Phase Diagram in a Random Mixture of Two Antiferromagnets with Competing Spin Anisotropies: Evaluation of Tetracritical Concentration and Temperature, and of Critical Concentration at $T=0$ K

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§1. Introduction.

In recent years, magnetic properties of a random mixture A_cB_{1-c} of two antiferromagnets with competing spin anisotropies have attracted much theoretical and experimental attention. Matsubara and Inawashiro studied this problem theoretically using a mean-field approximation in the case of $S_A=1/2$ and $S_B=1$, where $S_A(S_B)$ is a magnitude of $A(B)$-spin (M-I).[1] They showed that there appeared three ordered phases on the concentration versus temperature phase diagram; two AF phase and an "oblique antiferromagnetic (OAF) phase".

After that, Oguchi and Ishikawa extended the theory of M-I to the case of orthorhombic anisotropy assuming $S_A=S_B=1/2$ (O-I).[2] They showed that two different types of phase diagram existed; one type contains three ordered phases (one of the three phases is an OAF phase), and the other type contains five ordered phases (two of the five phases are OAF phases); a balance between anisotropy energies determines which type of phase diagram appears.

In both the theories, the η component of the exchange integral between A- and B-spin J^{η}_{AB} ($\eta=x, y, z$) is assumed to be $(J^{\eta}_{AA}\cdot J^{\eta}_{BB})^{1/2}$, where J^{η}_{AA} means the η component of the exchange integral between A-spins, and J^{η}_{BB} has the similar meaning.

We have extended the theories of M-I and O-I to the case in which S_A, S_B and J^{η}_{AB} have no restriction. We have obtained new analytic equations for determining a concentration dependence of T_N and a critical concentration at $T=0$ K. The details about the derivation of the analytic equations are shown in the reference 3. A comparison with the experimental results obtained for the mixtures $Fe_{1-x}Co_xCl_2$, $K_2Mn_{1-x}Fe_xF_4$ and $Fe_{1-x}Co_xCl_2\cdot 2H_2O$ is also made in the reference 3. In this paper, we show the values of the tetracritical concentration, the tetracritical temperature and the critical concentrations at $T=0$ K for various possible sets of values of α ($\equiv S_B/S_A$) and J^{η}_{PQ} (P, $Q=A$, B and

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$\eta = x, y, z$), using these analytic equations.

§ 2. Concentration versus Temperature Phase Diagram.

In this section, we give a summary of the results obtained in the reference 3. Because, to understand the theory in that paper is necessary for discussions in § 3.

2.1. *Model*

We consider a system in which two kinds of magnetic ions A and B are quenched on sites at random.

ion	concentration	magnitude of spin	easy axis
A	c_A	S_A	x
B	c_B	S_B	z

We assume only the nearest neighbor interactions. The anisotropic exchange interactions between nearest neighboring P ion on α-sublattice and Q ion on β-sublattice are written in the form

$$\sum_{\eta=x,y,z} 2J^{\eta}_{PQ} S^{\eta}_{P,\alpha} \cdot S^{\eta}_{Q,\beta} ,$$

where $S^{\eta}_{P,\alpha}$ is the η component of spin operator of P ion on α-sublattice, and $S^{\eta}_{Q,\beta}$ has the similar meaning. We assume that $J^{x}_{AA} > J^{y,z}_{AA} \geqq 0$ and $J^{z}_{BB} > J^{x,y}_{BB} \geqq 0$.

We use a mean-field approximation following M-I and O-I. Then, the Hamiltonian of P ion on α-sublattice is written as

$$\mathcal{H}_{P,\alpha} = X_{P,\alpha} S^{x}_{P,\alpha} + Y_{P,\alpha} S^{y}_{P,\alpha} + Z_{P,\alpha} S^{z}_{P,\alpha} , \tag{1}$$

where

$$X_{P,\alpha} = 2z(J^{x}_{PA} c_A \langle S^{x}_{A} \rangle_{\beta} + J^{x}_{PB} c_B \langle S^{x}_{B} \rangle_{\beta}) ,$$

$$Y_{P,\alpha} = 2z(J^{y}_{PA} c_A \langle S^{y}_{A} \rangle_{\beta} + J^{y}_{PB} c_B \langle S^{y}_{B} \rangle_{\beta}) ,$$

$$Z_{P,\alpha} = 2z(J^{z}_{PA} c_A \langle S^{z}_{A} \rangle_{\beta} + J^{z}_{PB} c_B \langle S^{z}_{B} \rangle_{\beta}) ,$$

and $\langle S^{\eta}_{P} \rangle_{\alpha}$ ($\langle S^{\eta}_{P} \rangle_{\beta}$) is the thermal average of $S^{\eta}_{P,\alpha}$ ($S^{\eta}_{P,\beta}$), and z the number of nearest neighbors.

2.2. *Néel Temperature*

We denote the antiferromagnetically ordered phase along $\pm\eta$—axis by $[\eta]$. Assuming $\langle S^{\eta}_{P} \rangle_{\alpha} = -\langle S^{\eta}_{P} \rangle_{\beta} \equiv \langle S^{\eta}_{P} \rangle$, we put $\langle S^{y}_{P} \rangle = \langle S^{z}_{P} \rangle = 0$ and $\langle S^{x}_{P} \rangle \to 0$. Then, we obtained the equations for the Néel temperature of $[x]$, T^{x}_{N}, as

$$(t^{x}_{N})^2 - (t^{x}_{N})(\mathcal{J}^{x}_{AA} c_A + \mathcal{J}^{x}_{BB} c_B) + (\mathcal{J}^{x}_{AA} \mathcal{J}^{x}_{BB} - \mathcal{J}^{x}_{AB} \mathcal{J}^{x}_{AB}) c_A c_B = 0 , \tag{2}$$

where

$$t^{x}_{N} \equiv k T^{x}_{N} ,$$

$$\mathcal{J}^{x}_{AA} \equiv \frac{2zS_A(S_A+1)}{3} J^{x}_{AA} ,$$

$$\mathcal{J}^x_{BB} \equiv \frac{2zS_B(S_B+1)}{3} J^x_{BB},$$

$$\mathcal{J}^x_{AB} \equiv \left(\frac{2zS_A(S_A+1)}{3} \cdot \frac{2zS_B(S_B+1)}{3}\right)^{1/2} J^x_{AB}.$$

Similarly, we obtain t^y_N or t^z_N by replacing x by y or z, respectively, in eq. (2).

We see that a concentration dependence of T^η_N is determined by $\mathcal{J}^\eta_{PQ}$. We define R^η as $R^\eta \equiv J^\eta_{AB}/(J^\eta_{AA} \cdot J^\eta_{BB})^{1/2}$. If $R^\eta=1$, then T^η_N is a linear function of concentration (Fig. 1(a)). On the other hand, if $R^\eta>1$ ($R^\eta<1$), then T^η_N becomes a convex (concave) function. (Fig. 1(b) and Fig. 1(c)).

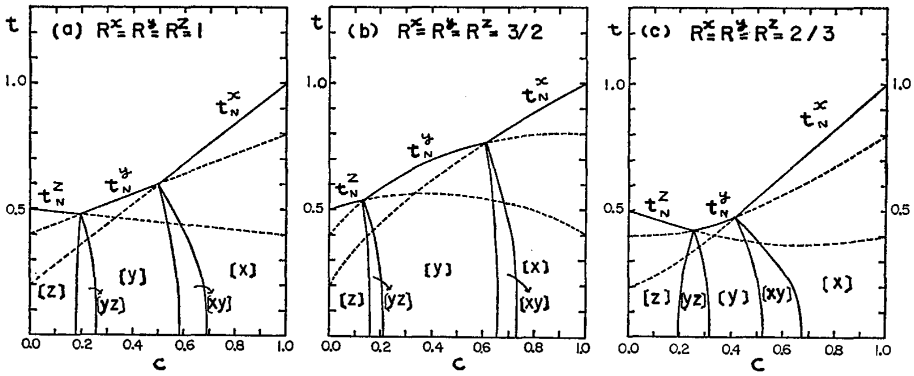

Fig. 1. $S_A=1/2$, $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0.8$, $\mathcal{J}^z_{AA}=0.4$.
$S_B=1/2$, $\mathcal{J}^x_{BB}=0.2$, $\mathcal{J}^y_{BB}=0.4$, $\mathcal{J}^z_{BB}=0.5$.
$\alpha=1$
(a) $R^x=R^y=R^z=1$, (b) $R^x=R^y=R^z=3/2$.
(c) $R^x=R^y=R^z=2/3$.

If T^y_N is lower than T^x_N or T^z_N for all values of concentration, the phase of [y] never appears, and we have a phase diagram which contains three ordered phases, [x], [xz] and [z] similar to those shown in Fig. 2, where [xz] means an OAF phase in which spin easy axis lies in the xz-plane. On the other hand,

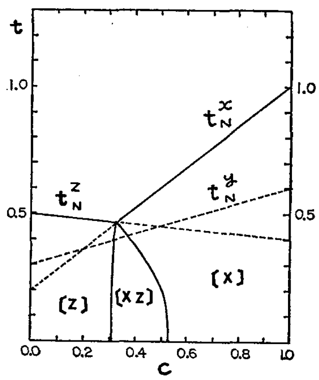

Fig. 2. $S_A=1/2$, $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0.6$, $\mathcal{J}^z_{AA}=0.4$.
$S_B=1/2$, $\mathcal{J}^x_{BB}=0.2$, $\mathcal{J}^y_{BB}=0.3$, $\mathcal{J}^z_{BB}=0.5$.
$\alpha=1$
$R^x=R^y=R^z=1$.

if T_N^y is higher than T_N^x and T_N^z in a certain range of concentration, [y] appears around this region, and we have a phase diagram which contains five ordered phases, [x], [xy], [y], [yz] and [z] similar to those shown in Fig. 1.

