STUDY OF AN ESSENTIAL FEATURE OF THE COMPLEX SYSTEMS – THE ENTANGLED STATES: FROM THE QUANTUM ENTANGLEMENT TOWARDS THE SEMIQUANTUM AND THE CLASSICAL ENTANGLEMENT

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Abstract. *The detailed study of a huge number of qualitatively different complex systems, points out that they are really complex (not only some complicate ones), only if their entanglement features are prevalent in their work. For this reason, this work achieves a rather extensive study of the main types of entanglements met today in the theoretical and technical sciences, trying to find also a quantitative characterization of the: a) entanglement degree, b) dis-entanglement processes, that lead usually to the destruction of the considered complex systems.*

Keywords: Complex systems, Semiquantum and classical entanglement, dis-entanglement

1. Introduction

As it is known, both the Theoretical Sciences and the Technical ones, especially, are complex sciences, with tremendous numbers of characteristic elements. We have to underline also that these characteristic elements are not related by some obvious deterministic relations, their connections being in fact rather hidden at first look and even after several other examinations.

We consider as a good example - the evolution of one of the most important inventors of the previous (20th) century in the field of Technical Mechanics: Robert Gilmour, perhaps the most prominent specialist in the frame of the land leveling works initiation.

As it results from his book [1], Robert Gilmour began his activities in the fields of the foundry, of the solder, of the electrical accumulators, of the electrical generators and engines, and begun only finally his works in the domain of the mechanical machines. His outstanding results in the field of mechanical machinery (tractors, scrapers, bulldozers, etc.) became possible only due to his remarkable experience and expertise in the totally different technical fields, as those of metallurgy, electrical engineering and many others.

We will start from the simplest types of entanglement (those met in the Quantum Physics) and continue with some examples from the semi-quantum, and finally from the classical sciences.

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2. Basic elements of the quantum entanglement

State vectors corresponding to the quantum entanglement based on a single two quantum-bit (qubit[1]) example, the pure states case:

a) "Separable state" (or un-entangled)

$$\left|\psi(1,2)\right\rangle = \frac{\left|\overset{1}{\uparrow}\overset{2}{\downarrow}\right\rangle + \left|\overset{1}{\uparrow}\overset{2}{\uparrow}\right\rangle}{2} = \left|\overset{1}{\downarrow}\right\rangle \otimes \left(\frac{\overset{2}{\left|\downarrow\right\rangle + \left|\uparrow\right\rangle}}{2}\right) \quad (1)$$

b) "Entangled state"

$$\left|\psi(1,2)\right\rangle = \frac{\left|\overset{1}{\uparrow}\overset{2}{\downarrow}\right\rangle + \left|\overset{1}{\downarrow}\overset{2}{\uparrow}\right\rangle}{\sqrt{2}} \quad (2)$$

respectively [3].

One finds that – independently on the separating distance – two entangled objects form only one block, any modification of one object state being immediately reflected on the second body.

3. Quantum Entanglement and some of its implications

In the Spring of 1935, Albert Einstein and his PhD students Boris Podolsky and Nathan Rosen have found – after some months of calculations – that (according to the Quantum Physics) two particles could be bound so that for any distance (even very large) between them, any action on a particle would have a very fast (immediate) repercussion (transmission to the other) [the so-called Einstein-Podolsky-Rosen (EPR) bound]. Toward the end of the 1935 Summer, Einstein and Rosen published a new unexpected result: "the substance (matter) can deform the Universe frame to open a tunnel between 2 very far away (distant) space regions", phenomenon named the "worm hole (bridge)", or the ER bridge [4a], pp. 50-51. In the last decade of the previous century, the cosmologists Juan Maldacena [4b] from Princeton and Leonard Susskind from Stanford University have found that the relations of the worm holes describe exactly the behavior of the entangled particles, hence the simplest entanglement is achieved by a worm hole (ER bridge), i.e. the EPR bound and the ER bridge are irremediably connected [4a], p. 54. It was found that even the (still) rather strange telepathy phenomena are strongly related to the quantum entanglement [9].

[1]A quantum bit (qubit – the quantum counterpart of the classical bit) is a two-level quantum system (like: a) the 2 spin states of a spin ½ particle, or: b) the vertical and horizontal polarization states of a single photon, or: c) two states of an atom), described by a two-level quantum system, described by a two-dimensional complex Hilbert space [2].

The connection of the ER bridges and of the EPR bounds (even through some black holes), deforms the Universe space-time frame.

4. The way from the quantum to the semi-quantum and (finally) to the classical entanglements

Examples:

a. In PHYSICS: Semi-quantum entanglement effects in the CCDs dark current

The studies [5] pointed out that the "constitutive" theoretical model of the semi-conductor materials involved by CCDs remains the rather old, but still the most effective, HSR quantum model of Hall, Shockley and Read [6].

