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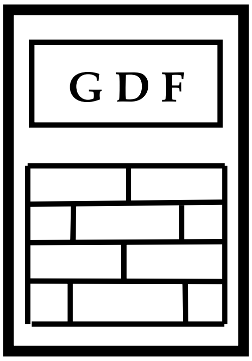
NTC – Thermistors -1



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NTC – Thermistors – 1

NTC-thermistors (materials with negative temperature coefficient) represent a typical example of materials with thermally activated electrical conduction triggered by a threshold temperature, To, below which this process is completely inhibited or has a different nature. These two main characteristics allow retrieving experimental data of electrical resistance vs absolute temperature, R(T), by using both Arrhenius and Universal representations by considering the general topoenergetic principles established on a large number of similar kinetic data. The present study takes into consideration the ratio θ(T) = R(T)/R(25) (R(25)= electric resistance at 25 ^{0}C) as the response function and U = T (in K) as the driven potential of the electrical conduction for series of selected NTC-thermistors described by 6 most important producers on their websites. Both Arrhenius and Universal representations are thoroughly reviewed and applied to these raw experimental data in view to estimate the two series of basic kinetic parameters denoted as: E= the activation energy (in kJ/mol), K = the free term in logarithmic scale (d-less) and respectively the so called Universal parameters known in general terms as (N, M, To) which univocally define the nature and amplitude of the process of electrical conduction for the considered NTC-thermistors. The main results show that: (i) roughly speaking this process has the same nature for all of them, but for more accurate experiments it is possible to differentiate specific nature depending on the exact chemical composition and processing conditions; (ii) To ranges between 80-160 K and is proportional with the kinetic entity, ln ctr, for which a structural explanation is presented; (iii) the coupling strength, CS, between inert (Cin) and transforming (Ctr) components is proportional with the ln Ctr; (iv) these results reveal new structural features of the electrical conduction in these NTC-thermistors and substantiate the existence of a phase transition at To which can be evidenced by calorimetry as more efficient experiment on materials of NTC-thermistors; (v) further experiments following the same Universal representation can establish and develop new practical properties and applications for materials used now as NTC-thermistors.

The brochure has 36 pages, 6 Tables, 15 graphics and costs 1,600 AUD.

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NTC – Thermistors – 1

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2. Introduction

NTC-thermistors are materials with negative temperature coefficient (NTC) of electrical resistance (R) as revealed both in dc and ac. More exactly, the dependence R(T) appears as a smooth exponential decrease from a threshold temperature, To, below which the electrical conduction is practically inhibited or has a different nature. It is important to notice for the further analysis of the nature (mechanism) of the electrical conduction in such materials, the fact that R(T) remains as unchanged in dc or ac polarization. These facts show that the electrical conduction is essentially given by free electrons whose density and mobility depends on the chemical structure of the material, the history of processing of the initial components and increase with temperature. At least for the commercial NTC-thermistors considered in this study, the electrical conduction does not involve directly positive ions (cations) forming the lattice as it is the case of semiconductors.

In 1833 Michael Faraday firstly observed the NTC behavior of silver sulphide (Ag2S). Now NTC-thermistors are used as commercial temperature sensors and are obtained by sintering fine powders of the transition metal oxides at high temperatures (1000-1300 ^{0}C). During sintering process these oxides undergo a solid chemical reaction forming a 3D polymeric structure whose the structural unit is the spinel (or garnet) structure of type AB2O4 or ABO2 (A,B transition metals).Literature on this topic is very rich and can be loaded from internet. Details from this literature are not relevant for the actual study.

The clear appearance of a specific threshold temperature To in R(T) characteristics was neglected up to now. On the other hand, the classical kinetic model of electrical conduction as thermally activated process based on Arrhenius principle is systematically avoided because it appears that the activation energy has negative values which have no significance in classical non-equilibrium thermodynamics. However, the experimental data of R(T) can be fitted by an Arrhenius-like eqn. with the exponent denoted as BETA instead of the activation energy.

The data of R(T) for commercial NTC-thermistors taken from the websites of 6 important companies are considered in the present study. The accuracy of these data is enough high for their retrieval according to the Arrhenius and Universal representations defined by topoenergetic principles and reviewed in details in the next chapters. The obtained results show structural aspects of the nature and amplitude of electric conduction in terms of global amplitude, value of the kinetic unit and the strength coupling between the kinetic units and inert lattice. These results reveal further properties of NTC-materials proper to other applications. However, in view to correlate the chemical composition, processing conditions and properties of NTC-materials there are necessary new experimental techniques and more accurate measurements.

3. Topoenergetic principles

Topoenergetic principles were developed starting from some experimental facts connected to the amorphous-crystalline coupling in some polyethylenes with grafted defects which apparently contradict the energy conservation law and could not be explained by the classical non-equilibrium thermodynamics [1].

The basic principle consists in considering any system in transformation as composite, i.e. it contains at least two components: one as inert, Cin, and another in transformation, Ctr. The standardized test specimen is represented according to this principle in Figure 1. The inert component Cin does not participate to the transforming process, while the transforming component defines the process amplitude and consists from kinetic units, ctr, defining the nature of the process. Starting from this point it is possible to build the energy circuit associated to the test specimen in similar manner as electric circuits by considering components with elementary behavior: dissipative, capacitive, inductive, etc. taking into account their definition and constitutive eqns. based on experimental facts.

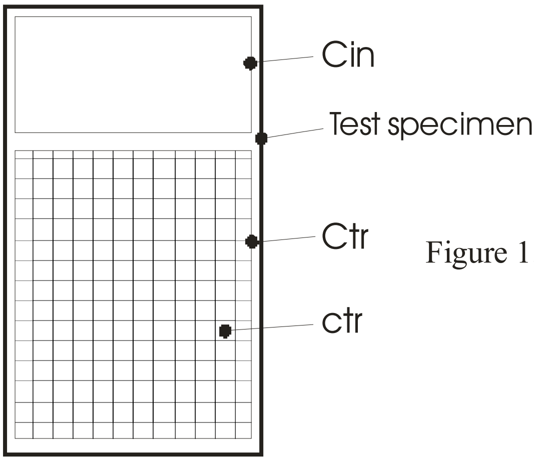

Figure 1. Topoenergetic representation of a test specimen.

This idea was firstly introduced by Oster and Auslander [2] as topological representation of non-equilibrium systems, but considering the spatial distribution of an elementary circuit, so that hard mathematical difficulties were raised and they abandoned their attempt.

The second working principle was to build the energy circuit of the all measuring system including the test specimen by avoiding the explicit spatial distribution of elementary components. Calorimetric measuring systems used to evidence most of thermally activated processes were described by this procedure [3-5] and allow evidencing also one new aspect of composite behavior of transforming systems, namely their polarity (P)[5]. This new characteristics can be easy understood by the following experiment: let us consider the calorimetric cell containing the test specimen which is transferred from an initial temperature T1 < To at which the transforming component is inhibited, to a final temperature T > To at which the process occurs. The threshold temperature To appears as a real and specific quantity of the tested specimen. In these conditions Cin is revealed by an endothermal flow, win, occurring immediately after the starting instant, but the heat flow associated to Ctr defining the amplitude of the transforming process (wtr) can be also endothermal or exothermal and appears as delayed at an induction time, ti, depending on the dissipative coupling between the two components [6, 7]. The reciprocal signs of the two heat flows as the product (sign(win))*(sign(wtr)) will define the process polarity. These principles were subsequently extended and developed for other thermal measuring systems and after that for transforming processes driven by other potentials, U, than temperature [8, 9].

The existence of a threshold value generally denoted as Uo triggering any kind of transforming process as a specific value, has been evidenced a new working principle according to which in view to reveal and measure this process in the framework of a measuring system, the test specimen must be imposed to a step like perturbation from an initial value U1 > or < Uo to a final value U < or > Uo , respectively depending on the U range where the process occurs. The test specimen is considered initially in an equilibrium state at value U1 and as a consequence of the imposed perturbation it will change towards a new equilibrium state. The measuring system which includes the test specimen allows the measurement of the time variation of a specific quantity denoted as response function, θ(t). The shape of this variation depends on the exact topological structure of the measuring system. For instance in a differential calorimetric system suitable for experiments like the once described above, the θ(t) appears as a differential curve starting from zero value and finishing for the final equilibrium also to zero value. By using an adiabatic calorimeter for the same transforming process the specific θ(t) appears as the integral function of the response function in differential calorimetric system as edged by the two equilibrium temperatures, so that the peak point of wtr (corresponding to ti) in the differential calorimetric system appears in the adiabatic calorimetric system as an inflection point corresponding to a ti value which depends on the exact values of elementary components in the topoenergetic structure of the overall measuring system (including the test specimen).

The value ti is a characteristic value from the response function denoted as eigenvalue, generally denoted as θe defining the process of transformation. This eigenvalue helps us to define the nature and the amplitude of the transforming process by identifying the values of Ctr, ctr, Uo and the coupling strength between Ctr and Cin. Taking into account that all these values are specific to the measuring system which includes the test specimen, a new working principle results according to which in view to compare and identify the nature and the amplitude of transforming processes of a series of test specimens it is absolutely necessary to test them in the same measuring system by keeping the same standard experimental conditions. In this manner a data bank is created available for the considered measuring system including the standard experimental conditions.

Before to describe in more detail the measurements according to these topoenergetic principles, let us recap them in more simple and suggestive form:

(i) any system in transformation has a composite structure consisting in an inert and transforming components;

(ii) the energy circuit associated to the system in transformation can be described by components with elementary behavior similar with the electrical circuits, without explicating their spatial distribution;

(iii) the process polarity is defined as the product of the algebraic signs of energy transfer of the inert and transforming components and is a key characteristic in defining the nature and the amplitude of the transforming process;

(iv) universal existence of the threshold value, Uo for the driving potential which triggers any kind of transforming process;

(v) the necessary and sufficient condition to compare and identify the nature and amplitude of a transforming process, is to create data banks with topoenergetic parameters obtained for test specimens of the same sample (system) and from other samples by using the same measuring system and by keeping the same standard experimental conditions.

These working principles can be better understood only by experiments. Furthermore, there are several recent applications describing them in more detail [10 – 15].