2.3. Critical concentration (phase boundary between an AF phase and an OAF phase)

In order to obtain the phase boundary between [x] and [xz] at a finite temperature, we put $\langle S_P^z\rangle \to 0$, $\langle S_P^x\rangle \neq 0$ and $\langle S_P^y\rangle = 0$. Then, we have the equations for the critical concentration;

$$\left(\frac{2z}{X_{A,\alpha}} J_{AA}^z c_A \langle S_A^x\rangle + 1\right)\left(\frac{2z}{X_{B,\alpha}} J_{BB}^z c_B \langle S_B^x\rangle + 1\right) - \frac{(2z)^2}{X_{A,\alpha} X_{B,\alpha}} J_{AB}^z J_{AB}^z c_A c_B \langle S_A^x\rangle\langle S_B^x\rangle = 0\,, \tag{3}$$

$$\langle S_A^x\rangle = -S_A \cdot B_{S_A}\left(S_A \cdot \frac{X_{A,\alpha}}{kT}\right),$$

$$\langle S_B^x\rangle = -S_B \cdot B_{S_B}\left(S_B \cdot \frac{X_{B,\alpha}}{kT}\right),$$

where $B_{S_P}(x)$ is the Brillouin function.

We obtain the phase boundary between [x] and [xy], replacing (x, z) by (x, y) in eq. (3). Similarly, we obtain the phase boundary between [xy] and [y], [y] and [yz], [yz] and [z], or [xz] and [z], replacing (x, z) by (y, x), (y, z), (z, y), or (z, x), respectively, in eq. (3).

We can obtain the phase boundary between [x] and [xz] at $T=0$ K, by putting $\langle S_P^x\rangle = S_P$ in eq. (3):

$$(J_{BB}^x - J_{BB}^z) J_{AB}^x c_B^2 \alpha^2 + [(J_{AA}^x - J_{AA}^z)(J_{BB}^x - J_{BB}^z) + J_{AB}^x J_{AB}^x - J_{AB}^z J_{AB}^z] c_A c_B \alpha + (J_{AA}^x - J_{AA}^z) J_{AB}^x c_A^2 = 0\,, \tag{4}$$

where

$$\alpha = S_B / S_A\,.$$

From eqs. (2)-(4) we reach the following conclusions. If the concentration dependence of T_N is given, i.e. $\mathcal{J}_{PQ}^\eta$ are given, critical concentrations at $T=0$ K are determined by α (several examples are shown in Fig. 3), and critical concentrations at $T=0$ K depend furthermore on S_A (or S_B). However, the latter dependence is small. For example, when $\alpha=1$, the difference between the critical concentration for the set of $S_A=S_B=1/2$ and that for $S_A=S_B=2$ is estimated to be at most the width of the drawn lines in Figs. 1-3. So, we may say that a shape of phase diagram is almost determined by $\mathcal{J}_{PQ}^\eta$ and α.

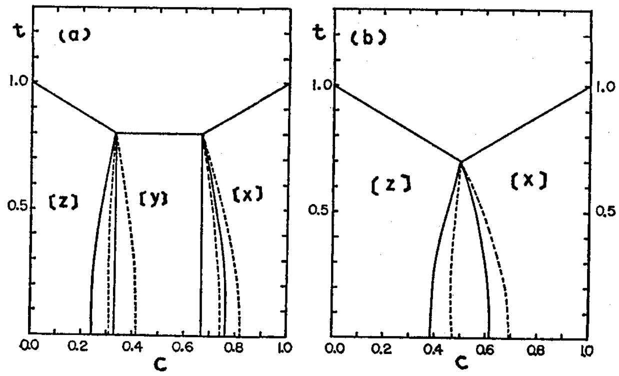

Fig. 3(a). $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0.8$, $\mathcal{J}^z_{AA}=0.4$.
$\mathcal{J}^x_{BB}=0.4$, $\mathcal{J}^y_{BB}=0.8$, $\mathcal{J}^z_{BB}=1.0$.
$R^x=R^y=R^z=1$.
solid curve $S_A=1/2$, $S_B=1/2$, $\alpha=1$.
broken curve $S_A=1/2$, $S_B=4$, $\alpha=4$.
(b). $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0.6$, $\mathcal{J}^z_{AA}=0.4$.
$\mathcal{J}^x_{BB}=0.4$, $\mathcal{J}^y_{BB}=0.6$, $\mathcal{J}^z_{BB}=1.0$.
$R^x=R^y=R^z=1$.
solid curve $S_A=1/2$, $S_B=1/2$, $\alpha=1$.
broken curve $S_A=1/2$, $S_B=2$, $\alpha=4$.

§ 3. Phase Diagrams for Various Sets of Parameters.

As was shown in § 2, there exist two different types of phase diagrams: the phase diagrams which contain three ordered phases and the phase diagrams which contain five ordered phases. Almost all the phase diagrams experimentally determined for various kinds of random mixture belong to the former type. The only exception known is the mixture $K_2Ni_{1-x}Fe_xF_4$, for which the Mössbauer measurement suggests the possibility of the latter type of phase diagram. Here, we confine ourselves to the former type.

We denote c_A simply by c, and its value at the tetracritical point by c_t, and the temperature at that point by t_t. We denote the phase boundary at $T=0$ K between [x] and [xz], and that between [xz] and [z] by c_1 and c_2, respectively. We calculate c_t, t_t, c_1 and c_2 for various sets of a ($\equiv\mathcal{J}^z_{AA}/\mathcal{J}^x_{AA}$), b ($\equiv\mathcal{J}^x_{BB}/\mathcal{J}^z_{BB}$), R^x, R^z and α. We vary continuously one or two of the five quantities, a, b, R^x, R^z and α, fixing the other four or three quantities at the values listed in Tables 1-10. Because, it is interesting to investigate the dependence of c_1, c_2, c_t and t_t on the one or two of these quantities.

3.1. $\mathcal{J}^x_{AA}=1.0$ *and* $\mathcal{J}^z_{BB}=1.0$.

In this subsection, we consider the case in which the Néel temperature of the pure A-system equals to that of the pure B—system.

(i) We put $a=b=x$, and determine the values of c_t, t_t, c_1 and c_2 as a function of x ($0.01\leqq x\leqq 0.99$). We fix R^x, R^z and α at the values of No. 1-6 listed in Table 1. The results are shown in Fig. 5 by the diagram.

From the diagram No. 5, for instance, when $x=0.2$, one can read $c_1=0.751$, $c_2=0.249$, $c_t=0.5$ and $t_t=0.549$. The phase diagram corresponding to this set of parameters is shown in Fig. 4(a). For each value of x, the values of c_t and t_t of No. 1 are equal to those of No. 2, since the value of $\mathcal{J}^{\eta}_{PQ}$ of No. 1 is equal to that of No. 2 ($P, Q=A, B, \eta=x, y, z$). However, c_1 and c_2 of No. 1 are different from those of No. 2, since the value of α of No. 1 is different from that of No. 2. When $x=0.4$, the phase diagram for $\alpha=1$ (No. 1) is shown in Fig. 3(b) by the solid curve, and that for $\alpha=4$ (No. 2) in Fig. 3(b) by the broken curve. From the diagrams No. 1-6, we see that, when the value of x becomes larger, i. e. the anisotropy of the pure systems, becomes smaller, the concentration range where an OAF phase appears becomes wider.

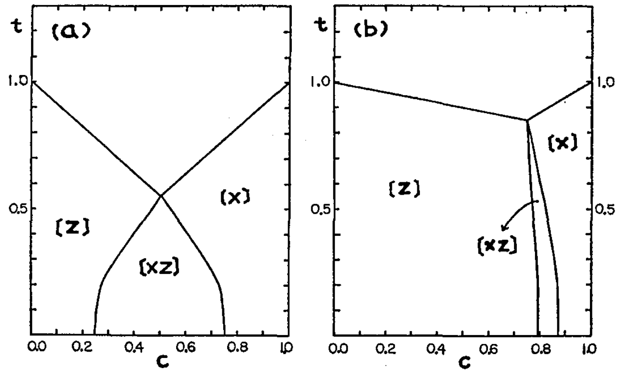

Fig. 4(a). $S_A=1/2$, $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0$, $\mathcal{J}^z_{AA}=0.2$.
$S_B=1/2$, $\mathcal{J}^x_{BB}=0.2$, $\mathcal{J}^y_{BB}=0$, $\mathcal{J}^z_{BB}=1.0$.
$R^x=R^y=R^z=2/3$.
(b). $S_A=1/2$, $\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^y_{AA}=0$, $\mathcal{J}^z_{AA}=0.8$.
$S_B=2$, $\mathcal{J}^x_{BB}=0.1$, $\mathcal{J}^y_{BB}=0$, $\mathcal{J}^z_{BB}=0.25$.
$R^x=R^y=R^z=1$.

(ii) We put $R^x=R^z=y$, and determine the values of c_t, t_t, c_1 and c_2 as a function of y ($0.5\leqq y\leqq 1.5$). We fix a, b and α at the values of No. 7-10 listed in Table 2. The results are shown in Fig. 6 by the diagram.

(iii) We put $a=x$, and determine the values of c_t, t_t, c_1 and c_2 as a function of x ($0.01\leqq x\leqq 0.99$). We fix b, R^x, R^z and α at the values of No. 11-28 listed in Table 3. The results are shown in Fig. 7 by the diagram.

We see that, when the value of x becomes larger, i. e. when the anisotropy of A-spin becomes smaller, the position of OAF phase shifts more and more toward the A-rich concentration side. In No. 12, we see that $c_2>c_t$ for range of $x\gtrsim 0.5$. The phase diagram for the case of $x=0.8$ in No. 12 is shown in Fig. 4(b).

(iv) We put $R^z=y$ and $R^x=1.0$, and determine the values of c_t, t_t, c_1 and c_2 as a function of y ($0.5\leqq y\leqq 1.5$). We fix a, b and α at the values of No. 29-39 listed in Table 4. The results are shown in Fig. 8 by the diagram.

3.2. $\mathcal{J}^x_{AA}=1.0$ ***and*** $\mathcal{J}^z_{BB}=0.5$.

We consider the cases in which t_N of the pure A-system is equal to unity, while that of the pure B-system is equal to 0.5 (eq. (5)).

(i) We put $a=b=x$, and determine the values of c_t, t_t, c_1 and c_2 as a function of x ($0.01\leqq x\leqq 0.99$). We fix R^x, R^z and α at the values of No. 40–48 listed in Table 5. The results are shown in Fig. 9 by the diagram. The phase diagram of $x=0.4$ in No. 40 is shown in Fig. 2.

