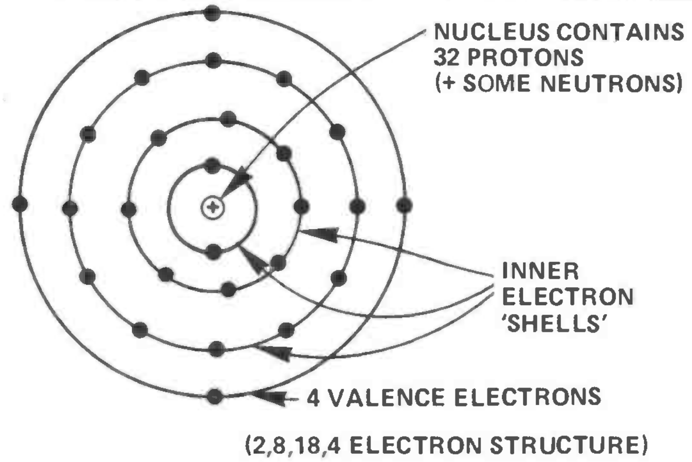

Fig. 2 The atomic structure of germanium, again highly diagrammatic.

couragement (say from an external electric field) one of the neighbouring atoms can give up an electron and become the one with an electron missing. This is possible because one atom will have gained exactly the same amount of energy as the other has lost, so there is no net loss or gain to the crystal. If the electric field persists, further swaps will occur, each of these moving an electron further in the positive field direction.

Rather than thinking of each electron involved in this swapping process as moving a little closer to the positive field, it is easier to think of one single hole moving towards the negative field. Nature is very helpful in this respect because the hole behaves almost exactly as if it were a positive electron.

However, this positive electron always runs the risk of meeting a free real negative electron travelling in the opposite direction. When this occurs, the two are attracted together with the result that the electron 'falls' into the hole; this is called **recombination**.

In semiconducting materials, electrons and holes are called current carriers or, more usually, just **carriers**. Pure semiconductors always have equal numbers of holes and free electrons; however, as will be shown shortly, it is possible to contrive situations where one or the other is very much in the majority.

Doping

Semiconductor devices use doped silicon and germanium. Doping adds impurity atoms to the intrinsic material in such a way that they fit into the original crystalline pattern, but in so doing they increase either the number of free electrons or the number of holes – but not both! This reduces the resistivity of the material and increases its ability to conduct electricity.

Doping is carried out either with **acceptor** impurities – which have trivalent atoms (atoms with 3 valence electrons) or **donor** impurities which are pentavalent (atoms with 5 valence electrons). Trivalent impurities include aluminium, gallium,, indium and boron; pentavalent impurities include antimony, arsenic and phosphorus.

P-type Semiconductor Material

If a trivalent impurity is 'mixed' in with the basic germanium or silicon, the crystal structure begins to look like that shown in **Fig. 4(a)**. Note, however, that the resulting material is still electrically neutral since the number of positive protons exactly balances the number of negative electrons.

Where atoms of the host (or intrinsic) material lie next to atoms of the impurity, there are intrinsic atoms whose valence electrons are not pair-bonded. Since the natural state is for the valence electrons to link in electron-pairs the 'lonely' electron

Fig. 3 A representation of the crystaline structure of a pure semiconductor material. Note that the valence electrons are held in place by both the electrostatic attraction between them and the protons in the atoms' nuclei, and the pair bonding with the other electron in the bond (this is a quantum-mechanical phenomenon).