4. Arrhenius representation

Thermally driven processes obey the generally accepted Arrhenius law according to which the kinetic entity undergoes a transformation by absorbing or releasing a specific energy through the activation state characterized by the activation energy, E, so that:

$$\text{process amplitude } (\theta e) = A*\exp(-E / (kB*T)) \qquad (1)$$

where A is a pre-exponential factor, E is expressed in J/(kinetic unit), kB – Boltzmann constant in J/K and T is absolute temperature at which process occurs (in K). By considering overall transforming component of the test specimen this eqn. becomes:

$$\text{process amplitude}(\theta e) = A*\exp(-E / (RG*T)) \qquad (2)$$

where RG = 8.31451 J/((mol of transforming component)*K) is the gas constant and E is expressed in J/(mol of transforming component). In eqns (1) and (2), A is the process amplitude in condition

$$\exp(-E / kB*T), \exp(-E / RG*T) \rightarrow 1 \qquad (3)$$

which is expressed in limit of T differently in the two situations:

$$\text{for } E > 0, \; T \rightarrow 0 \qquad (4)$$

$$\text{for } E < 0, \; T \rightarrow \infty \qquad (5).$$

These relationships already announce that the two T ranges are limited by a threshold value To.

By considering topoenergetic structure of the differential calorimetric system in which Cin and Ctr are purely dissipative coupled and taking into consideration the above mentioned Arrhenius eqns, it was obtained the following kinetic eqn. [6]:

$$\ln (ti*T) = - E / (RG * T) + K \qquad (6)$$

where

$$K = \ln (Cin*RD*E / RG) \qquad (7)$$

and RD is the dissipative coupling element between Cin and Ctr and practically firstly applied for crystallization of polyethylenes [6] and curing-polymerization of epoxy resins [7] - two transforming processes with opposite polarity.

Taking into consideration that for identical specimens tested at different temperatures T in the range of (To, T) in which process occurs the ratio of Cin and Ctr keeps constant, parameters (E, K) defines the nature and the amplitude of the tested sample, otherwise said, the relationships (1) – (3) defines the individual behavior or the ontogeny of the sample relative to the standard experimental conditions in which it was tested. It results immediately a linear relationship between the topoenergetic parameters E and K obtained in the same standard experimental conditions for samples with the same nature of the transforming process, but with different ratio Cin/Ctr :

$$K = n1 * E + m1 \quad (8)$$

where (n1, m1) defines the group behavior or phylogeny of the all samples tested in the same standard experimental conditions.

These relationships are valid for any thermally driven processes revealed by a wide variety of measuring systems. For instance taking as ti the inflection point in the ductile-to-brittle transition or other amorphous modifications induced in different polymers by physical ageing above Tg (glass transition point) considered as threshold temperature [16, 17] or considering as θe the equilibrium diffusion coefficient in pure metals at different temperatures below and their melting point, Tm, as threshold temperatures.

In view to define the process polarity on the base of the quantities introduced up to now, let us consider first some particular cases with different polarities as revealed by differential calorimetry.

In Table 1 are presented 3 different transforming processes occurring in the same tested sample of polyethylene revealed by the same differential calorimetric system. Incidentally the first two transforming processes are related to the same Ctr, namely the crystalline phase while the amorphous phase belongs to the Cin. In the third transforming process the two phases change their role.

These particular cases can be generalized for a large variety of thermally driven processes as shown in Table 2 below. It results that the process polarity can be defined on the one hand by the product

Table 1. Definition of process polarity (P) in representation for three different thermally driven transforming processes occurred in the same tested sample of polyethylene as revealed by the same calorimetric system (θe = ti, U = T).

Transforming process	To	Tin	T=Tfin	win	wtr	win*wtr	E	n1	E*n1	E	P
Melting of crystalline phase	Tm	<Tm	>Tm	endo	endo	+	+	+	+	ln Ctr	+
Crystallization from the melt	Tm	>Tm	<Tm	exo	exo	+	-	-	+	ln Ctr	+
Oxidation of amorphous phase	Tg	<Tg	>Tg	endo	exo	-	-	+	-	-ln Ctr	-

algebraic sign of (win*wtr) and (E*n1), both of them directly connected.

It is important to note that:

$$\ln Ctr = \ln Cin + c \qquad (9)$$

where c is a constant for the tested sample and defines the ratio Ctr/Cin.

Fr the particular case of NTC-thermistors it was considered in the present study:

$$\theta e = R(T) / R(25) \text{ , dless and } U = T \text{ , in K} \qquad (10)$$

where R(T) and R(25) are the Ohmic resistances at T and 25 ^{0}C, respectively. This eigenvalue practically avoids the problems of instrument calibration and of the size of the test specimens, so the obtained topoenergetic parameters can be compared for a large number of samples tested in different laboratories.

Some of NTC-thermistors are described by the manufacturers only by the values of BETA parameter (in K, always as positive values) and R(25) (in Ohm), so that

$$R(T) = Ro * \exp(BETA / T) \qquad (11).$$

From eqns (2) and (11) it is possible to calculate (E, K) from (BETA, R(25)) by using the following eqns:

$$E = - BETA * 8.31451 * 10^{-3} \text{ , in kJ/mol,} \qquad (12)$$

$$K = - BETA / 298.15 \text{ , dless.}$$

5. Universal representation

For the thermally driven transforming processes, but for all other ones driven by any kind of potential, U, it has been verified the following Universal kinetic eqn:

$$\ln \theta e + N * \ln |U - Uo| + M \tag{13}$$

where parameters (N, M, Uo) define the ontogeny or the individual behavior of a tested sample in the above mentioned standard experimental conditions. It results that for a series of samples showing the same nature of the transforming process in the same standard conditions, but differing with its amplitude (different Ctr/Cin ratios) always exists a phylogeny relationship:

$$M = n1 * N + m1 \tag{14}$$

where phylogenic parameters (n1, m1) define the behavior of the group of samples tested in the same standard experimental conditions.

By studying a large variety of transforming processes (some of them already cited), it was possible to establish the process polarity and its relationship with the above defined parameters (Table 3). Polarity, P, for particular case of thermally driven processes remains in the Universal representation in the same relationship with the algebraic sign of (win*wtr) as in Arrhenius representation (Table 2).

6. NTC – thermistors considered

In Tables 4-6 are presented NTC-thermistors considered in the present study by manufacturer, manufacturer's codes, associated codes attributed in the present

Table 2. Process polarity as defined in Arrhenius representation.

K = n1*E + m1

win*wtr	E*n1	Polarity, P	E
+	+	+	ln Ctr
-	-	-	- ln Ctr

Table 3. Process polarity as defined by Universal representation.

M = n1*N + m1 , for n1<0

N*n1	N	P	M	- M/N	- N^2/M
+	-ln Ctr	-	ln Ctr	ln ctr	CS
-	ln Ctr	+	-ln Ctr	-ln ctr	-CS

study and their values of R(25) (in kOhm). The manufacturer is mentioned by his website from which the data are taken. The codes attributed in this study are simplified in view to better evidence them directly on the graphics.

7. Results

www.thermistor.com shows their products only by he parameters (BETA, R(T)), so that it was possible to estimate (E, K) according to above eqns (12). The Arrhenius phylogenies of the two series of products from Table 4 are separately represented in Figures 2 and 3 in view to better reveal each sample. Parameter n1 estimated by linear regression shows that both series have the same nature of electrical conduction in Arrhenius representation of the considered standard experimental conditions. According to the assignments given in Table 1 and 2, the polarity of this process results to be negative (P -), so that a differential calorimeter simultaneously coupled to a tested specimen submitted to measurement of electric resistance, could evidence win as endothermal and wtr as exothermal. The experiment consists in stepwise temperature increase from an initial temperature below the threshold point To to a final temperature over To where both measurements (calorimetric and electric) are carried out. In these conditions win has an obvious endothermal sign while wtr is exothermal as the result of Joule effect of electric current through the tested specimen. The electron density increases with temperature and represent the main part of Ctr. As in the case of diffusion processes, also a part of hosting lattice is involved in Ctr [10].

Figure 4 shows the Arrhenius phylogeny for NTC-thermistors produced by www.ametherm.com. Parameters (E, K) are obtained by linear regression of the Arrhebius eqn (2) in logarithmic form by considering the process amplitude as θe (eqn (10)), with high correlation coefficients (>0.999). Parameters (n1, m1) are obtained also by linear regression, but result a little different from the previous products mainly caused by the estimation procedure. The same comments are available. It is important to verify the increasing direction of lnCtr along the sample series on the graphic as resulted from the general principles (Table 1 and 2) and the variation of (R(-40)-R(25)) (Table 5).

The complete values of θe(T) allow obtaining the Universal ontogenic parameters (N, M, To) by nonlinear regression according to eqn (13) and subsequently the phylogenic parameters (n1, m1) by linear regression according to eqn (14).Both regressions result with high correlation coefficients (>0.999).

Figure 5 shows the Universal phylogeny of these products and the assignments of the ontogenic parameters as shown in Table 3. The process polarity results also negative, so are available the same comments made for their Arrhenius representations. However, the increasing sequence for ln Cr has changed some samples in Universal representation relative to Arrhenius one. More detailed structural analysis of tested samples can verify what representation is more accurate.

Another important result obtained is the linear relationship between To and -M/N, this is in fact a direct measure of ln ctr by To (Figure 6). This result is essential in detailed identification of kinetic entity for the electrical conduction in this type of materials in correlation with structural data.

Universal representations allow to better separate individual behavior of tested samples than Arrhenius representation. Figure 7 and 8 shows distinct behavior of two groups of samples in the relationship between ln ctr and ln Ctr. Figure 6 shows a unitary behavior of sample series, while Figure 8 separates samples in two distinct series with apparent changed the increasing order in ln ctr according to To if we consider To ~ - ln ctr as a general principles. This result would be in contradiction with the increasing order in Figure 7. It results that parameter –M/N gives the real increasing order of ln ctr.

Although the nature of electrical conduction process for all these samples results from M(N) graphic to be the same, the two groups show structural differences originating from chemical composition and/or processing procedures.

Figure 9 shows a linear relationship between coupling strength, CS (Cin, Ctr), and the process amplitude, ln Ctr. It results also a unitary behavior along all series of samples and is common for other transforming processes studied (see cited references). If we compare Figures 6 and 9 it results that for almost all samples in the series the amplitude of conduction process (Ctr) increases together with the kinetic entity (ctr), but decreasing CS. This means that Ctr increases with the size of kinetic entity, so that CS is greater for small kinetic entities for which the overall active surface (interaction surface between Ctr and Cin) is greater than for bigger kinetic entities.

Figures 10 – 15 show the Arrhenius and Universal representations of the products from Table 6 for which the same comments as above are available. However, the diversity is bigger indicating structural differences originating both from chemical composition and processing conditions. In this way manufacturers can identify the exact structural explanation for their samples in these graphics.