(ii) We put $R^x=R^z=y$, and determine the values of c_t, t_t, c_1 and c_2 as a function of y ($0.5\leqq y\leqq 1.5$). We fix a, b and α at the values of No. 49–60 listed in Table 6. The results are shown in Fig. 10 by the diagram.

(iii) We put $a=x$, and determine the values of c_t, t_t, c_1 and c_2 as a function of x ($0.01\leqq x\leqq 0.99$). We fix b, R^x, R^z and α at the values of No. 61–78 listed in Table 7. The results are shown in Fig. 11 by the diagram.

(iv) We put $b=x$, and determine the values of c_t, t_t, c_1 and c_2 as a function of x ($0.01\leqq x\leqq 0.99$). We fix a, R^x, R^z and α at the values of No. 76–96 listed in Table 8. The results are shown in Fig. 12 by the diagram.

(v) We put $R^z=y$ and $R^x=1$, and determine the values of c_t, t_t, c_1 and c_2 as a function of y ($0.5\leqq y\leqq 1.5$). We fix a, b and α at the values of No. 97–108 listed in Table 9. The results are shown in Fig. 13 by the diagram.

(vi) We put $R^x=y$ and $R^z=1$, and determine the values of c_t, t_t, c_1 and c_2 as a function of y ($0.5\leqq y\leqq 1.5$). We fix a, b and α at the values of No. 109–120 listed in Table 10. The results are shown in Fig. 14 by the diagram.

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Table 1

($\mathcal{J}^x_{AA}=\mathcal{J}^z_{BB}=1.0$)

$a=b=x$, $0.01\leqq x\leqq 0.99$

No.	R^x, R^z	α
1	1	1
2	1	4
3	3/2	1
4	3/2	4
5	2/3	1
6	2/3	4

Table 2

($\mathcal{J}^y_{AA}=\mathcal{J}^z_{BB}=1.0$)

$R^x=R^z=y$, $0.5\leqq y\leqq 1.5$

No.	a	b	α
7	0.4	0.4	1
8	0.4	0.4	4
9	0.8	0.8	1
10	0.8	0.8	4

Table 3

($\mathcal{J}^x_{AA}=\mathcal{J}^z_{BB}=1.0$)

$a=x$, $0.01\leqq x\leqq 0.99$

No.	b	R^x, R^z	α
11	0.4	1	1
12	0.4	1	4
13	0.4	1	0.25
14	0.8	1	1
15	0.8	1	4
16	0.8	1	0.25
17	0.4	3/2	1
18	0.4	3/2	4
19	0.4	3/2	0.25
20	0.8	3/2	1
21	0.8	3/2	4
22	0.8	3/2	0.25
23	0.4	2/3	1
24	0.4	2/3	4
25	0.4	2/3	0.25
26	0.8	2/3	1
27	0.8	2/3	4
28	0.8	2/3	0.25

Table 4

($\mathcal{J}^x_{AA}=\mathcal{J}^z_{BB}=1.0$)

$R^z=y$, $R^x=1$, $0.5\leqq y\leqq 1.5$

No.	a	b	α
29	0.4	0.4	1
30	0.4	0.4	4
31	0.4	0.4	0.25
32	0.8	0.8	1
33	0.8	0.8	4
34	0.8	0.8	0.25
35	0.4	0.8	1
36	0.4	0.8	4
37	0.4	0.8	0.25
38	0.8	0.4	4
39	0.8	0.4	0.25

Table 5

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$a=b=x$, $0.01\leqq x\leqq 0.99$

No.	R^x, R^z	α
40	1	1
41	1	4
42	1	0.25
43	3/2	1
44	3/2	4
45	3/2	0.25
46	2/3	1
47	2/3	4
48	2/3	0.25

Table 6

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$R^x=R^z=y$, $0.5\leqq y\leqq 1.5$

No.	a	b	α
49	0.4	0.4	1
50	0.4	0.4	4
51	0.4	0.4	0.25
52	0.8	0.8	1
53	0.8	0.8	4
54	0.8	0.8	0.25
55	0.8	0.4	1
56	0.8	0.4	4
57	0.8	0.4	0.25
58	0.4	0.8	1
59	0.4	0.8	4
60	0.4	0.8	0.25

Table 7

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$a=x$, $0.01 \leqq x \leqq 0.99$

No.	b	R^x, R^z	α
61	0.4	1	1
62	0.4	1	4
63	0.4	1	0.25
64	0.8	1	1
65	0.8	1	4
66	0.8	1	0.25
67	0.4	3/2	1
68	0.4	3/2	4
69	0.4	3/2	0.25
70	0.8	3/2	1
71	0.8	3/2	4
72	0.8	3/2	0.25
73	0.4	2/3	1
74	0.4	2/3	4
75	0.4	2/3	0.25
76	0.8	2/3	1
77	0.8	2/3	4
78	0.8	2/3	0.25

Table 8

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$b=x$, $0.01 \leqq x \leqq 0.99$

No.	a	R^x, R^z	α
79	0.4	1	1
80	0.4	1	4
81	0.4	1	0.25
82	0.8	1	1
83	0.8	1	4
84	0.8	1	0.25
85	0.4	3/2	1
86	0.4	3/2	4
87	0.4	3/2	0.25
88	0.8	3/2	1
89	0.8	3/2	4
90	0.8	3/2	0.25
91	0.4	2/3	1
92	0.4	2/3	4
93	0.4	2/3	0.25
94	0.8	2/3	1
95	0.8	2/3	4
96	0.8	2/3	0.25

Table 9

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$R^z=y$, $R^x=1$, $0.5 \leqq y \leqq 1.5$

No.	a	b	α
97	0.4	0.4	1
98	0.4	0.4	4
99	0.4	0.4	0.25
100	0.8	0.8	1
101	0.8	0.8	4
102	0.8	0.8	0.25
103	0.4	0.8	1
104	0.4	0.8	4
105	0.4	0.8	0.25
106	0.8	0.4	1
107	0.8	0.4	4
108	0.8	0.4	0.25

Table 10

($\mathcal{J}^x_{AA}=1.0$, $\mathcal{J}^z_{BB}=0.5$)

$R^x=y$, $R^z=1$, $0.5 \leqq y \leqq 1.5$

No.	a	b	α
109	0.4	0.4	1
110	0.4	0.4	4
111	0.4	0.4	0.25
112	0.8	0.8	1
113	0.8	0.8	4
114	0.8	0.8	0.25
115	0.4	0.8	1
116	0.4	0.8	4
117	0.4	0.8	0.25
118	0.8	0.4	1
119	0.8	0.4	4
120	0.8	0.4	0.25

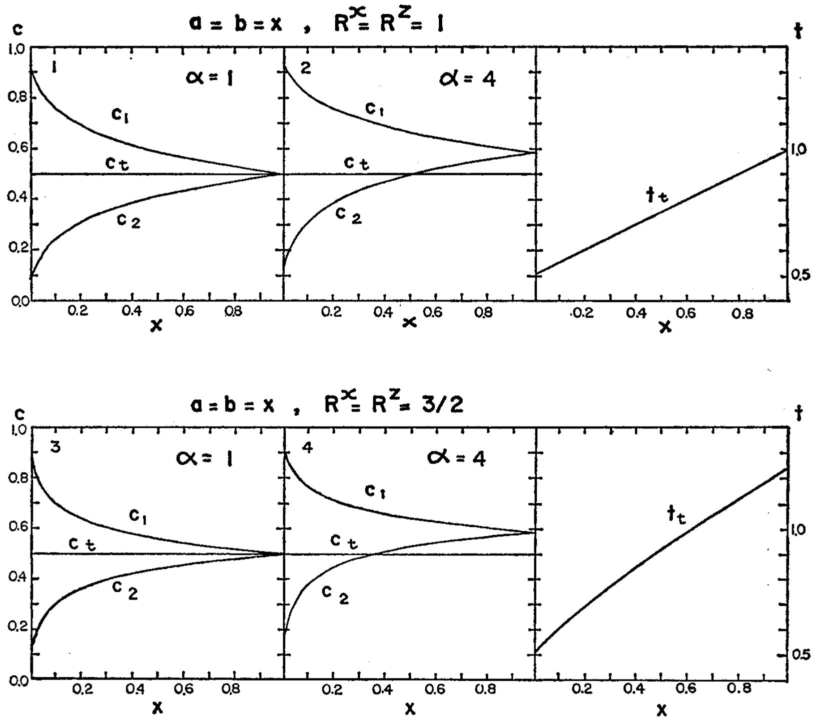

a = b = x , R^x = R^z = 1
α = 1
α = 4
c₁
c₂
c t
t t
a = b = x , R^x = R^z = 3/2
c
t
x

Fig. 5(a).

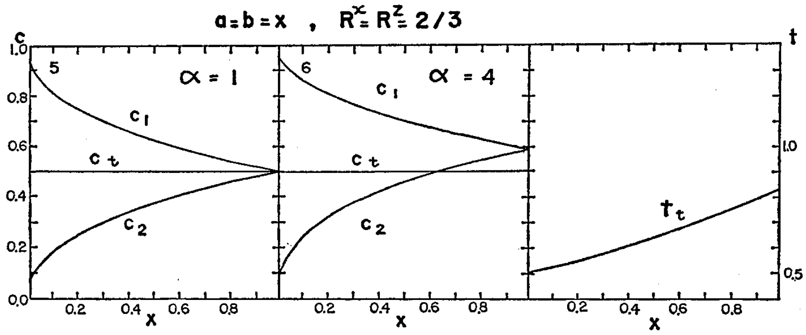

a = b = x , R^x = R^z = 2/3
α = 1
α = 4
c₁
c₂
c t
t t
c
t
x

Fig. 5(b).

