the intense L_1–Δ_1 nonequivalent intervalley scattering can lead to a large reduction in the effective electron mobility near band cross-over.

The observed resistivity and Hall data are both fitted following the approach of Nathan *et al.* (1961). In section 6, the parameter values obtained are compared with those derived from our resistivity data alone by Fawcett and Paige (1971) in the course of a Monte Carlo study of the high field properties of germanium.

2. Conduction band structure of Ge at high pressures

The measured effective masses in the longitudinal and transverse directions for the L_1 minima are approximately $m^*_{lL} = 1{\cdot}58\, m_e$ and $m_{tL} = 0{\cdot}08\, m_e$ respectively, giving a density of states effective mass $m^*_{DL} = (m^*_{lL} m^{*2}_{tL})^{1/3} \nu_L^{2/3} = 0{\cdot}54\, m_e$, where ν_L represents the number of minima. The pressure coefficient of the L_1 minima is $+5 \times 10^{-6}$ eV bar^{-1}, away from the central Γ_{25} valence band maximum (Paul 1961). Early measurements by Bridgman (1952) showed that the resistance passed through a maximum near 30 kbar, and then decreased in a manner similar to that observed in n type Si at lower pressures. Although these measurements were probably carried out under significantly nonhydrostatic conditions, further measurements on Ge–Si alloys (Bridgman and Paul unpublished) confirmed that it was a real effect. The analysis of Nathan *et al.* (1961) showed that intense intervalley scattering, giving rise to a reduction in mobility, between the L_1 and Δ_1 valleys was the principal cause of the maximum in the resistance. Later Jayaraman and Kosicki (1968) repeated the experiment to 50 kbar and estimated a pressure coefficient for the Δ_1 minima to be between -1×10^{-6} and $-1{\cdot}5 \times 10^{-6}$ eV bar^{-1}, which may be compared with that for Si of $-1{\cdot}5 \times 10^{-6}$ eV bar^{-1} (Paul 1961). They also determined the sub-band energy gap $E(\Delta_1$–$L_1)$ as $0{\cdot}18 \pm 0{\cdot}01$ eV.

To fit the Ge data previous workers have used either the Si effective mass $m^*_{l\Delta} = 0{\cdot}92\, m_e$, $m^*_{t\Delta} = 0{\cdot}19\, m_e$, that is $m_{D\Delta} = 1{\cdot}06\, m_e$ where $\nu_\Delta = 6$ (Hensel *et al.* 1965), or theoretical estimates which tend to be near the Si value. In attempting to fit our data we have started by taking the theoretical masses of Dresselhaus and Dresselhaus (1967), which give $m^*_{D\Delta}$ considerably less than for Si, and Cardona and Pollak (1965), where $m^*_{D\Delta}$ is comparable to the Si mass.

At atmospheric pressure the $\Gamma_{2'}$ conduction band minimum lies $\sim 0{\cdot}15$ eV above the L_1 minima (Zwerdling and Lax 1951), and hence below the Δ_1 minima. The pressure coefficient has been measured as $+14{\cdot}0 \times 10^{-6}$ eV bar^{-1} (Melz unpublished). Even at low pressures the minimum will have moved well above the Δ_1 minima and will have little effect on the results. Also because of the small density of states a negligible number of electrons will be transferred. Thus while the effect of the minimum might perhaps be considered in high field calculations it can be safely ignored in these high pressure experiments.

Nonparabolicity of the bands can also be ignored since the electrons will at all times be near the bottom of the minima at the low electric fields used here. Interesting effects might occur at high fields, however, but it is expected that transfer of the $\langle 100 \rangle$ valleys will occur before nonparabolicity in the $\langle 111 \rangle$ minima has any large significant effect (Fawcett and Paige 1971).