Table 4. Codes attributed to the thermistor selections from www.thermistor.com

code	part size	R(25),kOhm
1	402	10
2		10
3		100
4		100
5	603	1
6		10
7		10
8		10
9		10
10		10
11		30
12		50
13		100
14		100
15		200
16		300
17		400
18		500
19	805	5
20		10
21		10
22		10
23		30
24		50
25		100
26		200
27	QT0805K-500	0.05
28	QT0805K-101	0.1
29	QT0805X-102	1
30	QT0805T-202	2
31	QT0805Y-502	5
32	QT0805Y-103	10
33	QT0805Y-203	20
34	QT0805Z-503	50
35	QT0805Z-104	100
36	QT0805P-685	6,800
37	QT0805P-106	10,000

Table 5. Codes attributed to the thermistor selection from www.ametherm.com (all items with R(25) = 1 kOhm)

code	R(-40)
	kOhm
A	13.1
B	14.4
C	15.37
G	15.45
H	16.88
I	18.55
M	21.39
N	30.75
L	33.74
R	36.09
Q	40.7
S	63.29

Table 6. Codes attributed to the thermistor selections from the mentioned manufacturers

manufacturer	code	manufacturer's code	R(25) kOhm
www.YSI.com	Y1	L-100	0.1
	Y2	L-300	0.3
	Y3	L-1000	1
	Y4	B-2252	2.252
	Y5	B-5000	5
	Y6	H-10000	10
	Y7	H-30000	30
	Y8	H-100k	100
	Y9	H-300k	300
	Y10	H-1M	1000
www.betatherm.com	B1	1K1A1	0.1
	B2	1K2A1	1
	B3	3K3A1B	3
	B4	50K6A1B	50
	B5	1k7A1	1
	B6	2K3A1B	2
	B7	2.23A1B	2.252
	B8	10K4A1B	10
	B9	30K5A1B	30
	B10	30K6A1B	30
www.thermometrics.com	1	1	3.264#
	2	2	2.856#
	3	3	3.243#
	4	4	2.720#
	5	5	3.045#
	F	F	3.274#
	G	G	3.522#
	H	H	3.176#
	Y	10 KY	2.956#
	X	GC8	3.8085#
www.omega.com	O1	2.252, 3, 5	
	O2	10	
	O3	30	

values of R(0 oC)/R(25 oC)

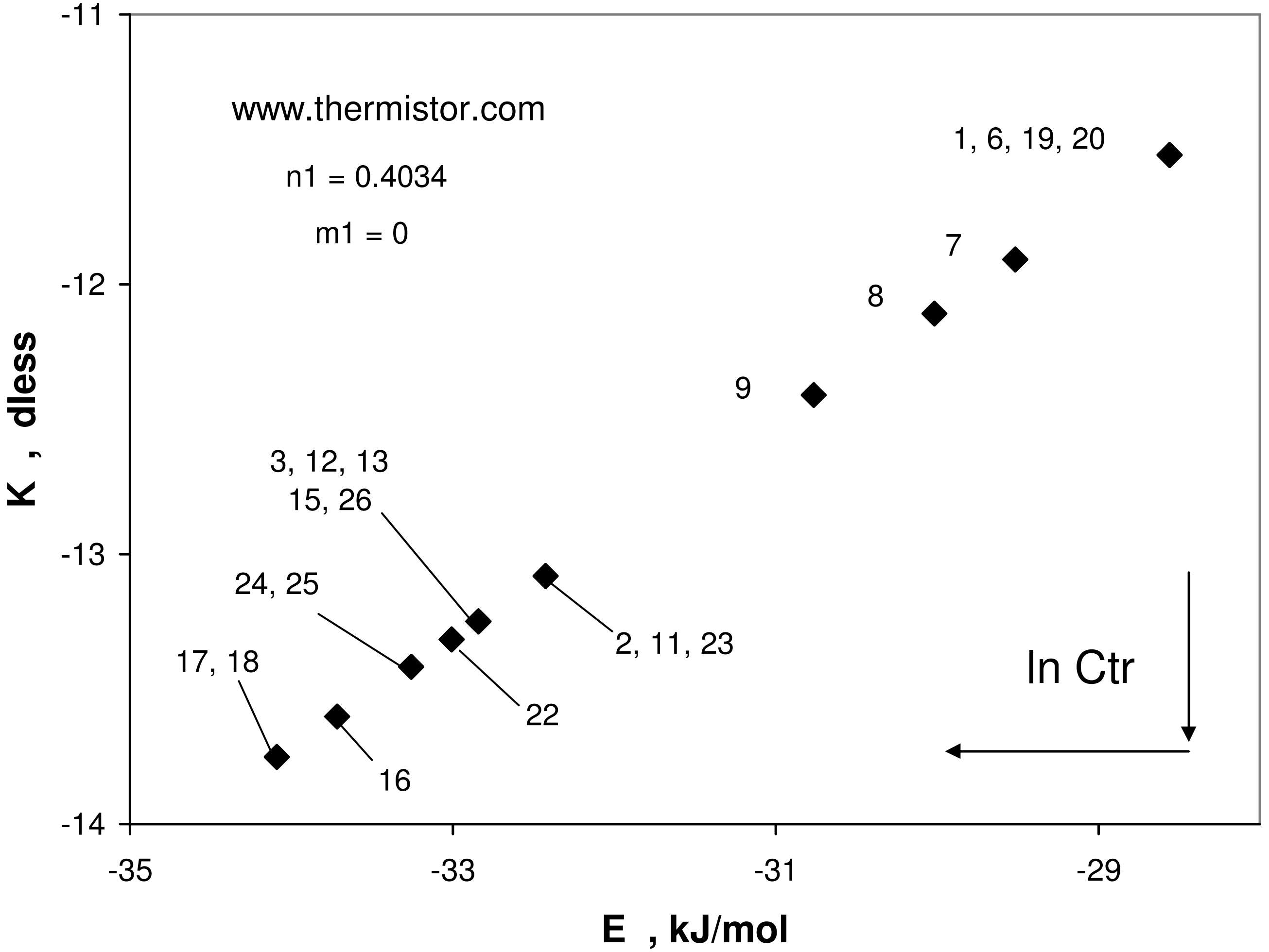

Figure 2. Arrhenius phylogeny of NTC-thermistors from Table 4 (left column).

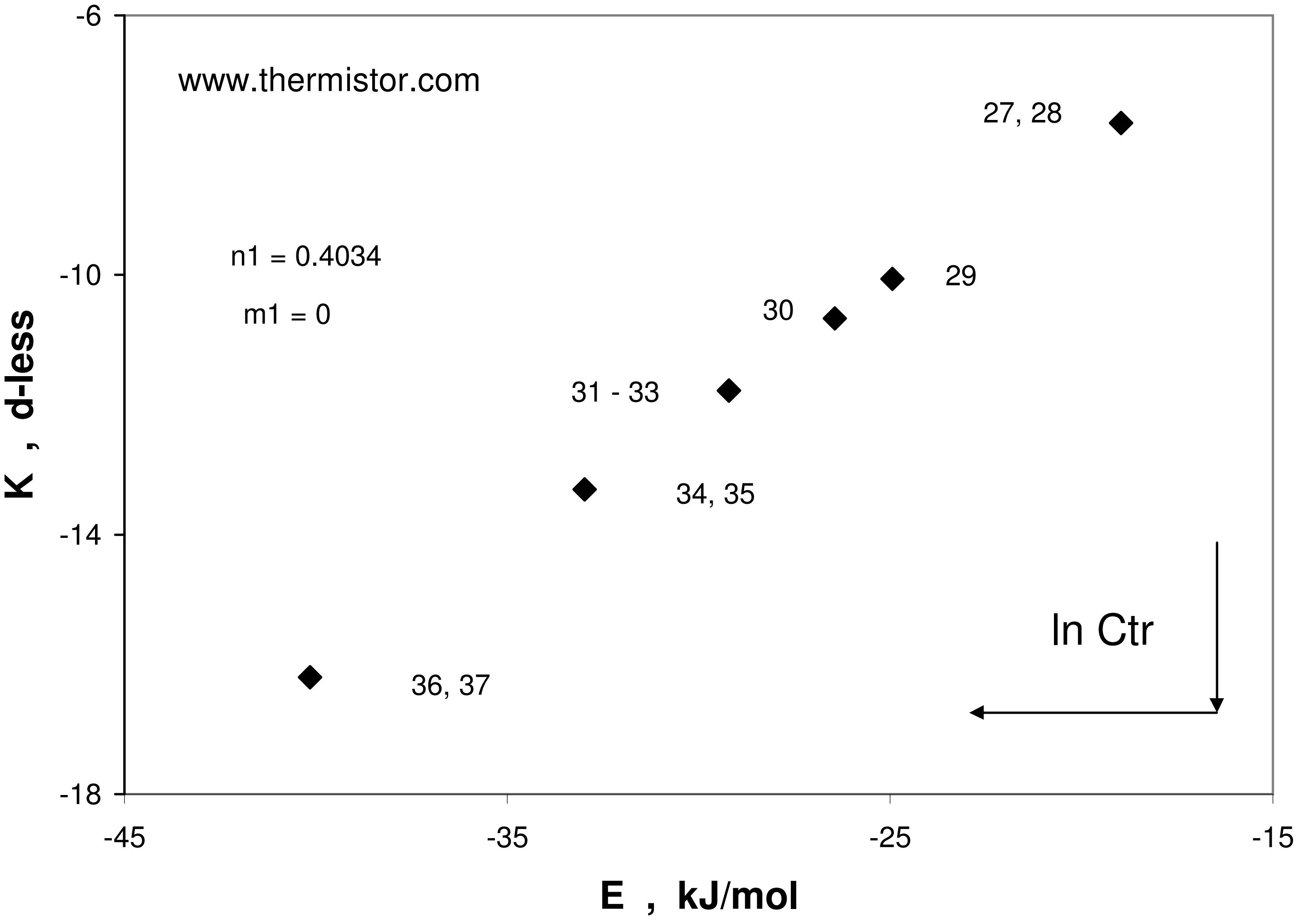

Figure 3. Arrhenius phylogeny of NTC-thermistors from Table 4 (right column).