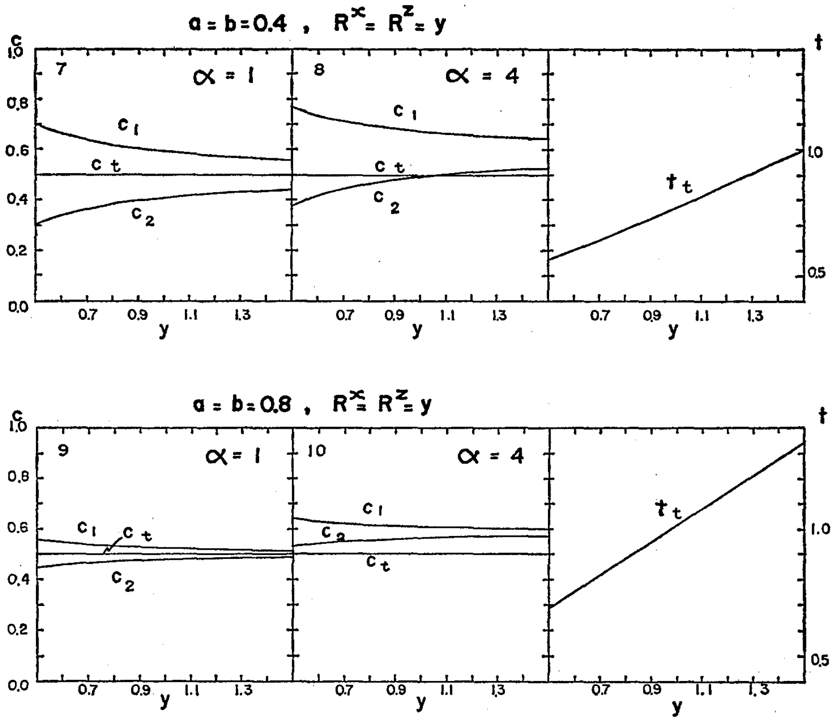

a = b = 0.4 , $R^x = R^z = y$
7
α = 1
8
α = 4
c_1
c_t
c_2
t_t
y
a = b = 0.8 , $R^x = R^z = y$
9
α = 1
10
α = 4
c
t

Fig. 6.

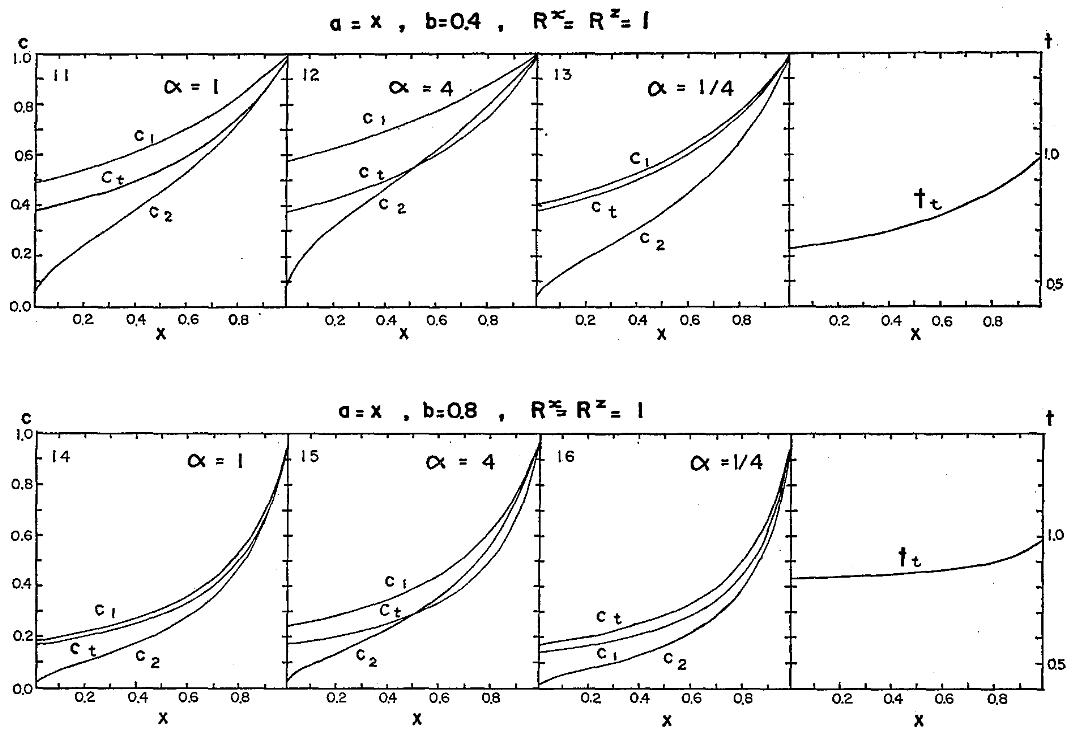
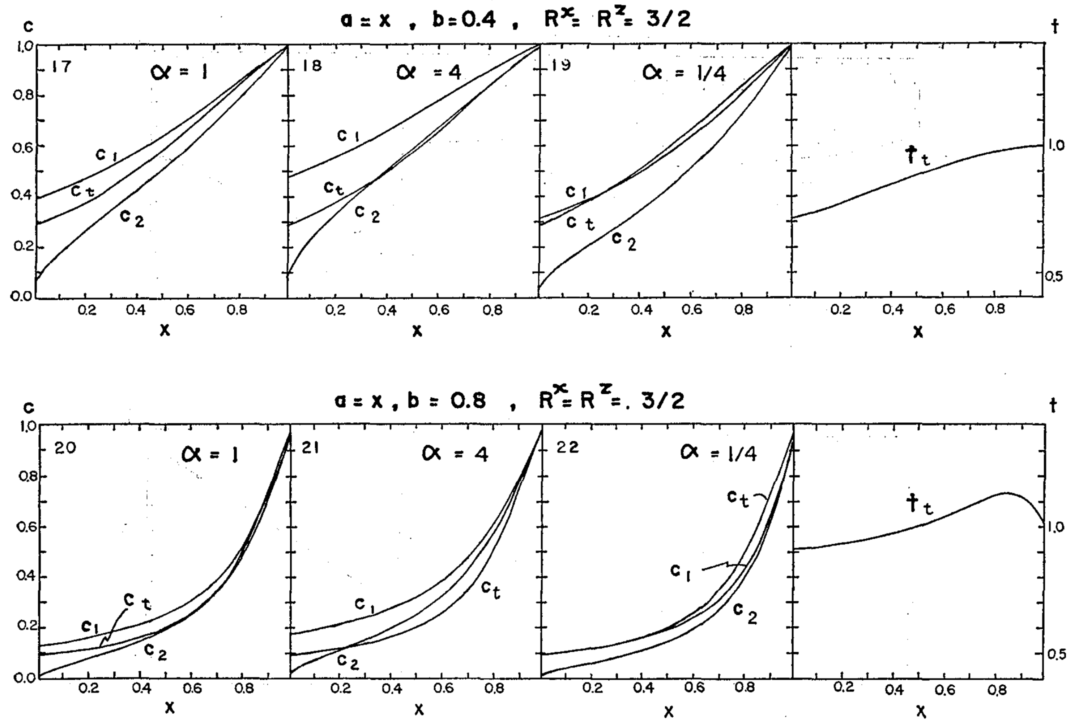
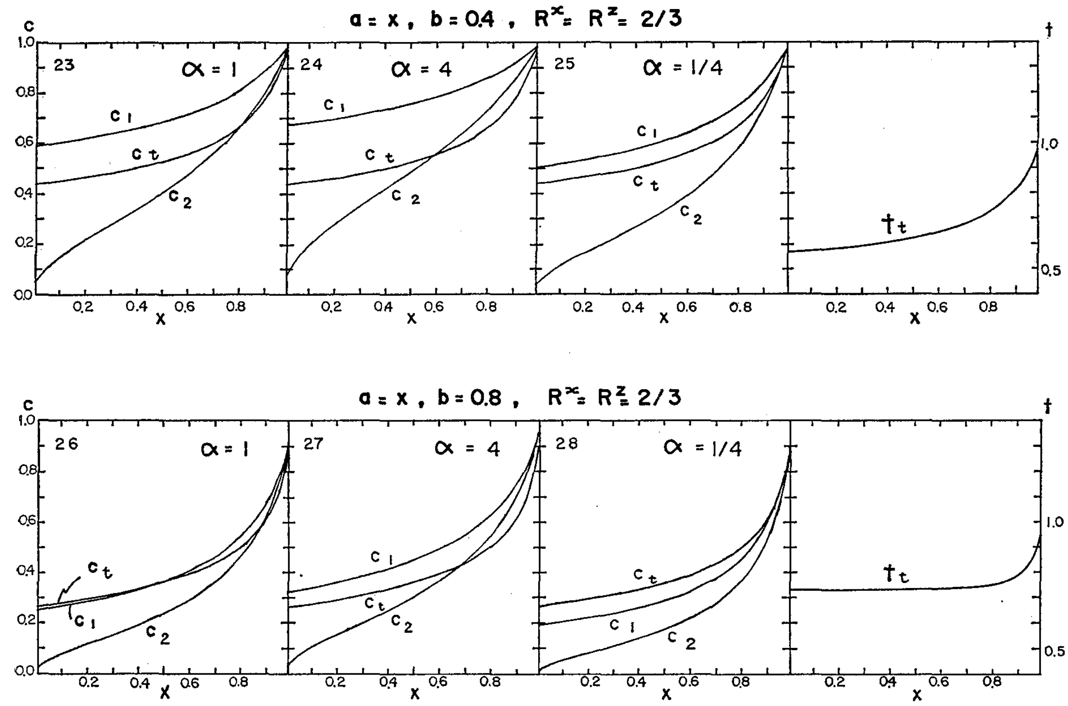

a = x , b = 0.4 , $R^x = R^z = 1$
11
α = 1
12
α = 4
13
α = 1/4
a = x , b = 0.8 , $R^x = R^z = 1$
14
α = 1
15
α = 4
16
α = 1/4
c_1
c_t
c_2
t_t
x
c
t

Fig. 7(a).



a = x , b = 0.4 , R^x = R^z = 3/2
17
α = 1
18
α = 4
19
α = 1/4
a = x , b = 0.8 , R^x = R^z = 3/2
20
α = 1
21
α = 4
22
α = 1/4
c
t
x

Fig. 7(b).



a = x , b = 0.4 , R^x = R^z = 2/3
23
α = 1
24
α = 4
25
α = 1/4
a = x , b = 0.8 , R^x = R^z = 2/3
26
α = 1
27
α = 4
28
α = 1/4
c
t
x

Fig. 7(c).