3. Experimental method and results

The apparatus and techniques have already been described in detail (Pitt 1968). The n type Ge crystal used for this study had the following electrical parameters: resistivity at atmospheric pressure $\rho_0 = 2{\cdot}65\ \Omega$ cm; carrier concentration $(N_D$–$N_A) = 8{\cdot}1 \times 10^{14}$ cm^{-3}; Hall mobility $\mu_{H_0} = 3340$ cm^2 V^{-1} s^{-1}. The crystals were cut and polished in $\langle 100 \rangle$ and $\langle 111 \rangle$ orientated slices and tin contacts soldered to the Van der Pauw samples cut from the slices.

The stresses on the crystal sample below 30 kbar in this apparatus are nonhydrostatic and, since electron transfer in Ge involves two sets of degenerate off centre minima near the zone edge, the nonhydrostatic stress would show large effects in resistivity and Hall constant due to splitting of the minima. The analysis of the results would then be extremely complicated. To circumvent this problem crystals with both ⟨100⟩ and ⟨111⟩ orientations were used. The conductivity versus pressure curve for our sample is shown in figure 1, and compared with the truly hydrostatic measurements of Nathan *et al.* (1961) to 27 kbar. Excellent agreement was obtained for the ⟨100⟩ samples (ie ⟨100⟩ direction perpendicular to the opposed anvils). This might be expected since the degeneracy of the occupied ⟨111⟩ minima is not removed by the stress differences inherent in the apparatus in this pressure

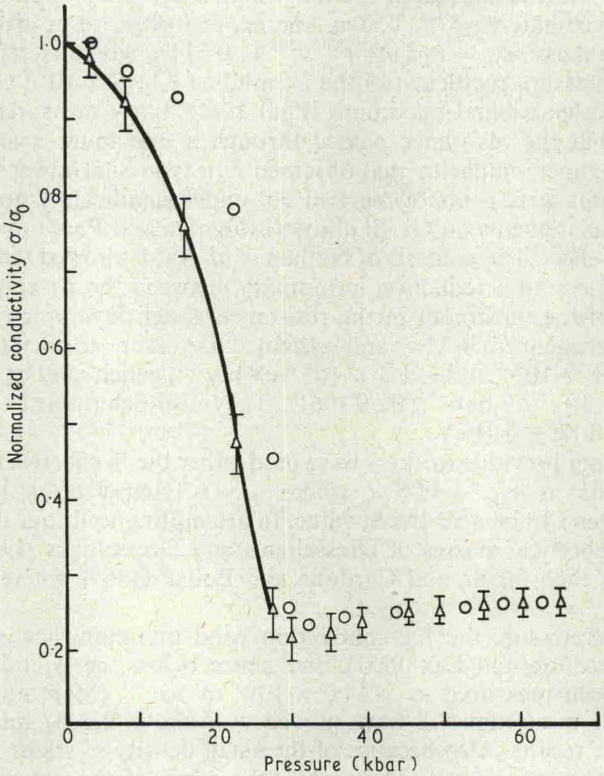

Figure 1. Normalized conductivity (σ/σ_0) results with pressure to 65 kbar in n type Ge at 295 K; △ for ⟨100⟩, and ○ for ⟨111⟩ orientations. Comparison is made with the truly hydrostatic measurements of Nathan *et al.* (1961) to 27 kbar. Indications of the errors on the ⟨100⟩ samples for four runs are given; the magnitudes for the ⟨111⟩ samples are similar at corresponding pressures. Full curve from Nathan *et al.* (1961).

range. The ⟨111⟩ samples, however, show a resistivity variation quite different from the hydrostatic results, as expected. By 30 kbar the two results have converged and pass through a minimum near 33 ± 1 kbar. The spread of results for five runs on both orientations are shown by the error bars. The largest variations occur in the highly nonhydrostatic pressure region below 20 kbar, in agreement with our previous results (Pitt 1968). Above 30 kbar the coalescing of results for both orientations further confirms that our conditions are reasonably hydrostatic. By 65 kbar the resistivity has almost levelled off at a value of $\rho/\rho_0 = 4{\cdot}0 \pm 0{\cdot}3$.

Figure 2 shows mean plots of the Hall constant R_H/R_{H_0} and Hall mobility μ_H/μ_{H_0}. Dimensional changes of the crystal have been allowed for by taking the compressibility