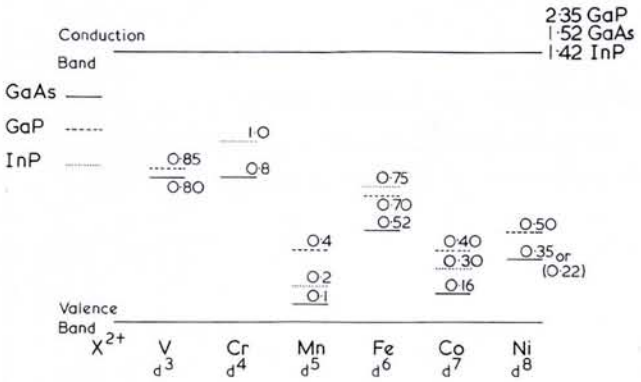


*Fig. 1 — Experimental results on the energies of the single acceptor state of the indicated cation substitutional transition metal ions in three III-V compound semiconductors. Relative to the conduction band minima, these levels indicate the threshold electronic energies $E_e$ required for the reaction $X^{2+} + E_e - X^{3+} + e_{CB}$. The energy $E_e$ may be estimated from thermal or optical excitation processes. The number of 3d electrons in the $X^{2+}$ charge states of the different transition metals is indicated at the bottom. Some individual results are still tentative; for example the level for $V^{2+}$ in GaAs may be only ~ 0.23 eV below the conduction band, not approximately mid-gap as drawn. The large step between $Mn^{2+}$ and $Fe^{2+}$ reflects the stability due to spin stabilisation in the half filled $3d^5$ shell for $Mn^{2+}$ and is an important experimental effect. (Courtesy M S Skolnick)*

the experimental ground state energies for substitutional transition metals in III-V semiconductors, including those shown in Fig. 1. There is some current debate over the absolute accuracy of these calculations and the derived conclusion that the excited $t_2$ states usually described by the crystal field splitting are almost entirely host-like, in contrast to the ground states which are of predominantly d character. However, the major chemical trends certainly seem to be well represented by this theory.

A transition between an open and closed shell behaviour may be observed across a series of semiconductors such as the Zn chalcogens as a function of the differential electron affinity between the Cu impurity and host semiconductor. Green's function and cluster calculations both suggest that even transition metal impurities like Co and particularly Ni exhibit gap states in Si and GaAs which are essentially dangling bond-like, with d-like states of similar symmetry deep within the valence band. However, this conclusion may be controversial. The electronic properties of some similar systems appear to exhibit strong d-character, for example from the form of phonon coupling which appears characteristic of intra-d state transitions. It has been suggested recently that the s-d interaction between host and transition metal may have been substantially over-emphasised, perhaps through neglect of stabilisation against covalent mixing by the strong interactions between d electrons. Neglect of many electron effects is a generally recognised weakness of the current status of deep level theory. Much more work needs to be done on the magnitudes of such effects, but this remains a daunting task.

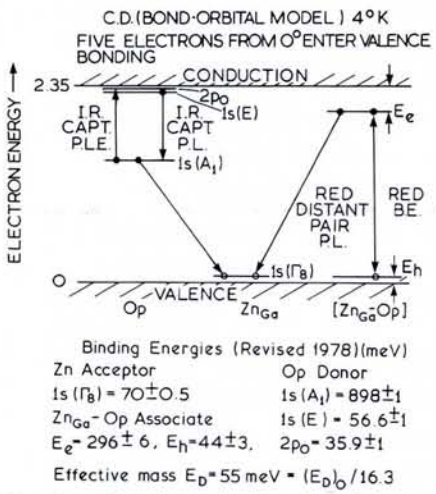


*Fig. 2 — Experimental properties of the on-electron state of the deep $O_p$ donor and the $Zn_{Ga}$ - $O_p$ "molecular" isoelectronic trap in GaP. A relatively unusual feature for deep levels in semiconductors is the cross-check provided from intercomparison of energies from the several different types of optical spectra indicated.* PL *represents photoluminescence,* PLE-PL *excitation,* BE-*bound exciton,* IR *capt-infra red radiative (electron) capture.*

**Summary**

The amount of accurate experimental data on many deep level systems has grown rapidly in the past decade. We are still far from a thorough theoretical account of the complete set of properties for any one system, however. Current indications are that each system may require particular, special treatments. Excited states are hard to calculate on the self consistent basis used for ground states. However, useful generic trends have emerged within series of closely related defects or for a given defect in different binary hosts, or as a function of ternary alloy composition. An important joint outcome of the theoretical and experimental work is the recent recognition of the importance of antisite defects in the electronic properties of semiconductors.

**BIBLIOGRAPHY**

For a recent general review of deep levels, see Jaros M., *Deep Levels in Semiconductors* (Adam Hilger, Bristol) 1982.

## Liquids Section

With the approval of the Executive Committee it has been decided to set up a Liquids Section of the **Condensed Matter Division**.

Individual Members of EPS interested in joining this Section should inform the Secretariat as soon as possible.

## ACAPPI

Copies of the new EPS booklet of ACAPPI, *Improving Interaction Between Universities and Industries*, are available, free of charge, from the Secretariat. A review will be published in the next issue of *Europhysics News*.



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