Inside the CCD region depleted of carriers, where n and $p << n_i$, the rigorous quantum SRH relations (1) and (5) of the work [6] lead to the following expression of the dark current:

$$j_{dark}(T) = j_{diff}(T) + T^{3/2} \cdot \exp\left(-\frac{E_g}{2kT}\right) \cdot c_n \frac{qV_{th} x_{dep} A_{pix}}{2} \sum_{k=1}^{n} \sigma_k N_{tk} \sec h\left[\frac{E_t - E_i}{kT} + pdg_{n,k}\right] \qquad (3)$$

where n is the number of contaminant traps types, σ_k is the geometrical average ($\sqrt{\sigma_{nk}\sigma_{pk}}$) of the capture cross-sections of the free electrons and holes, respectively, and $pdg_{n,k}$ is the polarization degree of capture cross-sections corresponding to traps of type k.

Finally, the depletion dark current [the second term of relation (1)] can be described by the "global" expression:

$$j_{dep}(T) = q \cdot De^{-}_{0,dep.eff.} \cdot \sec h\left(\frac{E_t - E_i}{kT} + pdg_n\right)_{eff.} \cdot T^{3/2} \cdot \exp\left(-\frac{E_{g,eff.}}{2kT}\right) \qquad (4)$$

where the effective depletion pre-exponential factor is a weighted sum [the weights being the hyperbolic secant factors: $\mathrm{sech}\left(\frac{E_{tk} - E_i}{kT} + pdg_{n,k}\right)$] of the pre-exponential factors of each type of traps:

$$De^{-}_{0,trap\ k} = \frac{1}{2} x_{dep} A_{pix} c_n V_{th} \sigma_k N_{tk} \qquad (5)$$

where N_{tk} is the number of traps of type k in the considered pixel.

From relations (1)–(3), one finds that the expression of the depletion dark current corresponds to a semi-quantum entanglement of the effects of several types of traps (for more details see Table 2 (and its comments) of paper [7]).

b. In BIOLOGY: Effects of the clouds of entangled mobile electrons

There were pointed out and emphasized the effects of the large numbers of pairs of entangled particles[1] on:

(i) *the stability of the complex systems* (of DNA molecules, particularly) [8], pp. 66-69,
(ii) *the space orientation of certain living beings* (of the birds, particularly), according to the model of Klaus Schulten and Peter Hore [8], p. 69,
(iii) *the telepathy* – starting from certain entangled systems, according to the Physics Nobel prize winner – Brian David Josephson (1988), [8], p. 72 and [9].

5. Entanglement evidence in the Human genome

The human genome shares a rather large percentage of its genes with the genomes of:

a) another animals (e.g. approx. 98% common genes with the chimpanzees, see [10b], and even with the pigs!),
b) certain flowers (up to 35% [10b]), aliments, as the rice; see [12], pp. 94-95,
c) even of some bacteria[2], viruses, etc (act they as natural vaccines?).

The group of the remaining 2% genes (hence about 400 genes, from those common with the chimpanzees) involves also:

a) 385 genes of the Denisova man (a Siberian pre-human being, extinguished approximately 40,000 years ago), [11a], p. 69;
b) about 200 genes of the Neanderthal man (an European human being, extinguished approximately 30,000 years ago):
   (i) as certain genes of the language (as FOXP2), see [11b], page 57,
   (ii)other genes, up to 1÷4% of total, according to [12a], p. 66; [12b], p. 74,
c) about 60 genes (0.3% of total), are specific to the modern man [there were compared in this aim the genes of a: (i) French, with those of a: (ii) Han of China, (iii) Papua from the New Guinea, (iv) Yoruba from the Western Africa, and those of a: (v) San from the Southern Africa)],
d) the genes of the modern men from a certain geographic region, differing between them only by max. 0.1% (20 genes) of the total of their genes [12c], p. 29.

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[1]The 3 life pillars that challenge the chemistry are: a) the energy supply, b) the activation, and: c) the reproduction. Even today, the biochemists have considerable difficulties to explain how the living beings succeed to ensure these three essential functions, given being in the classical sciences, nothing allows to justify neither: (i) the extraordinary energy efficiency of the photo-synthesis, (ii) the impressing efficiency of the enzymatic activity, nor: (iii) the incredible stability of the DNA [8], p. 56.

[2]For each human cell, our body hosts approximately 10 bacteria, and for each human gene, our microbes total about 100. Besides our approximately 20,000 genes, we have therefore several millions of genes of microbial origin (one finds so they are necessary, the humans being so huge eco-systems), hence 2 genetic sets that have to work in coordination! [13], p. 108.

The importance of the genetic entanglement is pointed out and underlined also by the special interest of biologists for the genetic diversity.