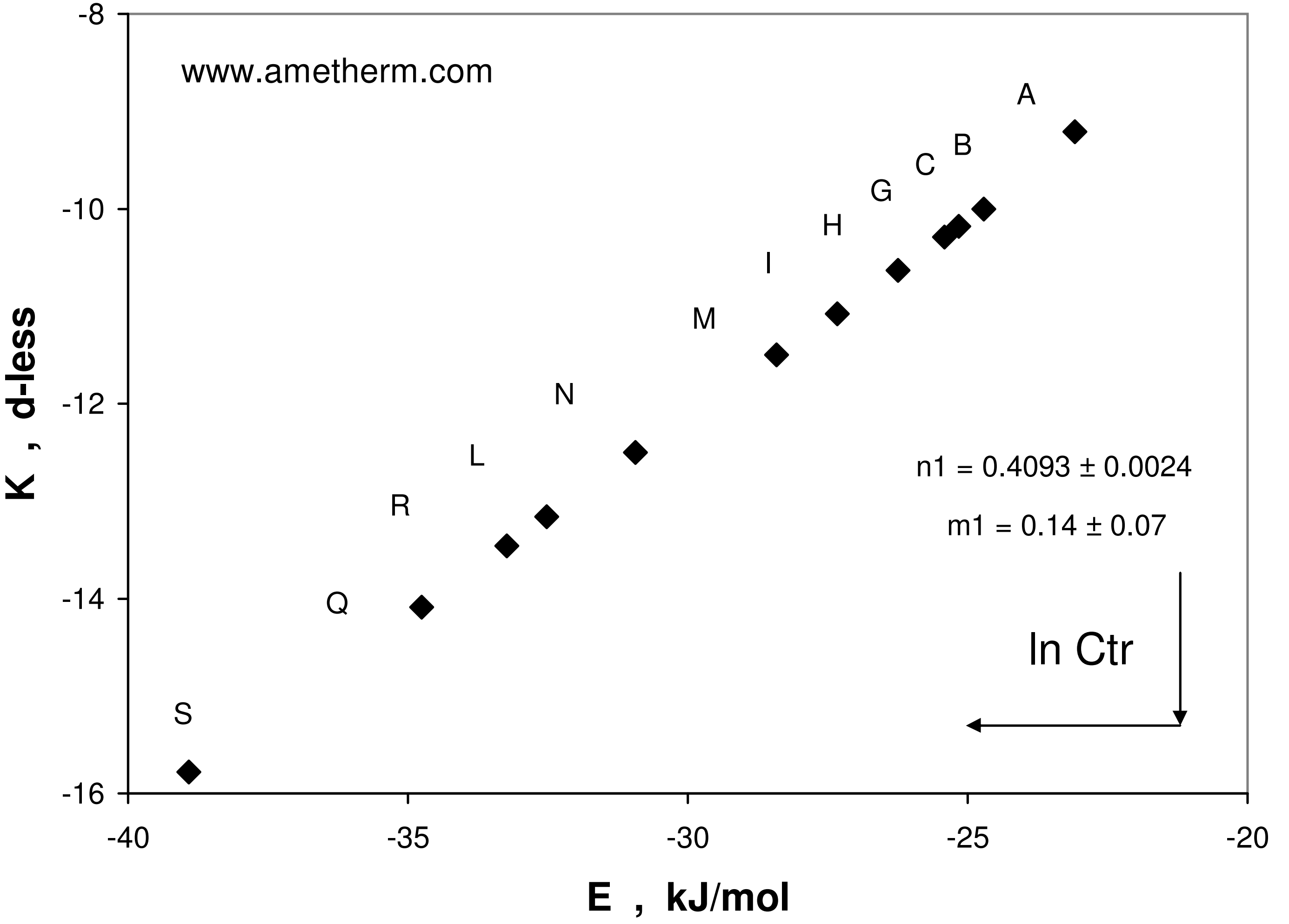

Figure 4. Arrhenius phylogeny of NTC-thermistors from Table 5.

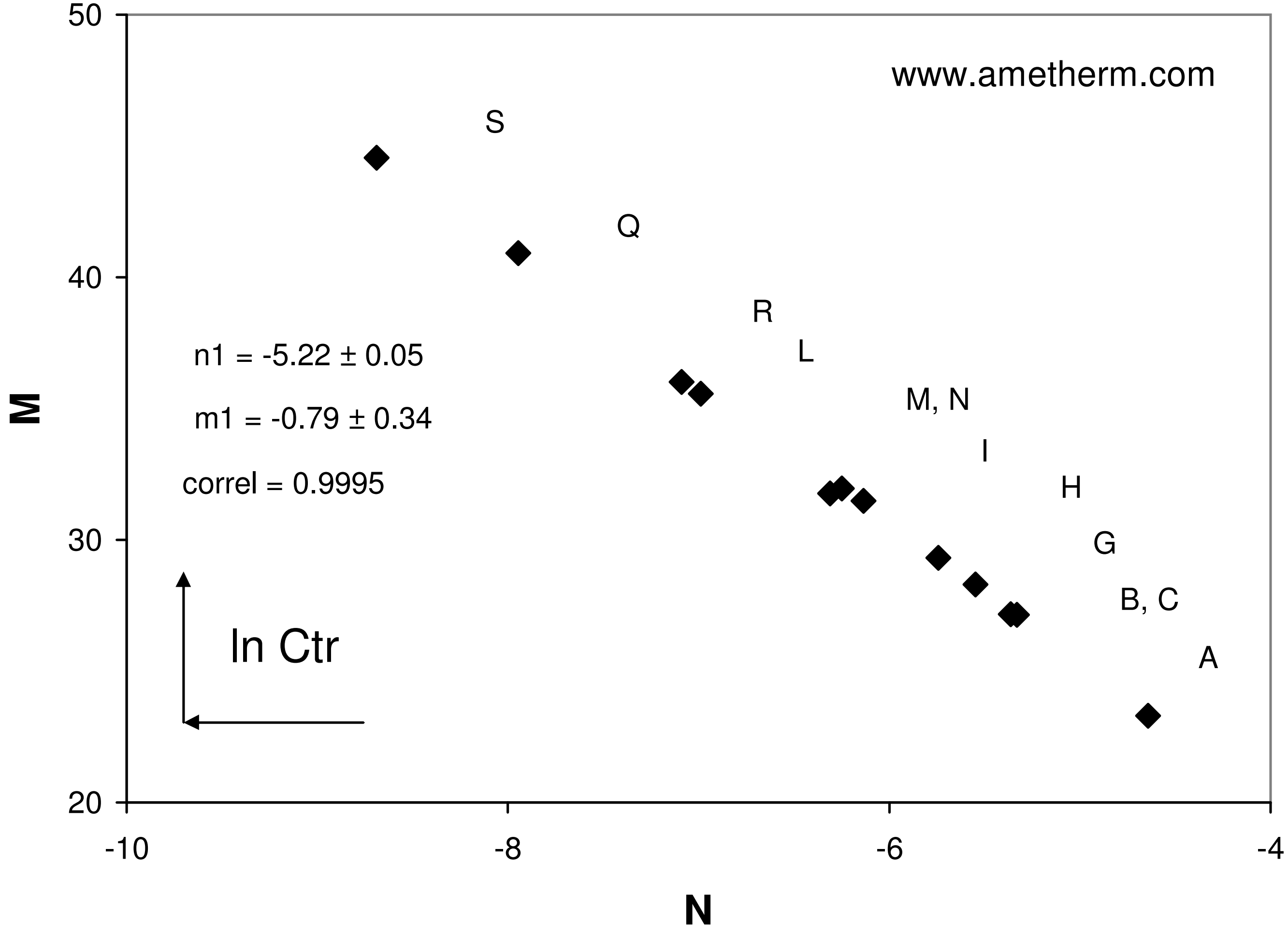

Figure 5. Universal phylogeny of NTC-thermistors from Table 5.

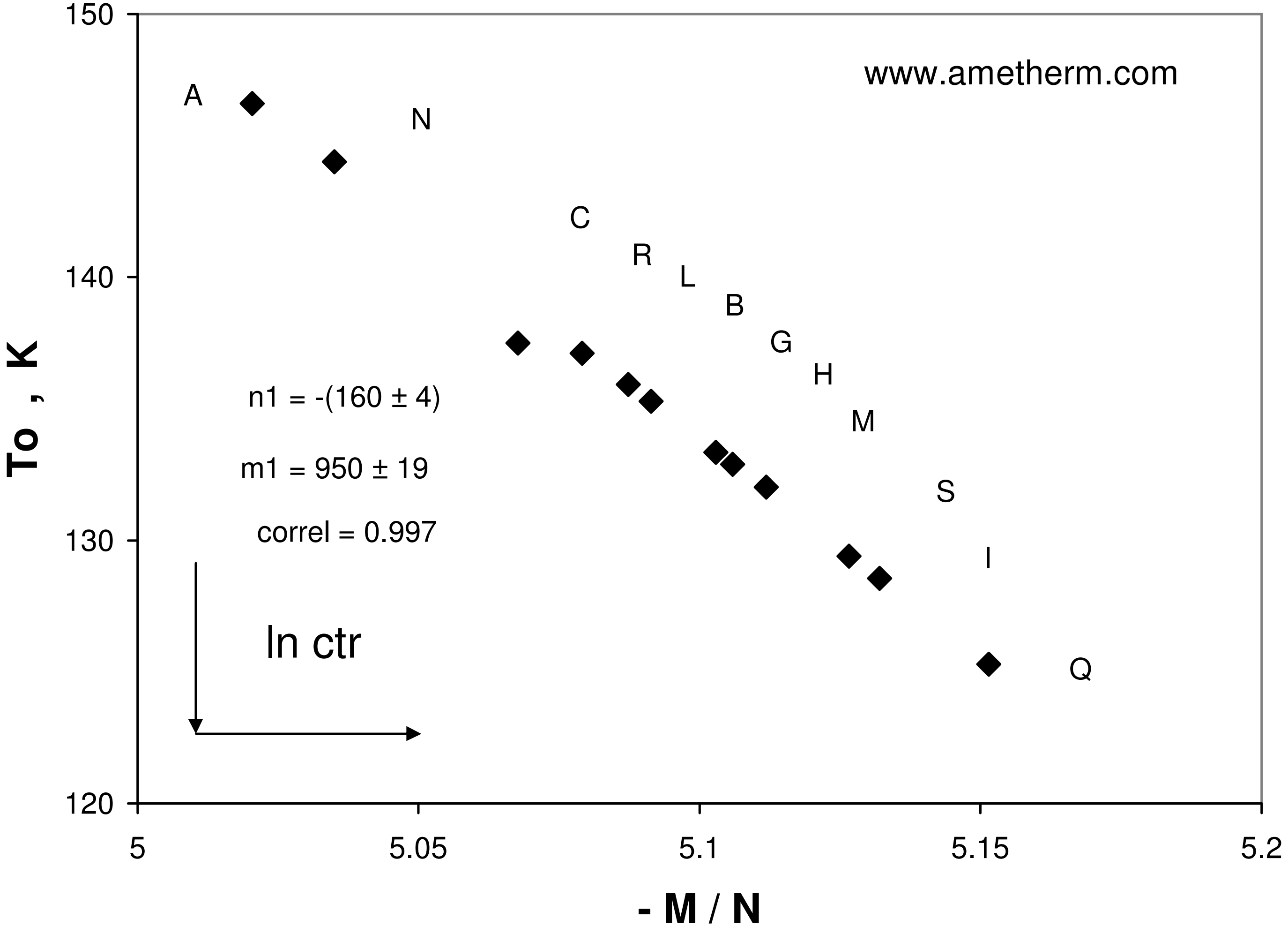

Figure 6. To vs -M/N for NTC-thermistors from Table 5.