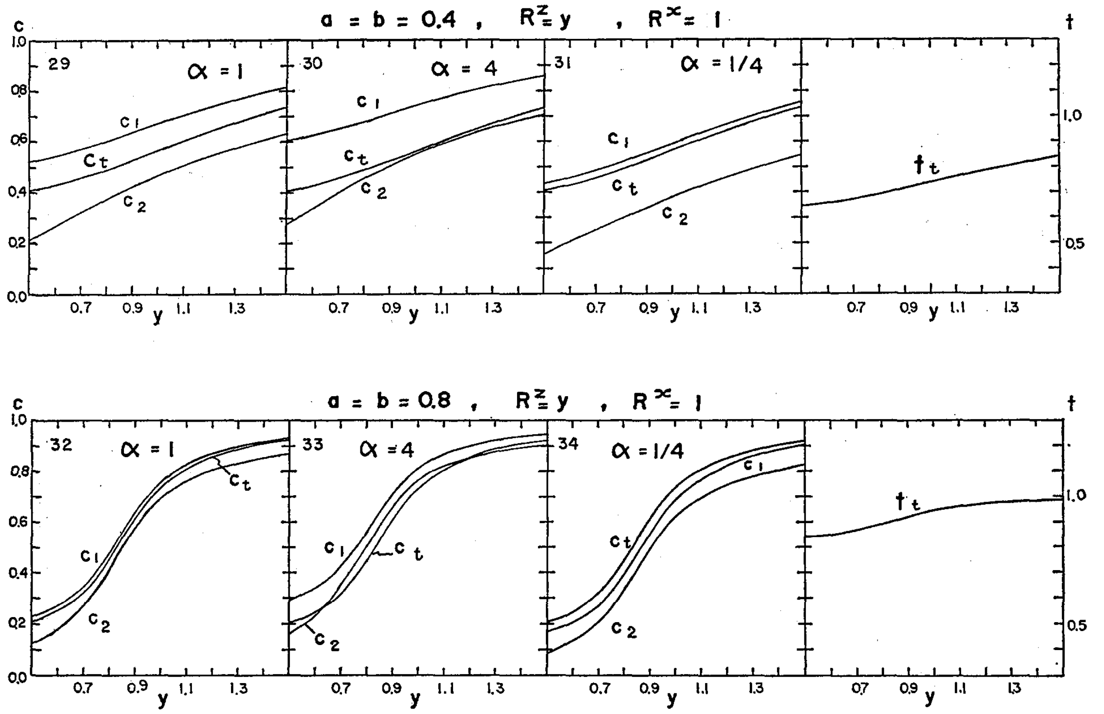

a = b = 0.4 , R^z = y , R^x = 1
a = b = 0.8 , R^z = y , R^x = 1
29 α = 1
30 α = 4
31 α = 1/4
32 α = 1
33 α = 4
34 α = 1/4
c
t
y

Fig. 8(a).

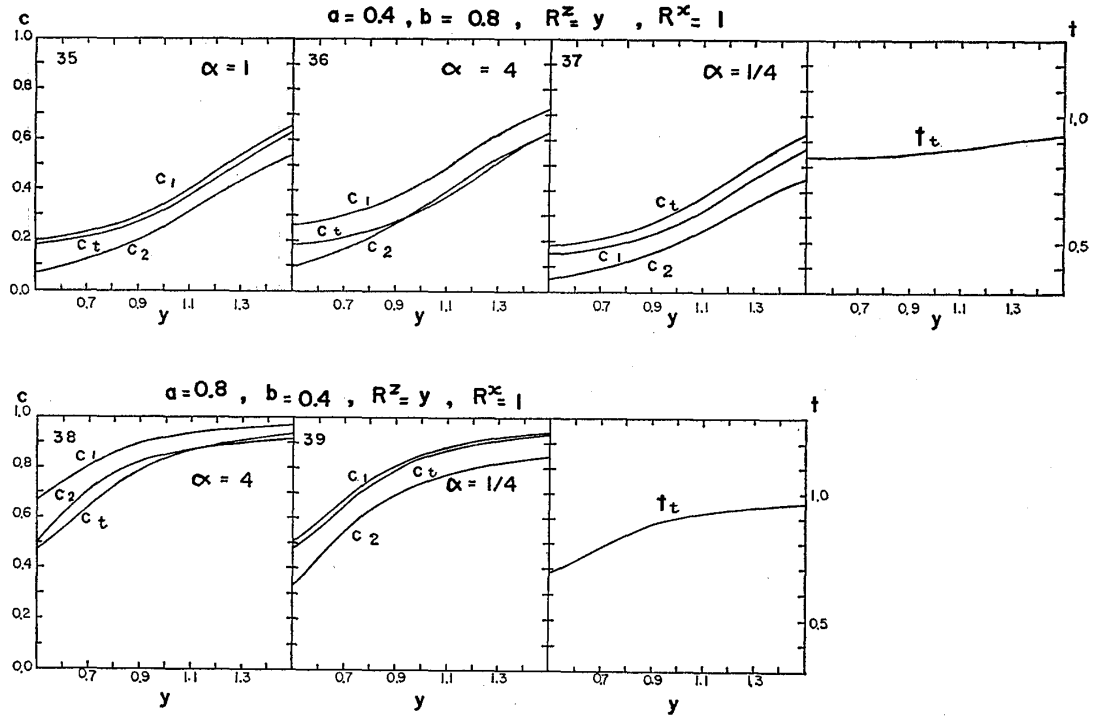

a = 0.4 , b = 0.8 , R^z = y , R^x = 1
a = 0.8 , b = 0.4 , R^z = y , R^x = 1
35 α = 1
36 α = 4
37 α = 1/4
38 α = 4
39 α = 1/4
c
t
y

Fig. 8(b).

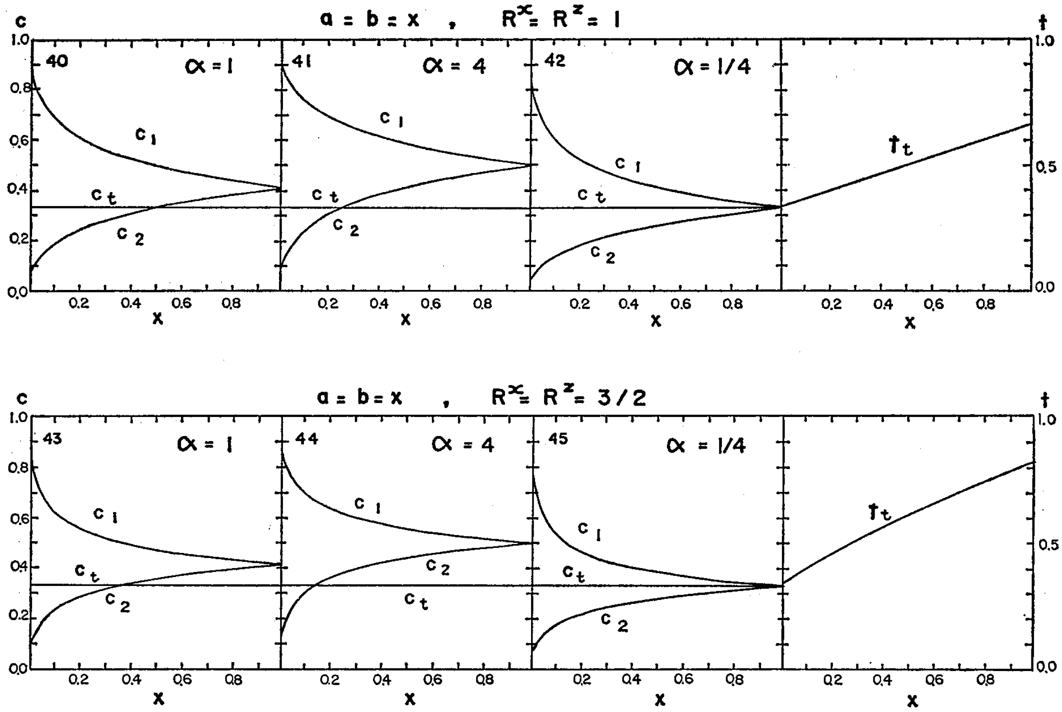

a = b = x , R^x = R^z = 1
40 α = 1
41 α = 4
42 α = 1/4
a = b = x , R^x = R^z = 3/2
43 α = 1
44 α = 4
45 α = 1/4
c
t
x
c1
c2
ct
tt

Fig. 9(a).

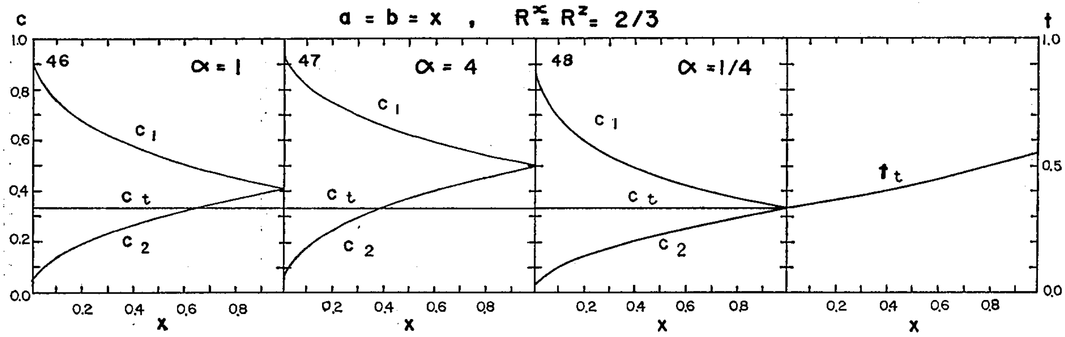

a = b = x , R^x = R^z = 2/3
46 α = 1
47 α = 4
48 α = 1/4
c
t
x
c1
c2
ct
tt

Fig. 9(b).