6. Ways of genes modifications

a) by some food assimilation, [12], pp. 92-97, and [14],
b) by emotions or stress, vs. relaxation, [15], pp. 102-103, and [16],
c) sex relations, according to [12], p. 74.
d) the massage activates the genes with anti-inflammatory (swelling) properties [17].

7. Health and psycho-physical implications

According to [18], pp. 54–61, and [19]. The absolute necessity of the (aural) tuning of the musical instruments due to the strong entanglement of the equal-temperament exponential scale with the practically linear dependence of the partials frequencies on their indices was pointed out by work [20].

8. Entanglement by some priorities in the genes transmission, as those referring to the mother→son→his daughter and the implied interweaving

As the old Scandinavian knew the main behavior features of the sons resembled more to those of their mothers, while the main behavior features of daughters resembled more to those of their fathers. For this reason - beginning with the third generation (see the following diagram) - the next king was not the son of the previous king, but … the son of the sister of the previous king! [see also in the Bible the net behavior differences of the sons of Eli, Samuel, Saul (Jonathan), etc. relative to those of their fathers].

Using the symbols “K” to denote the king, “D” – the king’s daughter, “Q” – the queen, “N” – the King’s nephew (son of the King’s daughter) and “S” to denote the behavior similitude, one finds that in the old Scandinavian royal inheritances, the succession to the throne was the following one:

Generation 1:	K1	Q1
Generation 2:	K2 ≡ S(Q1)	Q2 and D(K1)
Generation 3:	K3 ≡ N[D(K1)]	Q3 and D(K2) ≡ D[S(Q1)]
Generation 4:	K4 ≡ N(D[S(Q1)]	Q4, etc.

One finds that by such an interweaving, the basic genes of all following kings correspond to those of the first (remarkable) royal pair (K1 and Q1).

9. Entanglement of Sciences

There were often observed some entanglements of the “humanistic” sciences [e.g. as the classical languages (old Greek, Latin)], with Mathematics, Physics, etc.

So, the Physics Nobel prize laureate Max von Laue pointed out in the frame of his “Physics History” [21], the study of the Old Greek language is very important for the formation of … scientists (physicists, mathematicians, etc.)!

Similarly, the academician Miron Nicolescu has indicated in his Order (as State Secretary) [22], p. 4, that according his opinion the most important high-school disciplines - for the Education of Romanian students - are: the Romanian Language, the Mathematics, the Latin Language and the French Language! The specific explanation of these somewhat surprising entanglements refer probably to *the central role of the Logic in all scientific, technical and "humanistic" sciences.*

10. Content entanglement (e.g. of populations)

To be easier understood we will consider the particular example of the percentages of the different nationalities in the frame of the Republic of Moldova, according to [23]:

Moldavian nationality[1] [hence Romanian, according to MDA2 and MDA4]	76.1%,
Ukrainian	8.4%,
Russian	5.8%,
Găgăuz	4.4%,
Romanian (the most resistant to the assimilation)	2.1%,
Bulgarian	1.9%,
Other nationalities	1.3%.

In this case, the uncertainty degree: $H = -a\sum_i p_i \log_b p_i$ defined by the Claude Shannon – Khinchin Information theory [24], [25] can be used as a measure of the content entanglement degree. The numerical results corresponding to this particular case are synthesized in the frame of the next Table.

I	p_i	$-\log_2 p_i$	$-p_i \log_2 p_i$ [2]
1, i.e. Moldavian (hence, also in fact Romanian)	0.761	0.3940317	0.2998581
2, i.e. Ukrainian	0.084	3.573467	0.3001712
3, i.e. Russian	0.058	4.107803	0.2382526
4, i.e. Găgăuz	0.044	4.506352	0.1982795
5, i.e. Romanian	0.021	5.573467	0.1170428
6, i.e. Bulgarian	0.019	5.717857	0.1086393
7, i.e. Other nationalities	0.013	6.265345	0.08144948
$H = -\sum_i p_i \log_2 p_i$ (bits)			1.34369298 bits

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[1] According to the Russian classification.

[2] Given being $\frac{d}{dp_i}\left[-p_i \log_b p_i\right] = -\log_b p_i - p_i \cdot \frac{\log_b e}{p_i} = -\log_b(p_i \cdot e)$, the maximum of the function $-p_i \log_b p_i$ is reached for $p_i = \frac{1}{e} \cong 0.367879553$, where e is the Euler's number ($e \approx 2.718281$).

11. Numerical Simulations of Entangled States in Complex Systems by means of some Games

There are many games that simulate the entangled states in some Complex systems, as the: a) Chess, b) Sudoku[1], etc.

Given being Sudoku indicates an absolute degree of the students preparation for the study of complex systems [while, e.g. the chess gives only a relative appreciation (in comparison with that of certain competitors) of this preparation degree], we will prefer to examine in following the main features of Sudoku's approach of entangled states.

