value of ε at normal pressure, we can fit the experimental curve quite well, in particular the position of the maximum, between 0 and 27 kbar, where 27 kbar corresponds to $\varepsilon = -\Delta/3$. However, between $\varepsilon = -\Delta/3$ and $\varepsilon = 0$ (near the magnetic–nonmagnetic transition) the theoretical curve departs from the experimental curve. The occurrence of the maximum in the depression of T_c can be explained by expression (4), whereas it cannot be explained by the Schrieffer–Wolff formula (3).

In the nonmagnetic domain, we use the Ratto–Blandin theory[17] which does not take into account spin fluctuations. The Ratto–Blandin expression (in the previous notation) is given by

$$\ln \frac{T_c}{T_{c_0}} = -c\alpha \frac{n_f(E_F)}{n_s(E_F)} \left(1 + \alpha \frac{n_f(E_F)\, U_{\text{eff}}}{\xi}\right) \tag{10}$$

where T_{c_0} is the superconducting transition temperature of pure lanthanum (which varies with pressure), and α is a parameter given by

$$\alpha = \ln \frac{1.14\,\omega_D}{T_c} \text{ for } E \gg \Delta, \omega_D \tag{11}$$

In the limiting case of small concentration and $E \gg \Delta$, we obtain:

$$-\left(\frac{dT_c}{dc}\right)_{c=0} = \left(\frac{\alpha \xi T_{c_0}}{\pi \Delta n_s(E_F)}\right) \left(\frac{\Delta}{E}\right)^2 \left(1 + \frac{2\alpha}{\pi}\frac{\Delta}{E}\right) \tag{12}$$

Curve (II) plotted in Figure 1 has been obtained using expression (12) with the following two sets of parameters:

—either $\xi = 6$, i.e. the large spin–orbit coupling limit, by taking a linear variation of E versus pressure with $E = 6\Delta$ at $p = 125$ kbar and $E = 3{\cdot}675\ \Delta$ at $p_c = 32$ kbar. This corresponds to a change of E by $\Delta = 0.02$ eV for a pressure of 40 kbar. The total number of 4f electrons, N, varies from 0.32 at 125 kbar to 0.52 at $p_c = 32$ kbar.

—or $\xi = 14$, i.e. the zero spin–orbit coupling limit, by taking a linear variation of E versus pressure with $E = 9\Delta$ at $p = 125$ kbar and $E = 5.28\Delta$ at $p_c = 32$ kbar. This implies a change of E by $\Delta = 0.02$ eV for a pressure of 25 kbar. N varies from 0.5 at 125 kbar to 0.85 at p_c. The relevant case is probably the large spin–orbit coupling limit which, incidentally, corresponds to the smallest values of N.

Above 50–60 kbar, the agreement between experiment and the theoretical curve (II) is very good, without taking into account spin fluctuations. However, when we approach p_c from high pressures, the theoretical curve (II) deviates markedly from experiment. An expression which takes into account correctly the spin fluctuations will certainly improve the agreement between experiment and theory in the pressure range p_c to 50–60 kbar, although even without such an expression, the Ratto–Blandin formula gives a reasonable qualitative explanation demonstrating unambiguously the nonmagnetic character of cerium impurities above p_c.

Around p_c, we are unable to describe the magnetic–nonmagnetic transition, nor can we link the variables ε and E to each other. Thus, although we can accurately describe the pressure dependence of the depression of T_c at pressures sufficiently far from p_c, our description of the magnetic transition in the vicinity of p_c is rather crude.

T_c as a function of Ce concentration for the nonmagnetic **Th**Ce system has recently been measured between 0 and 18 kbar.[9,10] Although it has been shown[10] that the T_c versus c curves may be *quantitatively* described by a recent extension of the Ratto–Blandin theory due to Kaiser,[18] we consider here only the low concentration limit where the depression of T_c is linear in c for which the Ratto–Blandin theory is adequate. Using equation (10) or (12), we obtain the theoretical curve for $-(dT_c/dc)_{c=0}$ versus pressure in Figure 3 which agrees well with the experimental data using again the following two sets of parameters:

—either $\xi = 6$, by taking a linear variation of E versus pressure with $E = 4.3\Delta$ at 0 kbar and $E = 5\Delta$ at 18 kbar. This corresponds to a change of E by $\Delta = 0.02$ eV for a pressure of 26 kbar. N varies from 0.44 at 0 kbar to 0.38 at 18 kbar;

—or $\xi = 14$, by taking a linear variation of E versus pressure with $E = 6{\cdot}2\Delta$ at 0 kbar and $E = 7.1\Delta$ at 18 kbar. This implies a change of E by $\Delta = 0.02$ eV for a pressure of 20 kbar. N varies from 0.72 at 0 kbar to 0.63 at 18 kbar.

The variation of $-(dT_c/dc)_{c=0}$ versus pressure in **Th**Ce alloys is explained by the same argument as for **La**Ce alloys with a change of E with pressure of the same order. By comparison with the **La**Ce system, zero pressure for **Th**Ce alloys corresponds roughly to 50 kbar for **La**Ce alloys. Noting that Ce impurities are magnetic in Y, the ternary alloy system $(Th_{1-x}Y_x)_{1-c}Ce_c$ should exhibit the same variation of $-(dT_c/dc)_{c=0}$ with increasing x as with decreasing pressure in **La**Ce alloys. This has been observed recently by Huber and Maple[8] as shown in Figure 3. $-(\mathrm{d}T_c/\mathrm{d}c)_{c=0}$ increases with x and has the same value for $x = 0.35$ as for **La**Ce at 35 kbar. By again increasing x to 0.70 (where the $Th_{1-x}Y_x$ alloys are no longer superconducting), one should be able to generate a curve similar to that of Figure 1 to roughly the maximum.