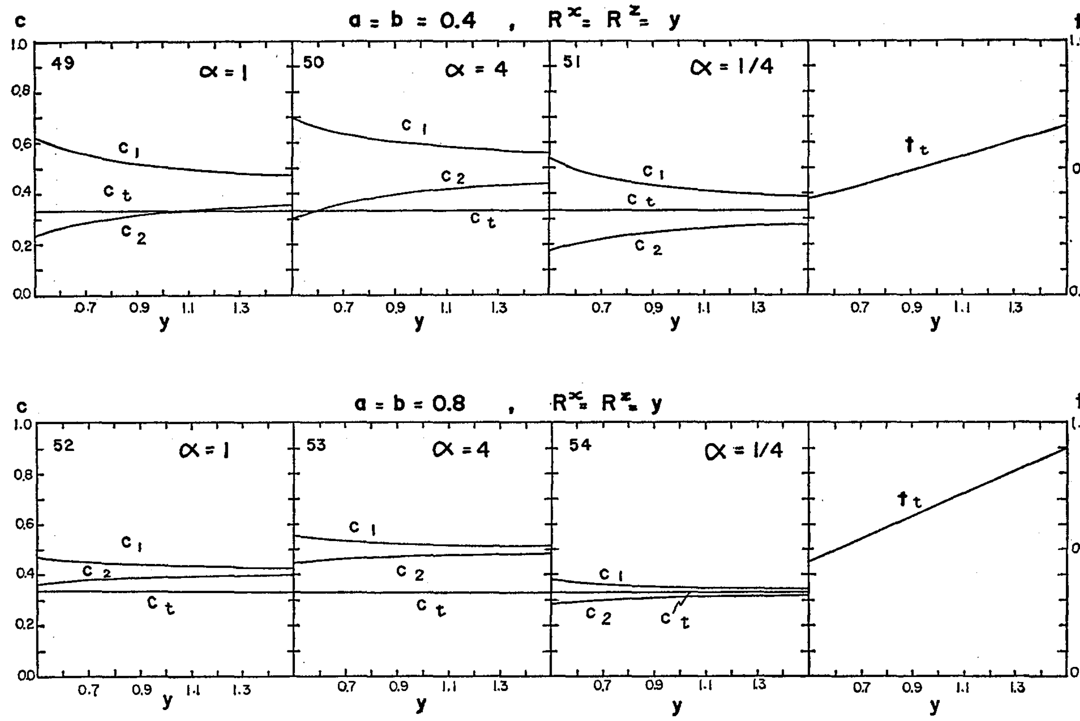


Fig. 10(a).

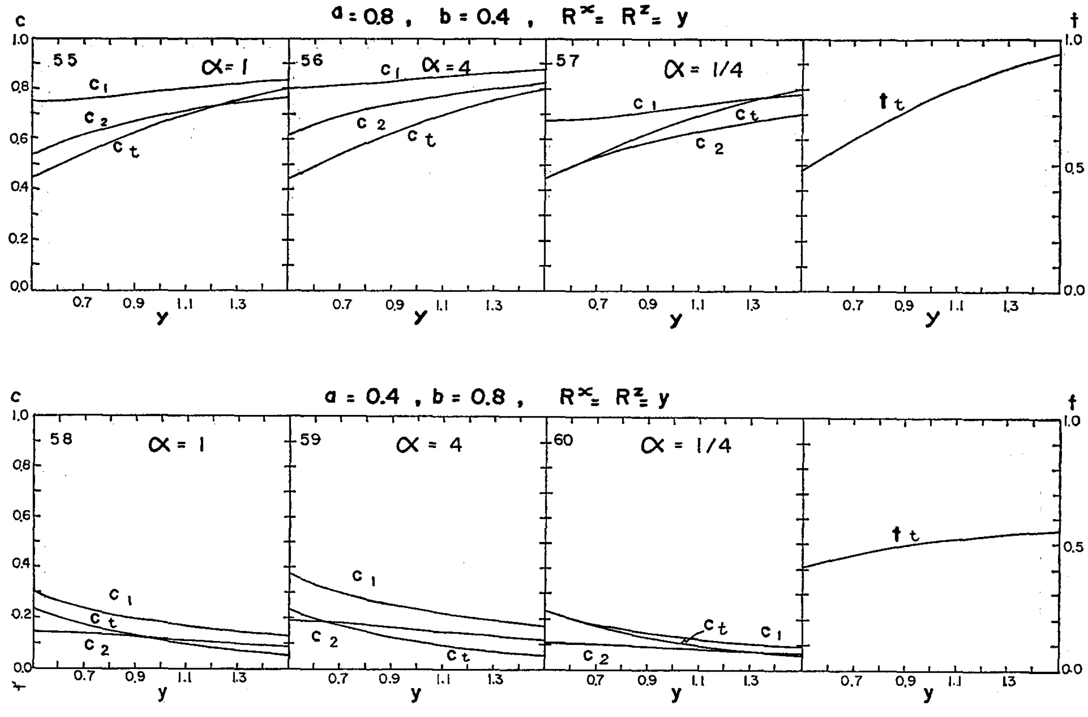


Fig. 10(b).

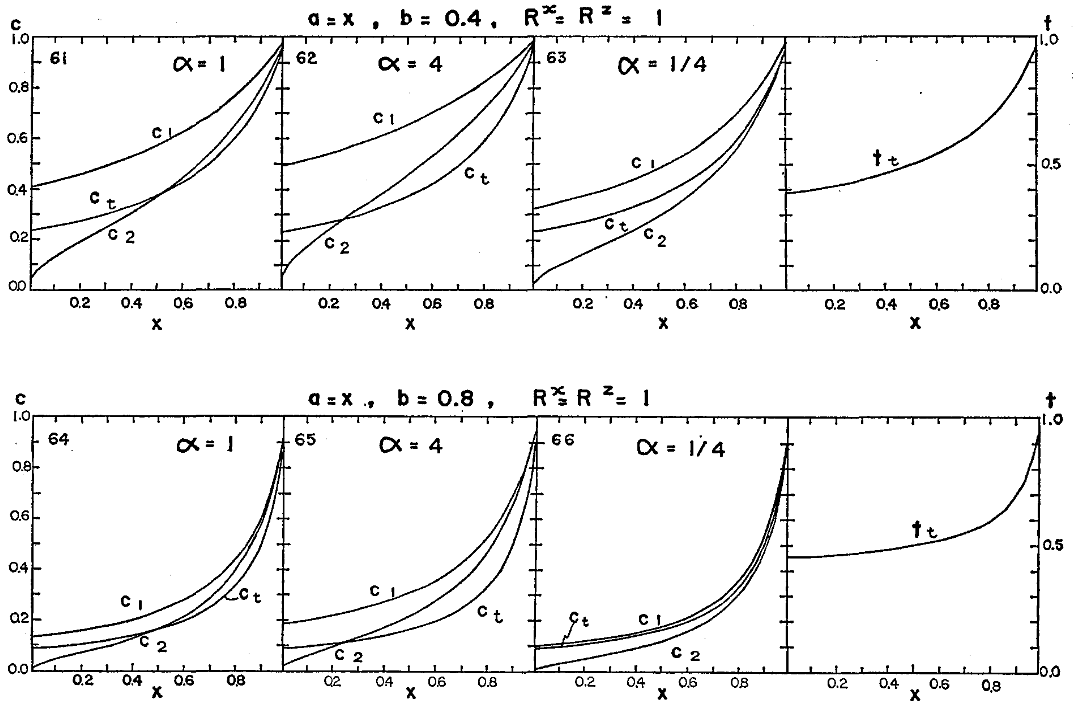


Fig. 11(a).

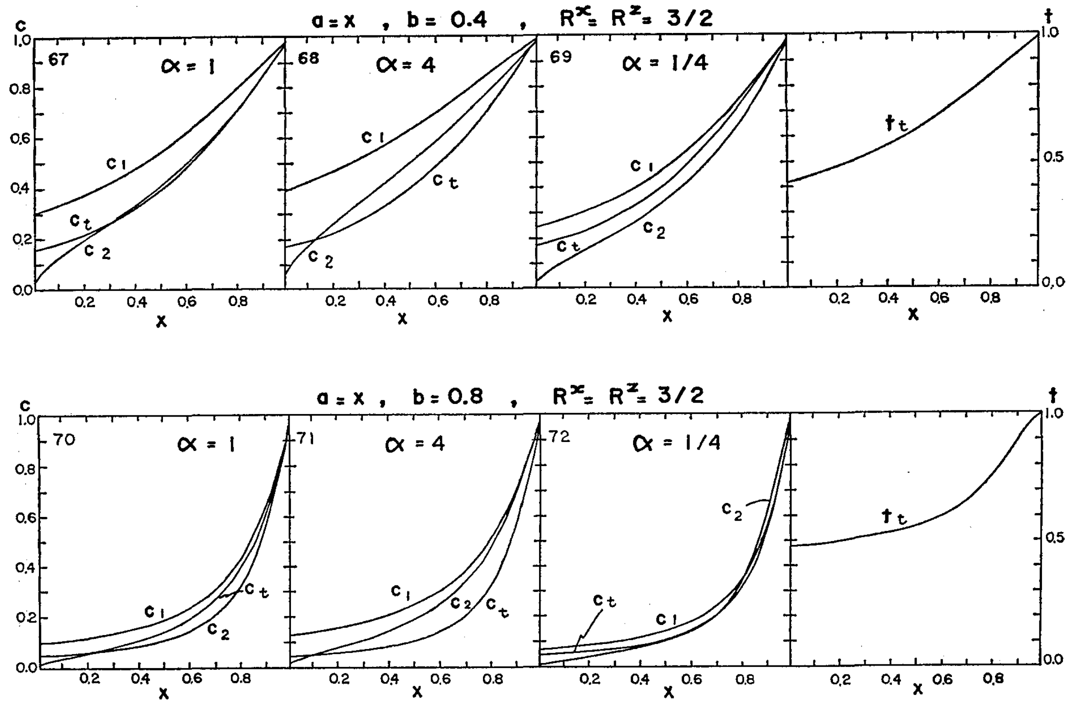


Fig. 11(b).