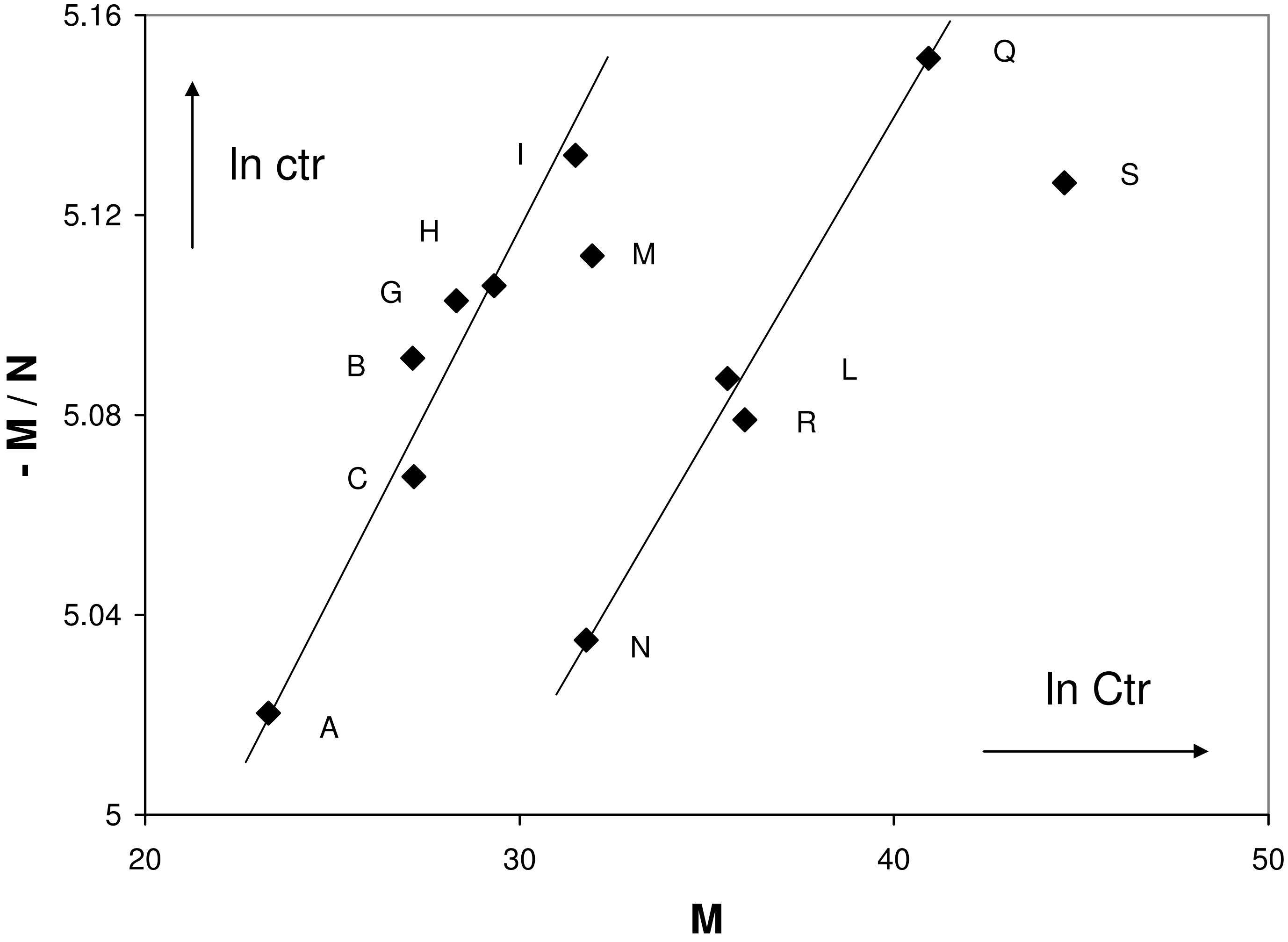

Figure 7. -M/N vs M for NTC-thermistors from Table 5.

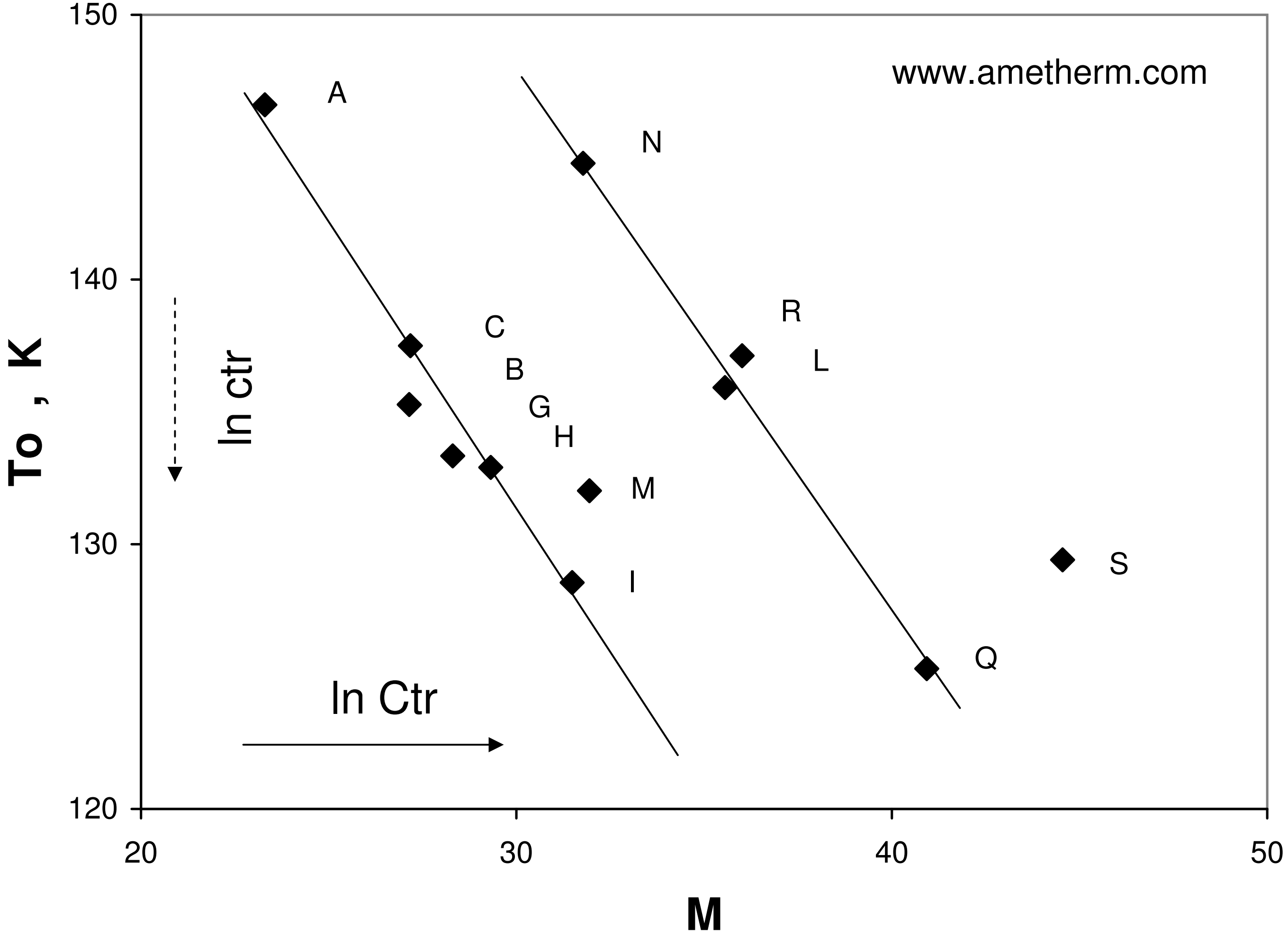

Figure 8. To vs M for NTC-thermistors from Table 5.

