have been the right amount of absorption if the intergalactic gas were hotter for a period of time corresponding to a range in red-shift of less than 0.5, roughly between the times corresponding to red-shifts of 2.0 and 2.4. The higher gas density present at this earlier stage in the expansion of the universe suggests that excitation from the cosmic rays emitted by young radio galaxies could heat the gas, causing it to be more highly ionized than at earlier epochs, and it seems likely that, once heated, the gas would remain ionized indefinitely. Beyond some critical red-shift the unionized hydrogen atoms would then absorb nearly all the radiation falling on them, but within this distance the highly ionized gas would be almost transparent, causing exactly the distribution of visible quasars seen now, if the critical red-shift lies close to 2.0. For the spectra of quasars just beyond this distance, broad absorption bands corresponding to partially ionized hydrogen should be seen. Any such observation would be of immeasurable importance to cosmology, confirming that the large red-shifts of quasars do correspond to large distances from the Earth, implying the existence of the so far largely hypothetical intergalactic gas, and providing the strongest evidence yet in favour of an evolving universe model. Rees's work will certainly stimulate observational astronomers to intense study of the spectra of the few known quasars with red-shifts above 2.0.

QUASARS

Red-shifts are Recessive

from a Correspondent

FOLLOWING closely on the theoretical prediction of D. Lynden-Bell, of the Royal Greenwich Observatory, that there may be a direct physical link between quasars and clusters of galaxies (*Nature*, **223**, 690; 1969) comes news from America that five relatively nearby quasars seem to lie within the physical boundaries of five recognized clusters of galaxies. J. N. Bahcall, of the California Institute of Technology, and J. E. Gunn, of Princeton University, recently began a search for clusters of galaxies associated with nearby quasars, and immediately found five such coincidences. In a paper with M. Schmidt, also of Caltech, Bahcall and Gunn give the red-shifts for the five quasars, each falling within the limits of the associated cluster of galaxies, which they have determined from new spectra of these galaxies (*Astrophys. J. Lett.*, **157**, L77; 1969). Although still in a preliminary stage, this investigation has clearly already proved its worth, and for one of the cluster/quasar systems Bahcall and Gunn have found no less than four galaxies with red-shifts within five per cent of the red-shift of the associated quasar (QSO B264). This agreement is so striking that they propose that this cluster should really be considered as two overlapping clusters, one composed only of these four galaxies, with an average red-shift of 0.0949 (B264 has a red-shift of 0.0953), and the other with an average red-shift of 0.165, believed not to be associated with this quasar.

Quite apart from their significance for rather speculative theories, like Lynden-Bell's, these observations seem to settle once and for all the argument about whether or not the red-shifts of quasars are cosmological in origin, resulting solely from their natural motion in an expanding universe. Nobody questions that the

red-shifts of galaxies arise in this way, so the definite physical association of B264 with four galaxies essentially of the same red-shift means that one quasar at least has a purely cosmological red-shift. It would be a very brave man who complicated the quasar puzzle further by suggesting that B264 might be radically different from other quasars, but further evidence will, of course, be most welcome, and should become available as the work of Bahcall and Gunn continues. At least cosmologists will be able to attempt to interpret quasar observations with confidence that in some cases they are indeed the most remote objects yet observed, and therefore the most revealing about the overall nature and evolution of the universe.

SOLID STATE PHYSICS

Prisms and Plants

THE minimum deviation method, popular in physics teaching laboratories for measuring the refractive index, n , of glass prisms, has been applied in a novel way by A. C. Sinnock and B. L. Smith at the University of Sussex. They have used it to determine values of n for prisms of liquid and solid inert gases at various low temperatures (*Phys. Rev.*, **181**, 1297; 1969).

The work was stimulated by a number of theoretical suggestions that the dielectric properties of the solid inert gases could be explained in terms of excitons (for example, T. H. Keil, *J. Chem. Phys.*, **46**, 4404; 1967). Exciton levels occur in the forbidden energy gap between valence and conduction bands in insulators and semiconductors, and it is found that the position of the lowest exciton level relative to the bottom of the conduction band is a strong function of refractive index. Excitons, which can be thought of as bound states of hole-electron pairs, are responsible for the transport of energy through a solid in much the same way as phonons—they are excited, and subsequently give up their energy to the lattice, thus interacting with it. Excitons have also been suggested as the means of movement of energy along chains of organic molecules, and, in particular, they may play an important part in the process of photosynthesis.

Sinnock and Smith used solid and liquid prisms made by condensation of argon, krypton or xenon in a hollow stainless steel prism with sapphire windows. The samples were prepared by slowly admitting the gas into the steel prism while maintaining the base of the prism block at a predetermined temperature—usually near the triple point for greatest freedom from visual defects in the solids. The whole prism was kept in a cryostat so that the temperature could be varied within a wide range, from about 20 to 180 K. The cryostat and sample were stationary throughout the experiment, and the spectrometer, which was of conventional design, was mounted on a coaxial turntable, thus allowing the relative movement of collimator, prism and telescope necessary for minimum deviation measurements. The prism was viewed through windows in the vacuum jacket of the cryostat.

The refractive indices and the numerical quantities which can be deduced from them are in moderate agreement with the predictions of the exciton models, but, so far, the behaviour of solid krypton seems anomalous. Refinements of the models may explain the discrepancies.