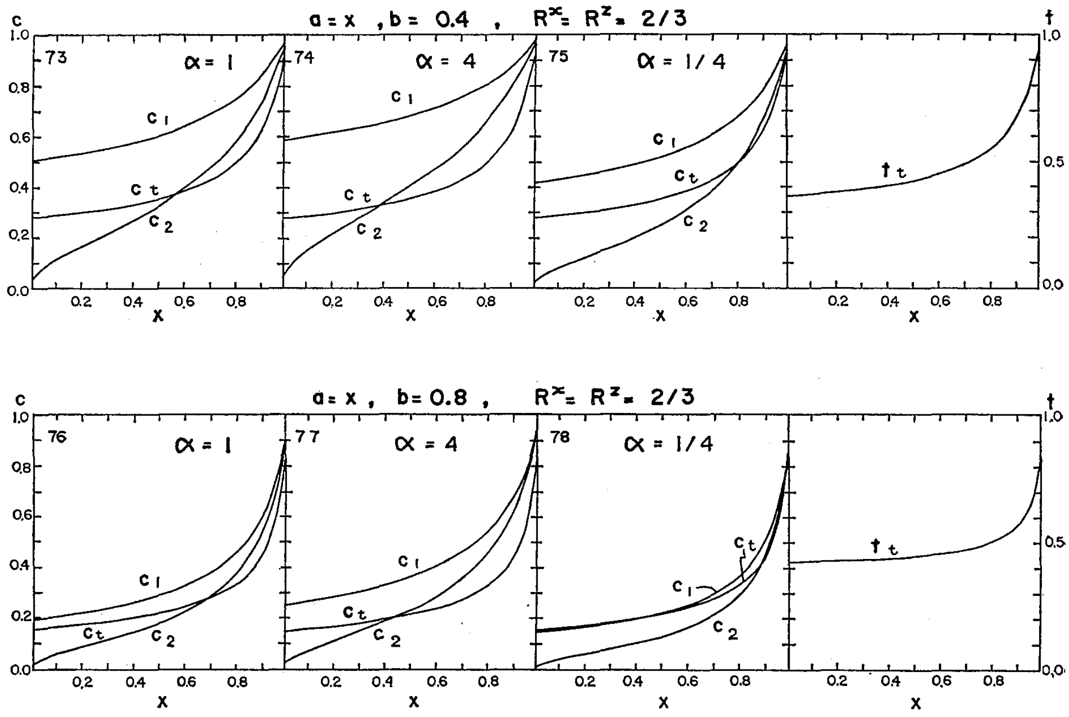


Fig. 11(c).

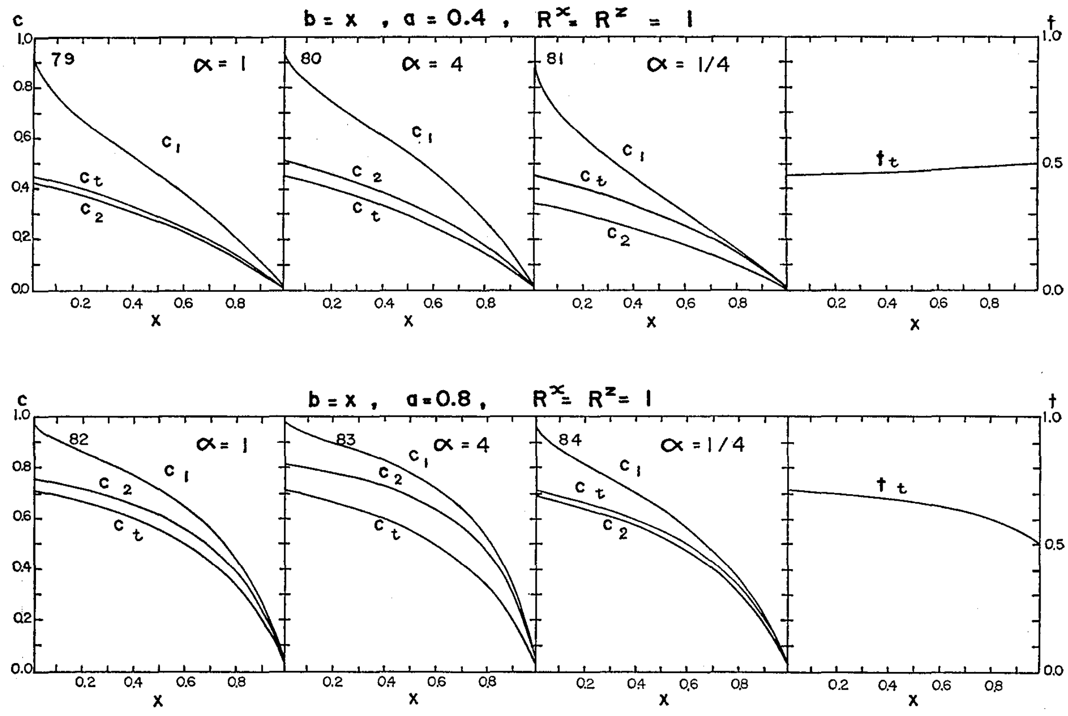


Fig. 12(a).

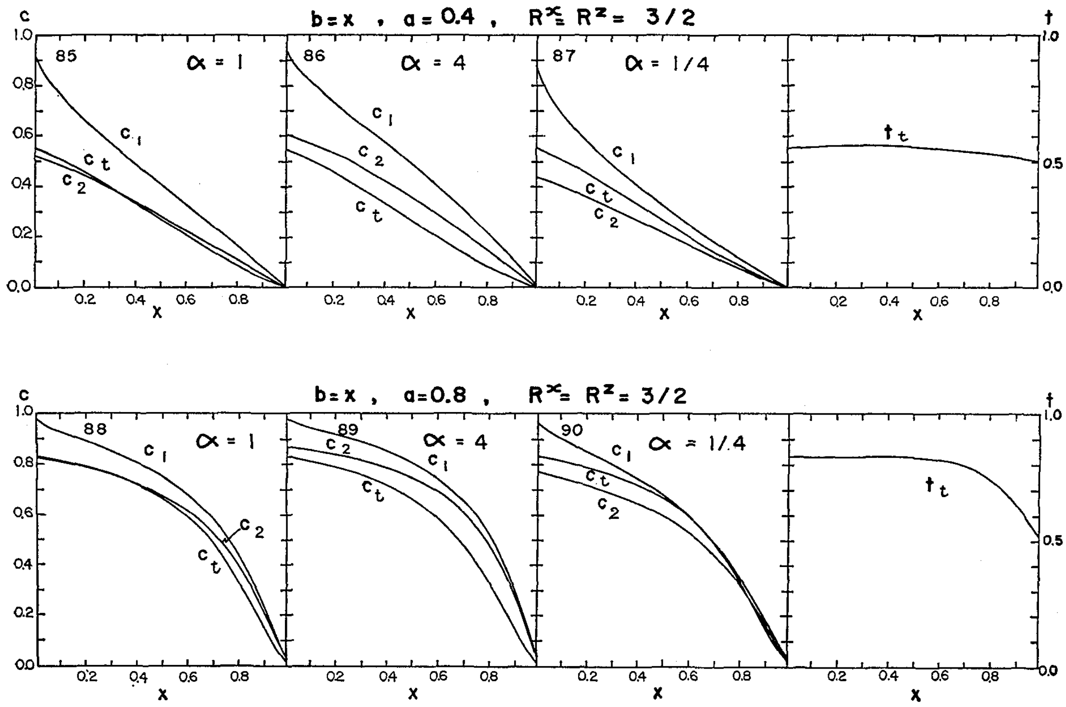


Fig. 12(b).

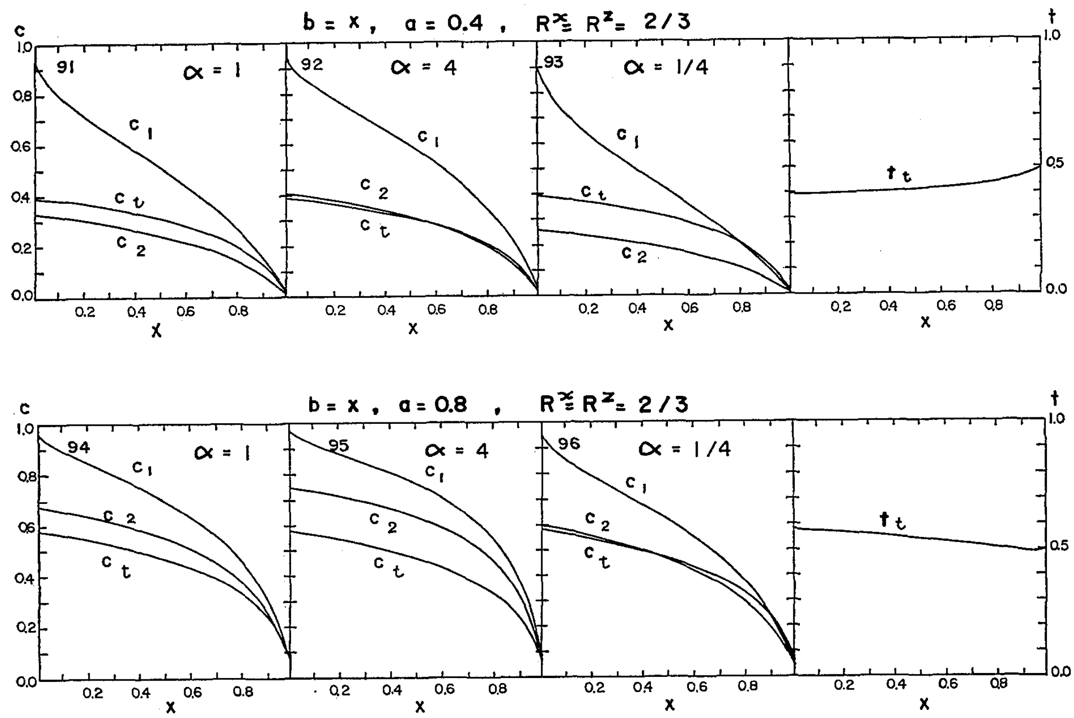


Fig. 12(c).