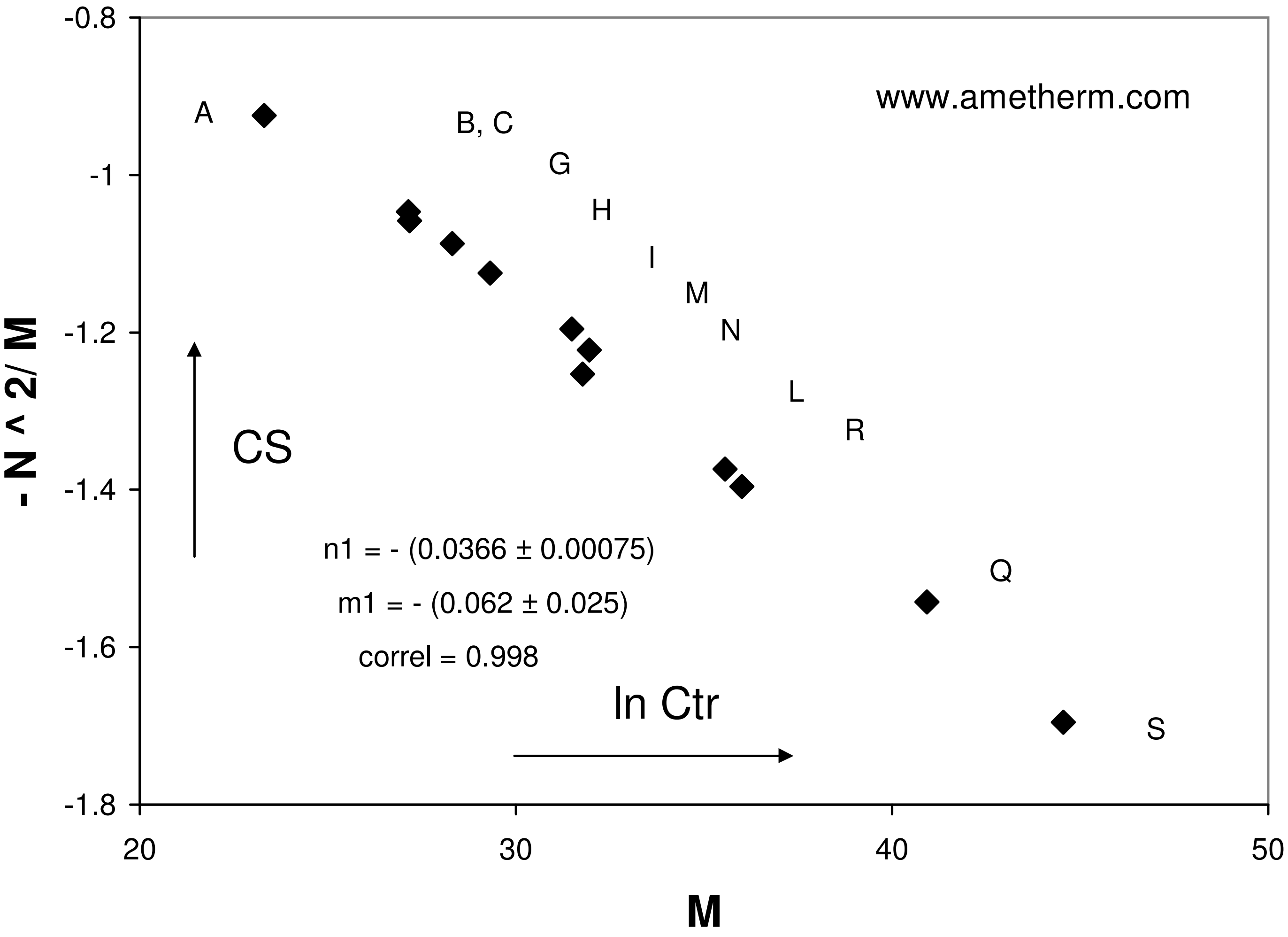

Figure 9. -N^2/M vs M for NTC-thermistors from Table 5.

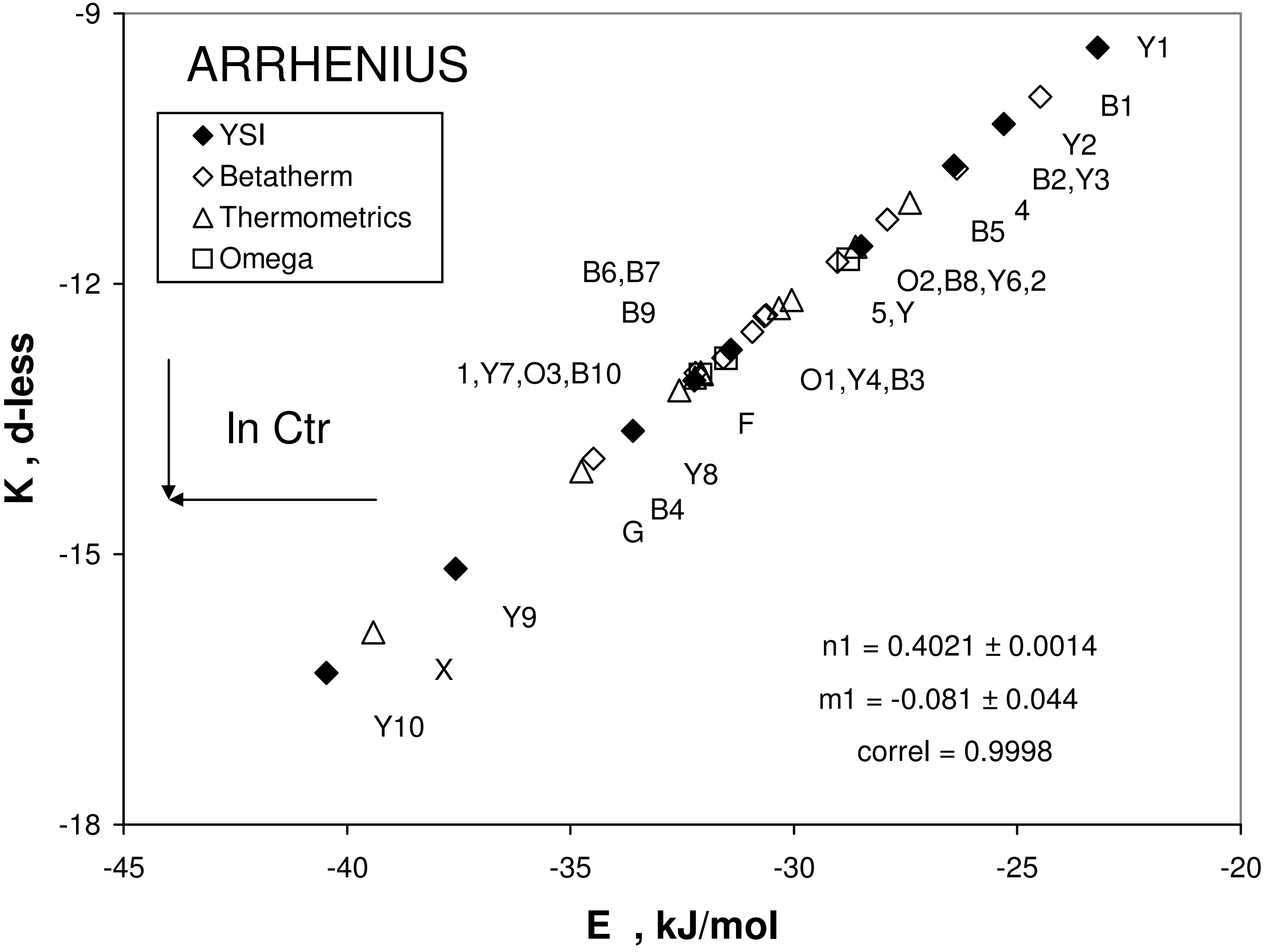

Figure 10. Arrhenius phylogeny for NTC-thermistors from Table 6.

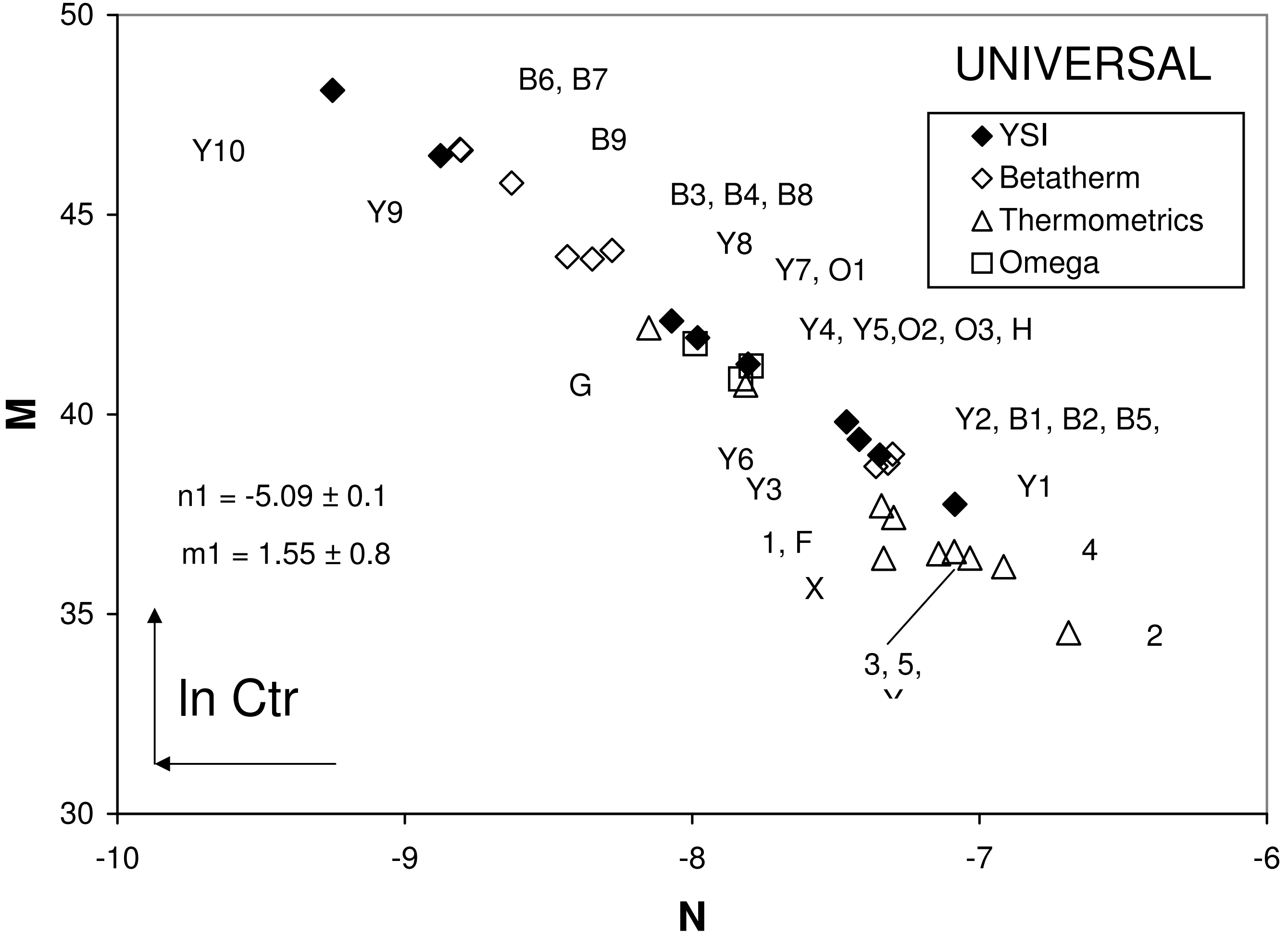

Fig 11. Universal phylogeny for NTC-thermistors from Table 6.

