

Female grouse spend an average of 2–3 mornings (and maybe evenings as well) at the lek observing males⁷, time that could instead be spent feeding or starting to incubate eggs.

If copying serves to reduce the costs of mate choice, we should expect that the behaviour would be most obvious in those females less able to bear them. On these grounds, first-year females are good candidates for copying — younger hens are less experienced and tend to arrive later in the season. But there is no measurable increase in copying through the season on sage grouse leks (R. Gibson *et al.*).

A final twist to the story is the reverse behaviour observed in peacocks (M. Pet-

rie, Open University). Dominant females stayed on the lek after copulating and courted their mate again whenever another female approached. In all cases, 'post-coital' courtship stopped the secondary female's advance, forcing her to mate with less attractive males that had previously been avoided. Prevention of copying was observed only for the most attractive males. This looks like spiteful behaviour⁸; dominant females monopolize the best males to reduce the quality of other females' choice of mate. □

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CHEMISTRY

Photochromic memory devices

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MATERIALS which undergo a reversible change in their optical transmission characteristics when irradiated (the photochromics) offer potentially exciting applications as optical data-storage media; they may be switched at one wavelength and interrogated at another. But, as yet, the majority have the disadvantage of thermally reverting to the unswitched form. On page 658 of this issue¹, Liu, Hashimoto and Fujishima disclose a stable recording medium based upon the photoelectrochemical reduction of an azobenzene derivative. The photochromic properties of the azobenzenes are well established^{2,3}; *trans*-to-*cis* isomerization occurs when they are irradiated with an ultraviolet source with reversal occurring either thermally or at visible wavelengths. Liu *et al.*¹ now show that the less stable *cis* form (but not the *trans* form) may be electrochemically reduced to hydrazobenzene which is stable in an inert atmosphere (scheme 1), revealing the potential of the azobenzenes for use in optical memory devices.

There are numerous other classes of photochromic compounds, but the molecular changes that occur during irradiation divide the majority into five categories; photo-induced *trans*-to-*cis* isomerization (as with the azobenzenes^{2,3} and thioindigos⁴); homolytic cleavage (for example, hexaphenylbisimidazole⁵); hydrogen transfer (such as in salicylidene anils⁶); valence tautomerism (for example, the fulgides⁴ and spiropyrans⁷); and charge transfer (such as the viologen salts⁸, Cu⁺TCNQ⁻ (ref. 9) and a class of zwitterionic materials of general formula D⁺-CH=C(CN)-C₆H₄-C(CN)⁻, where D⁺ is a heterocyclic cation¹⁰). In this final category, a requirement for optical bistability is that changes in the electronic distribution must be accompanied by modifications to either the molecular structure or the film structure.

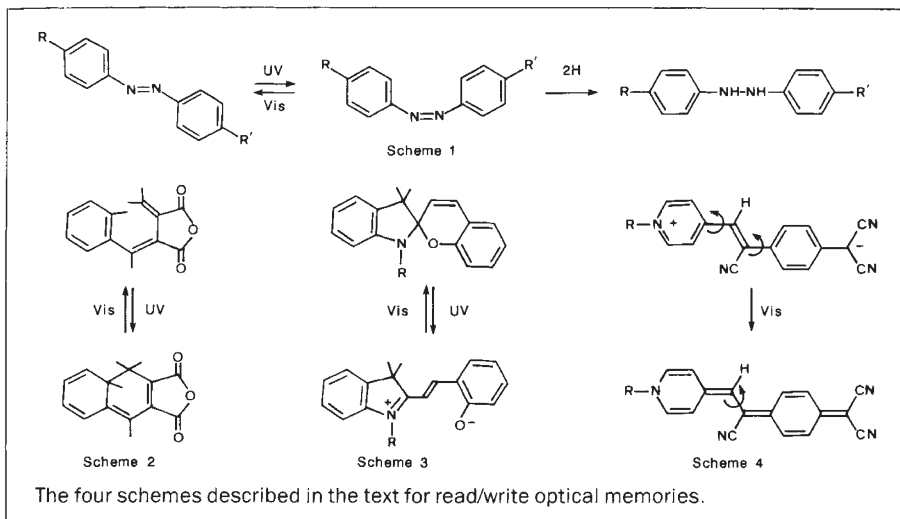
Photochromic materials have been studied for many years but so far their properties have not been exploited. Nonetheless, in the short term, the fulgides (scheme 2) and spiropyrans (scheme 3)

should find applications in security printing; they switch from being colourless to being coloured when irradiated with an ultraviolet source, the process being reversible at visible wavelengths, and some are fatigue resistant.

The spiropyrans⁷ also offer potentially exciting applications as components of a multifrequency memory device. Such devices require layers of different photochromic materials with non-overlapping absorption bands; by addressing each at a material-specific wavelength the layers may be switched independently of each other and thus provide the basis for three-dimensional data storage. But most photochromic materials have broad spectra when in the solid state whereas storing several bits per pixel requires materials with sharp absorption bands. Some π -bridged donor-acceptor systems satisfy this criterion and show promise in this area; Langmuir-Blodgett films of *Z*- β -(1-hexadecyl-4-pyridinium)- α -cyano-4-styryldicyanomethanide (scheme 4) and its quinolinium congener have sharp photochromic absorption maxima at 495 and 565 nm with half widths at half height of 22 and 27 nm respectively¹⁰. These bleach when irradiated at wavelengths which overlap the bands, the process being reversible in solution but irreversible in the films. Thus, they have a potential use as components of a multifrequency write-once/read-many (WORM) memory.

Although azobenzene is unsuitable as a multifrequency switching component, its absorption bands being too broad, Liu *et al.*¹ now demonstrate that it has an advantage over many other systems in so far as the read state (the hydrazobenzene) is both stable and erasable; it may be electrochemically oxidized to *trans*-azobenzene (the write state). They also show that the state of the film remains reversible over several hundred write/read cycles. Thus, this preliminary work is an important step forward in the development of an erasable photochromic memory and it is anticipated that such a device would have a storage density of 10⁸ bits per square centimetre. □

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