Another example is the ternary alloy system $(Th_{1-x}Sc_x)_{1-c}Ce_c$ where $-(\mathrm{d}T_c/\mathrm{d}c)_{c=0}$ is roughly independent of x to $x = 0.35$.[8] This indicates that E does not change with matrix composition in this concentration range. It is interesting to note that **Sc**Ce alloys are nonmagnetic as shown by recent magnetic susceptibility experiments.[19]

Finally, the extreme sensitivity of $-\mathrm{d}T_c/\mathrm{d}c$ to the relative position of the 4*f* level and E_F makes it a very good tool for studying magnetic–nonmagnetic transitions in dilute alloys.

(2°) *Resistivity*

The second result concerns the occurrence of the Kondo effect and the variation of the slope of the Kondo resistivity in the magnetic domain. In the nonmagnetic domain, far from the transition, there is obviously no resistivity minimum and the slope $\mathrm{d}R_m/\mathrm{d}\ln T$ is positive.

In the magnetic region, above the Kondo temperature, the magnetic resistivity is given (in the usual notation) by:[15]

$$R_m = \frac{m_0 c}{\pi z N e^2 \hbar \rho}\left(2\sin^2\delta_v + 2\pi^2\rho^2\Gamma^2\cos 2\delta_v S(S+1) + 8\pi^2\Gamma^3\rho^3 S(S+1)\cos 2\delta_v \ln\frac{k_B T}{D}\right)$$

Since Γ and δ_v vary with pressure, while ρ and S are assumed to be constant, the slope of the resistivity is conveniently written as:

$$\frac{\mathrm{d}R_m}{\mathrm{d}\ln(k_B T/D)} = \alpha c \Gamma^3 \cos 2\delta_v \tag{14}$$

where α is independent of pressure and given by:

$$\alpha = \frac{8 m_0 \pi S(S+1)}{z N e^2 \hbar \rho} \tag{15}$$

Expression (14) becomes:

$$\frac{\mathrm{d}R_m}{\mathrm{d}\ln(k_B T/D)} = \alpha c {\Gamma_1}^3 z \tag{16}$$

with:

$$z = \left(1 + \frac{2\Gamma_0}{\Gamma_1}\frac{x}{1+x^2}\right)^3 \frac{x^2-1}{x^2+1} \tag{17}$$

as a function of $x = \varepsilon/\Delta$; while $(\mathrm{d}T_c/\mathrm{d}c)_{c=0}$ is given by

$$-\left(\frac{\mathrm{d}T_c}{\mathrm{d}c}\right)_{c=0} = -\frac{\pi^2}{4} n_s(E_F) S(S+1) {\Gamma_1}^2 y \tag{18}$$

with

$$y = -\left(1 + \frac{2\Gamma_0}{\Gamma_1}\frac{x}{1+x^2}\right)^2 \tag{19}$$

The two parameters y and z are plotted in Figure 6 as function of x for $\Gamma_1 = 0.028$ eV and $\Gamma_0 = 0.145$ eV. z and y are negative and increase in absolute value when x increases by negative values, z has a minimum around $x \cong -1.5$ and a

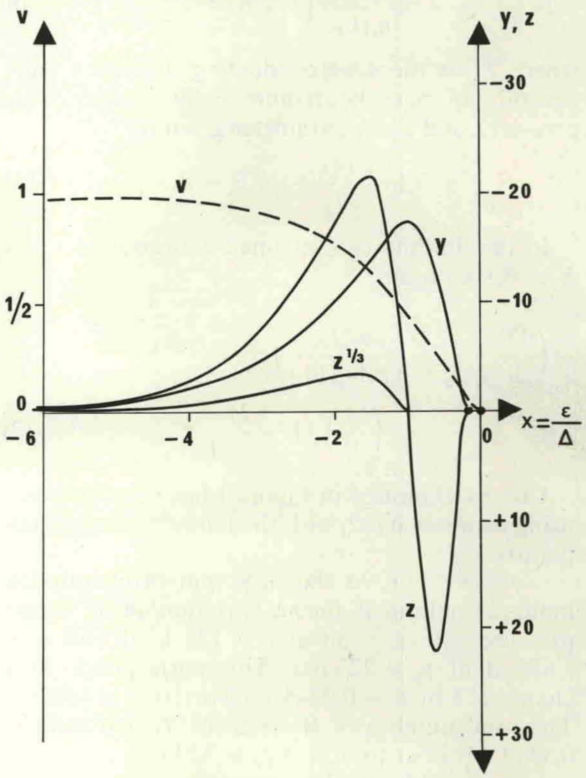

FIGURE 6 The functions y, z, $z^{1/3}$ and v versus the parameter $x = \varepsilon/\Delta$ for $2\Gamma_0/\Gamma_1 = 10.4$.

maximum around $x \cong -0.6$, while y has only a minimum at $x = -1$. y is always negative and has two zero values at $x_1 = -(2\Gamma_0/\Gamma_1)$ and $x_2 = (-\Gamma_1/2\Gamma_0)$; z has three zero values at x_1, x_2 and -1. Thus z is negative in the present case