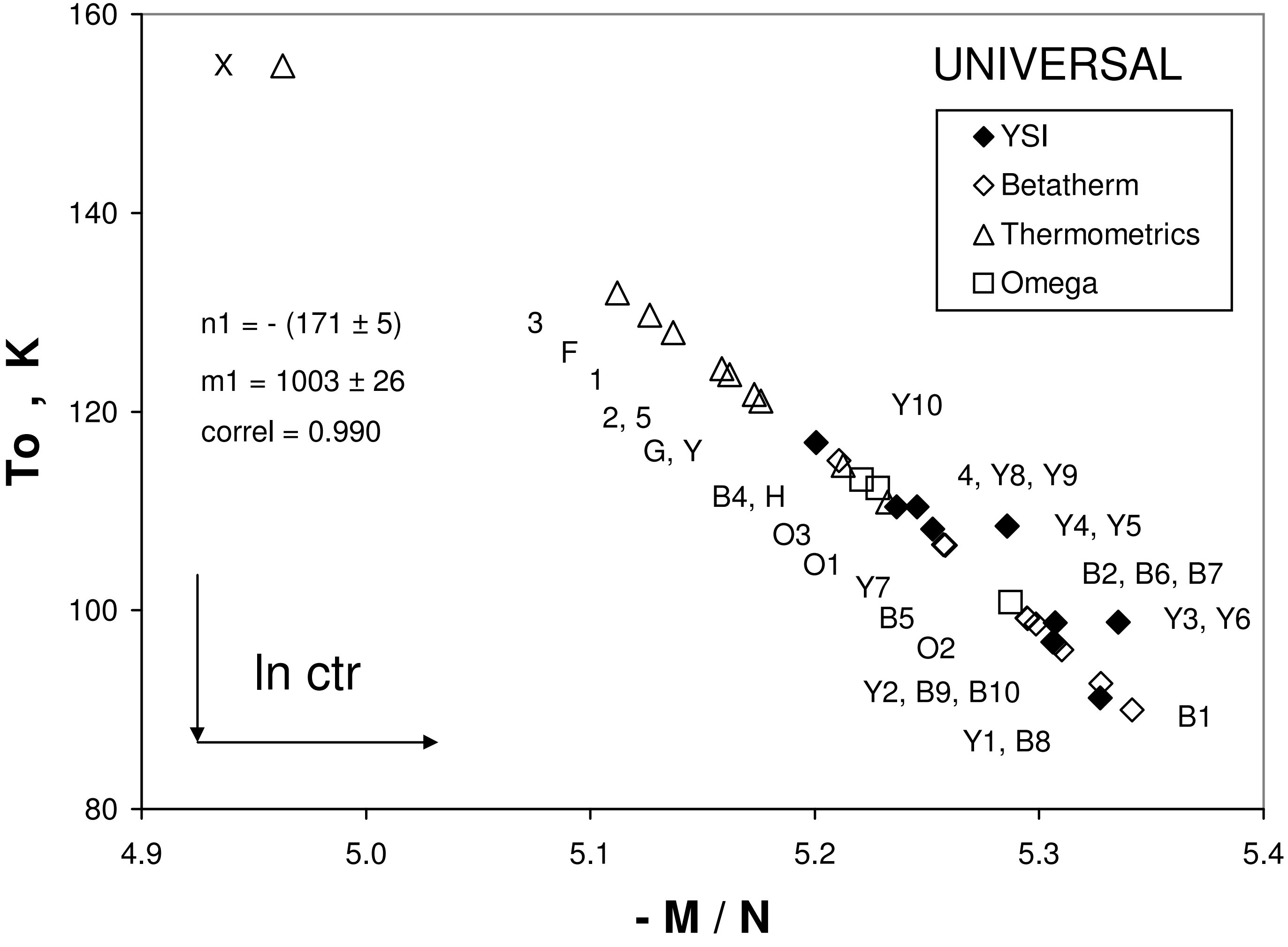

Figure 12. To vs -M/N for NTC-thermistors from Table 6.

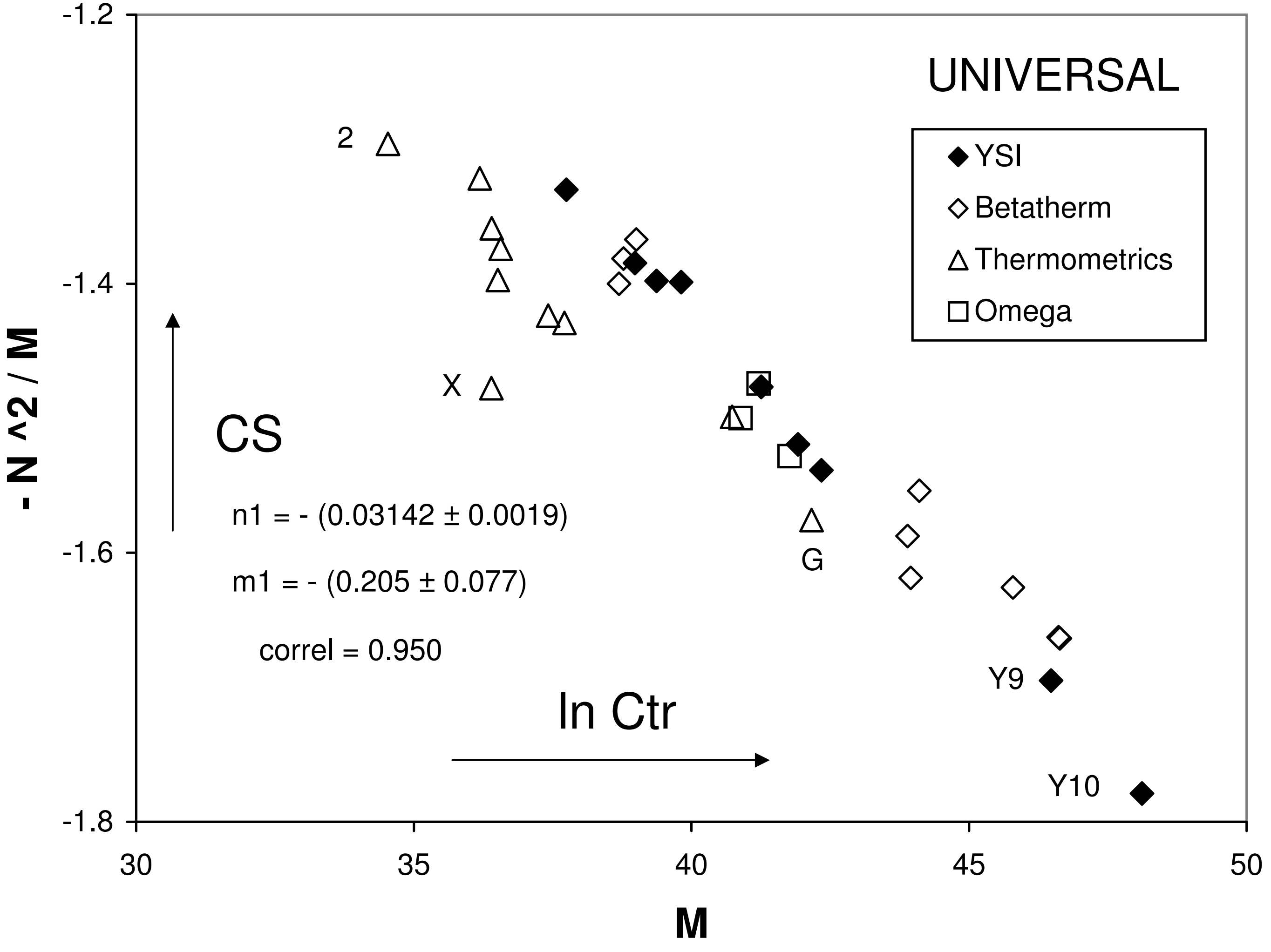

Figure 13. -N^2/M vs M for NTC-thermistors from Table 6.

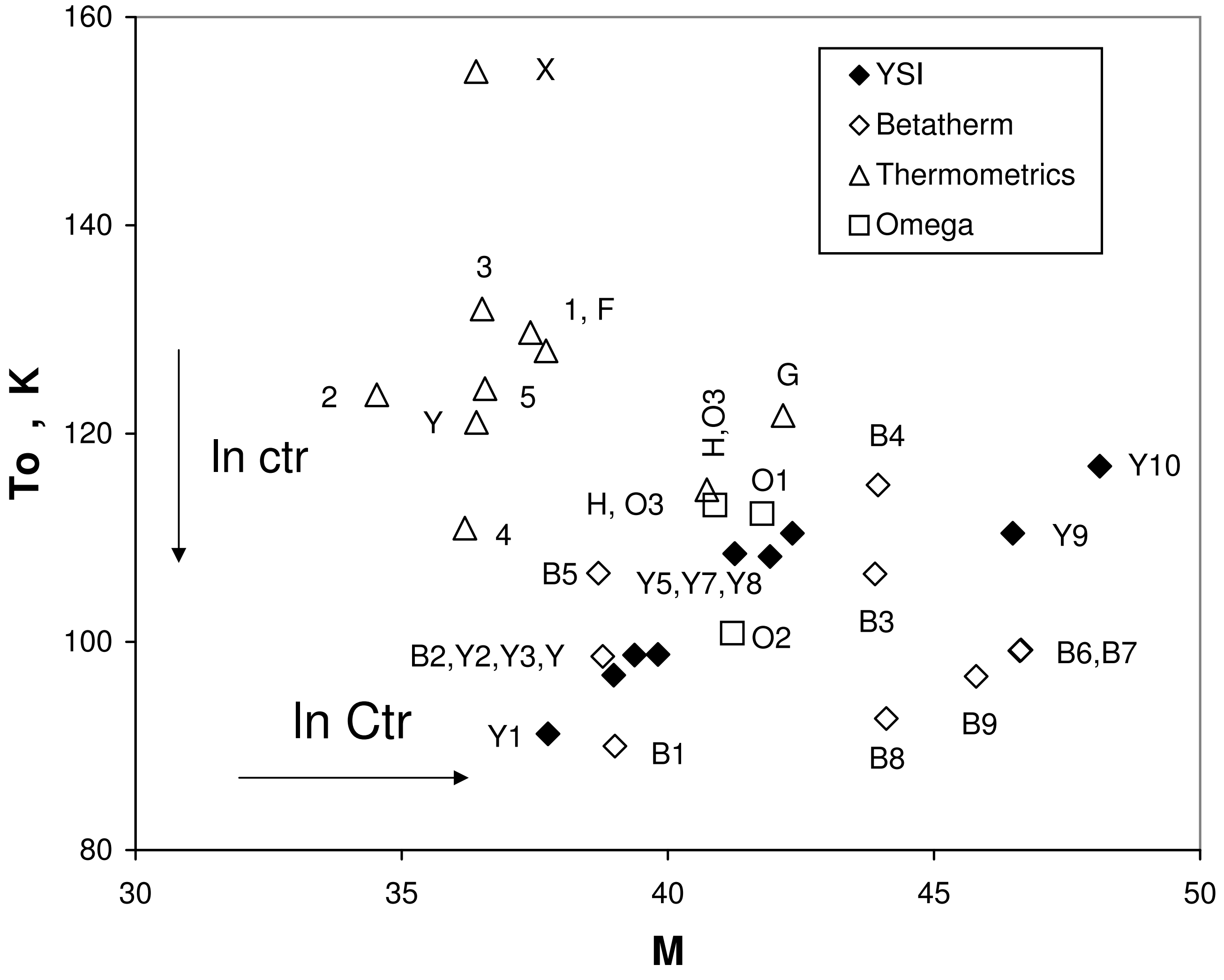

Figure 14. To vs M for NTC-thermistors from Table 6.

