five arms. In some light-insensitive species, these plates constitute a relatively open, three-dimensional mesh of single-crystal calcite, with mesh pore sizes of around one-hundredth of a millimetre. But in *O. wendtii* the outer surface of this mesh has a characteristic array of larger, spherical protuberances, each about one-twentieth of a millimetre in diameter and linked to six neighbours (see the figure). When seen in cross-section, each protuberance has the appearance of a double lens: the radius of curvature of the upper face is about 20 to 30 μm, that of the lower face rather less. This combination gives a focal length of about 10 μm, with a focal-spot size of less than 3 μm. There are bundles of nerve fibres of about that size at each focal spot, and the authors suggest that these bundles are responsible for the documented sensitivity of *O. wendtii* to light stimuli.


J. AIZENBERG

The construction and operation of microlenses have strict requirements. First, there has to be exquisite control of calcite growth to form the lens structures. Second, calcite is optically anisotropic, with different refractive indices for light polarized in different directions. So, to avoid birefringence effects, it has to grow as single crystals with the optical axis parallel to the axis of the double lens. Third, each microlens should ideally have minimal optical aberration, and that seems to be the case. The authors have checked this last point both in experiments using an extracted array of lenses as the focusing elements and by modelling the optical response of such structures.

Human ingenuity came up with microlens arrays only a few years ago, and they are used in directional displays and in micro-optics, for example as signal-routing connectors for signal processing. Once again we find that nature foreshadowed our technical developments. The same applies to photonic solids, structures that can selectively reflect light in all directions. Photonic materials have stimulated much research over the past ten years because of their potential in light manipulation, yet they are to be found in opals and in the wings of butterflies. But then, nature has been in the business of developing functioning optical structures for a very long time.

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