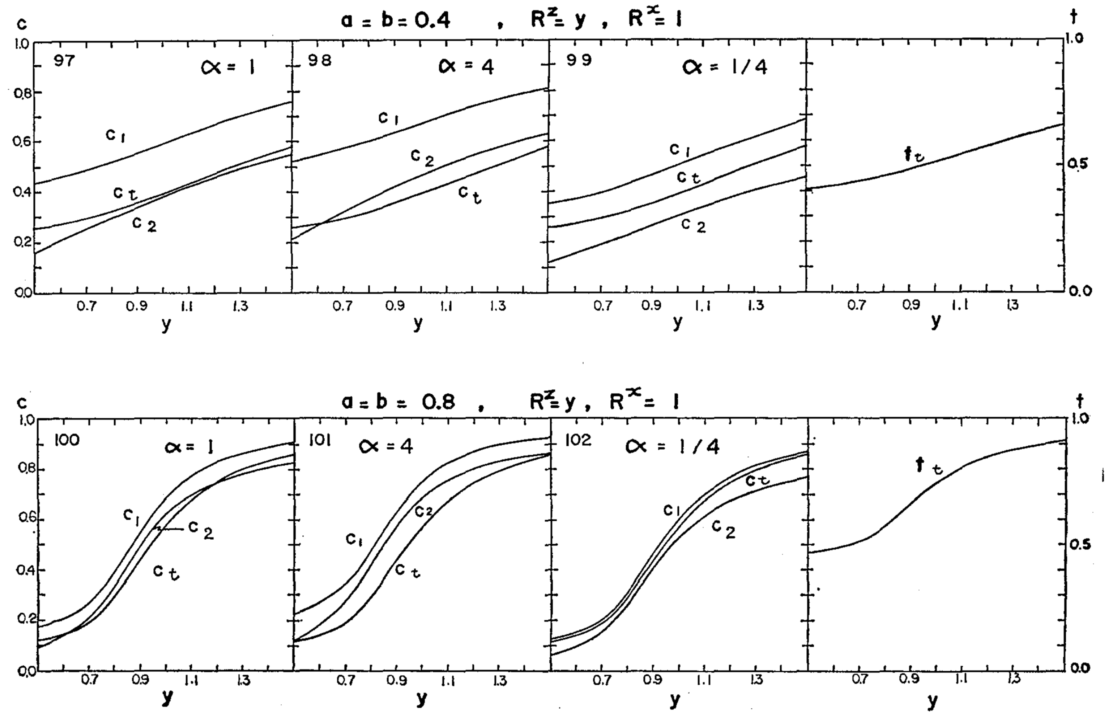


Fig. 13(a).

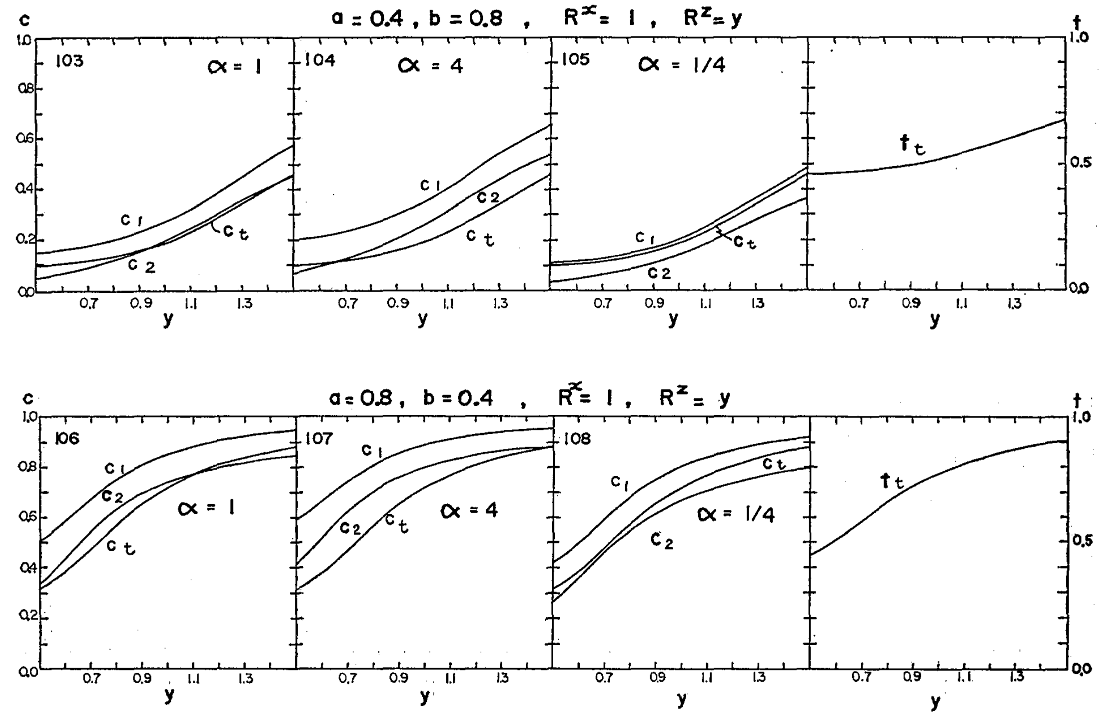


Fig. 13(b).

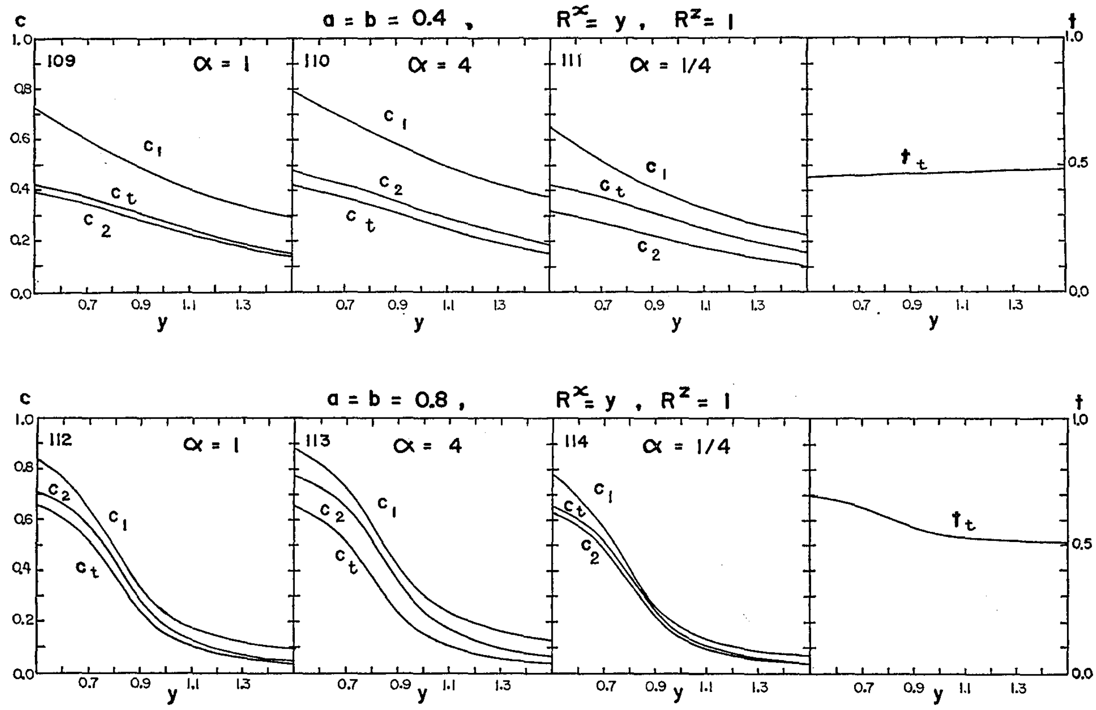


Fig. 14(a).

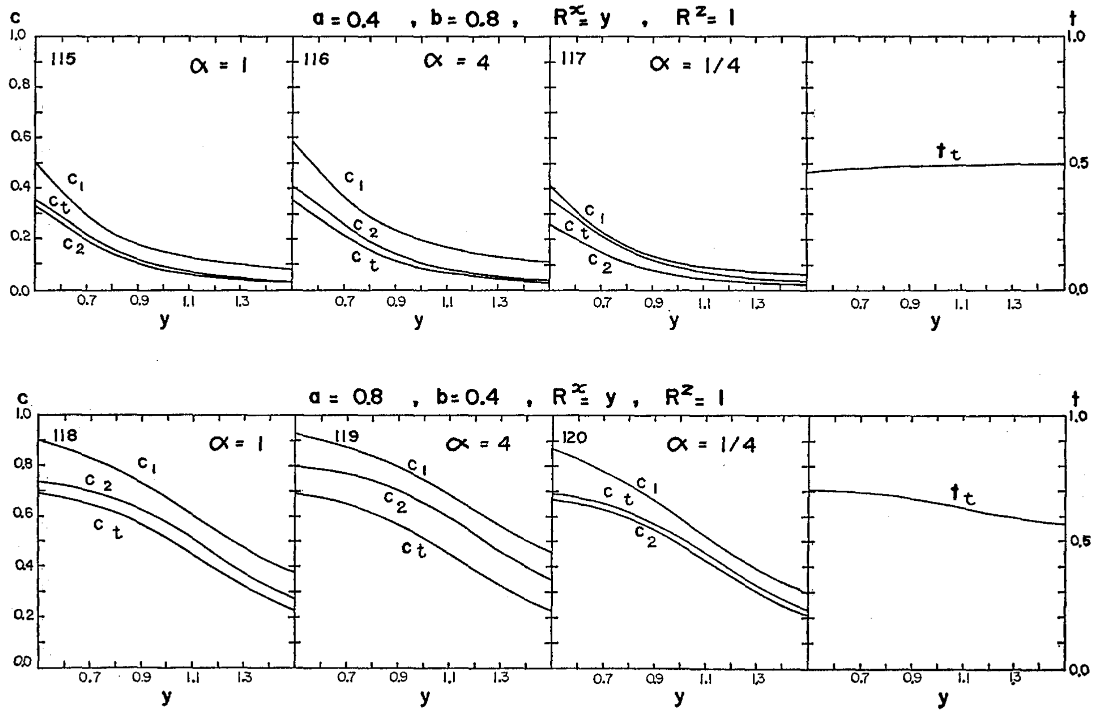


Fig. 14(b).