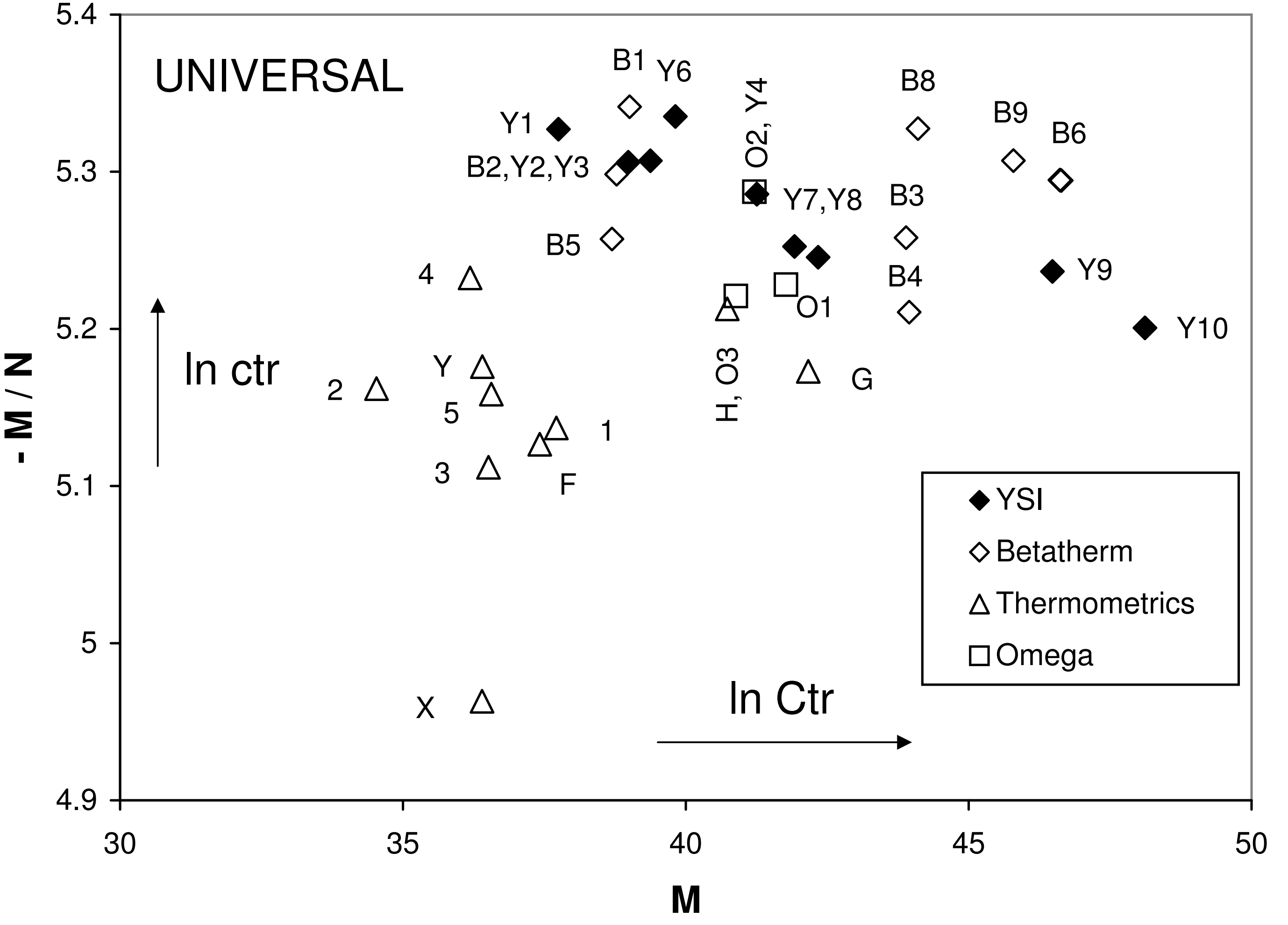

Figure 15. -M/N vs M for NTC-thermistors from Table 6.

8. Structural model of electrical conduction

The above results allow evidencing some important features of the electrical conduction in considered NTC-thermistors. As we already pointed out this process is essentially given by free electrons thermally separated from the lattice. The lattice results after a sintering process as a 3D polymeric structure with the spinel unit cell. These compounds may have some additional filler as structure stabilizers which modifies Ctr/Cin ratio. Electrical conduction results to be anisotropic because some preferential directions (conduction channels) appear in the lattice.

The relaxation time of the kinetic unit obeys the Arrhenius eqn similar to eqn (1), so that:

$$\tau = ctr*RD = \tau o * \exp(- E / (kB * T)) \quad (15).$$

For T = To this eqn becomes:

$$ctr = (\tau o / RD) * \exp(- E / (kB * To)) \quad (16)$$

or in logarithmic form this successively becomes:

$$\ln ctr = (- E / (kB * To) + k \quad (17)$$

$$To = ((E / kB) – k * To) * \ln ctr \text{ , where } k = \ln(\tau o / RD) \quad (18).$$

This last eqn could explain in a good approximation the above reported linear relationship between To and ln ctr modulated by sign (E), i.e. by process polarity. On the other hand, a quantum estimation of relaxation time in critical point To gives the following estimation [18]:

$$\tau = ctr * RD = hp / (kB * To) \tag{19}$$

where hp is Plank’s constant in (J*s). In logarithmic form this eqn becomes:

$$\ln ctr = - \ln To + \ln (hp / (kB * RD)) \tag{20}$$

which seems to be a little far from the observed relationship.

It is important to observe that the variation R(T) can be considered as a saturation process starting from an infinite value at To up to a baseline value. There are some questions to be answered by more accurate and new measurements, namely:

(i) the kinetic unit remains or not the same while Ctr increases up to saturation value;

(ii) in which conditions appears/disappears hysteresis in R(T);

(iii) specimen anisotropy relative to different vectorial properties;

(iv) specimen porosity in relationship with different properties;

(v) the exact nature of the coupling between conduction electrons and lattice.

Definitely To is a transition point which is associated to a phase transition, so it must be evidenced first by accurate calorimetric measurements. These certainly will find the answers to some of the above questions and much more.

9. Concluding remarks

The actual study on commercial NTC-thermistors by using values of R(T) given on 6 manufacturer’s websites and their retrieval in Arrhenius and Universal topoenergetic representations, allow to sketch the following concluding remarks useful for next studies on these materials:

1. the results presented in this study can be verified and furthermore analyzed by producers of the NTC-thermistors considered in view to identify the contribution of each chemical component and/or of processing conditions in Ctr, ctr, To and CS;
2. there are necessary more accurate and new measurements in view to make clear at least the aspects (i) – (v) pointed out in the above chapter. These experiments carried out on topoenergetic principles will certainly reveal new properties of these materials for new applications;
3. topoenergetic principles mentioned and used in this study must be substantiated by more experiments performed in many laboratories in view to become current working tools in identification and/or optimization of transforming systems by their behaviour in different measuring systems and standard experimental conditions.

10. References Cited

[1] G. Dragan, J.Polymer Sci., Polymer Symposium, **64**, 141-148 (1978).

[2] F. Oster, D.M. Auslander, J.Franklin Inst.,**292**, 211-220 (1987).

[3] G. Dragan, J.Thermal Anal., **9**, 405-414 (1976).

[4] G. Dragan, J.Thermal Anal., **15**, 297-306 (1979).

[5] G. Dragan, J.Thermal Anal., **23**, 173-193 (1982).

[6] G. Dragan, Rev. Roumaine Chim., **23**, 629-635 (1978).

[7] G.Dragan, Felicia Stoenescu, Rev.Roumaine Chim., **24**, 55-57 (1979).

[8] G. Dragan, Rev.Roumaine Chim., **24**, 627-640 (1979).

[9] G. Dragan, Acta Polymerica, **31**, 293-298 (1979); **34**, 1-8 (1983).

[10]G. Dragan, DIFFUTOR©-01: Thermally driven diffusion in pure metals, GDF Databanks Bull., **2**(3), (1998).

[11] G. Dragan, Solubility behavior introducing topoenergetic working principles, GDF Databanks Bull., **1**(1), 10-18 (1977).

[12] G. Dragan, VAPORSAT©-01: Data banks of thermally driven VLE, GDF Databanks Bull., **2**(4), (1998).

[13] G. Dragan, MOSATOR©-01: Topoenergetic data banks for one component molten salts; thermally driven viscosity and electrical conductance, GDF Databanks Bull., **6**(10), (2002).

[14] G. Dragan, Comments on 1- octanol-water partition of several n-alkane related series, GDF Databanks Bull., **1**(1), (1997).

[15] G. Dragan, Topoenergetic aspects of amorphous-crystalline coupling.I. Composite behavior of water and aqueous solutions, paper presented at Nanotubes and Nanostructures Workshop 2000, 24 September- 4 October 2000, Santa Margherita di Pula, Cagliary, Italy, GDF Databanks Bull., **5**(1), 5-24 (2001).

[16]G. Dragan, Gabriela Banica, Phys.Chem. Mechanics (Sofia), **10**, 41-44 (1983).

[17] G. Dragan, C. Oprea, Rev. Roumaine Chim., **30**(6), 447 – 452 (1985).

[18] E. Stanley, Introduction to Phase transitions and critical phenomena, Oxford, Clarendon Press, 1971.

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