In order to illustrate the simulated entangled states and the dis-entanglement procedures by means of the Sudoku game, we will organize the corresponding main elements by means of:

(i) some specific questions,
(ii) their answers and ways to be obtained.

Q: Analyzing the data of fig. 9.1, derive the: a) figures which could be introduced in each of the empty cells of the Sudoku diagram from the indicated figure; b) the magnitude order of the number of combinations of figures locally possible for each cell of the indicated diagram 9.1.

A. a) The locally possible figures for each empty cell of the studied Sudoku diagram, are indicated by figure 9.1S, where: (i) the larger fonts figures correspond to those indicated by the statement of this problem, which are useful to eliminate some wrong hypotheses, (ii) the figures of smaller fonts correspond to the locally possible for each cell, being underlined those corresponding to the general solution of this problem.

		A			B			C		
		a	b	c	d	e	f	g	h	i
D	1			6						4
	2	7		5			1			3
	3		3		8	2				
E	4		4	9						5
	5	1			5	9	7			2
	6	5						9	1	
F	7					8	4		2	
	8	2			9			4		1
	9	6						3		

Fig. 9.1.

		A			B			C		
		a	b	c	d	e	f	g	h	i
D	1	89	1289	6	37	357	359	12578	5789	4
	2	7	289	5	46	46	1	268	689	3
	3	49	3	14	8	2	569	1567	5679	679
E	4	38	4	9	1236	136	2368	678	3678	5
	5	1	68	348	5	9	7	68	3468	2
	6	5	2678	2378	2346	346	2368	9	1	678
F	7	39	1579	137	1367	8	4	567	2	679
	8	2	5678	378	9	3567	356	4	5678	1
	9	6	15789	14789	127	157	25	3	5789	789

Fig. 9.1S.

[1]The Sudoku game requires to fill the cells of the diagram (square) of 9×9 "cells" with figures from 1 to 9, so that each of these figures be present only once both inside the areas of 3×3 "cells" delimitated by thicker lines, as well as on each vertical (*a*, *b*, … , *i*), and horizontal, respectively, of the diagram.

b) The number of combinations of locally possible figures for each cell of the diagram from fig. 9.1 is derived by means of the multiplication of the numbers of figures corresponding to each empty cell (see the above figure): $N = 2 \times 4 \times 3 \times 3 \times \ldots \times 3 \times 2 \times 4 \times 3 \sim 6.057 \times 10^{26}$.

One finds that the difficulty of a problem of the Sudoku type is related to the huge number (of the magnitude order of the Avogadro's number: $N_A \simeq 6.023 \cdot 10^{23}\ \frac{\text{molecule}}{\text{mol}}$ sau $6.023 \cdot 10^{26}\ \frac{\text{molecule}}{\text{kmol}}$) of the combinations of the locally possible figures for each cell of the diagram.

12. Definition and calculation of the distribution entanglement degree

The successive identification stages of some unique figures from the studied Sudoku square correspond to the obtainment of a certain information amount. According to the Claude Shannon-Khinchin information theory [23], [24], the information amount corresponding to a certain identification stage *i* (dis-entanglement of the complex system) is given by the expression: $\Im(i) = -a \cdot \log_b p_i$, where p_i is the probability associated to the respective identification stage.

Starting from the "virtual" populations N_{ji} associated to the empty cells *j* in a certain identification stage, the probability p_i can be calculated as the inverse of the product $P_i = \prod_{j=1}^{n} N_{ji}$ of the virtual populations at the end of the identification operation (stage) *i*: $p_i = \left[\prod_{j=1}^{n} N_{ji}\right]^{-1}$.

Consequently, *the remaining distribution entanglement degree R(i)* of a complex system, at the end of the identification operation (stage *i*), can be calculated by the relation: $R(i) = a \cdot \log_b P_i$, where for the constant *a* is chosen usually the simplest value: $a = 1$, and the measurement units of the remaining entanglement degree ***R*(*i*)** are: bit, nit, and dit, respectively, depending on the value of the logarithms basis: $b = 2$; $b = e$ (the Euler's number), and: $b = 10$, respectively. Of course, the information amount obtained by means of the identification operation *i* will be calculated by the expression: $\Im(i) = R(i-1) - R(i)$.

A very small part of the obtained results by means of an elementary (Quick Basic) computation program are indicated by table 1 [The fluctuations of the information amounts obtained (for a monotonically decrease of the distribution entanglement degree) correspond to the irregular oscillations of the identification rate (of the unique figures associated to some empty cells)] around a certain average rate.

Tab. 1. Study of the **distribution** entanglement degree and of the information amounts in binary (bit), natural (nit) and decimal (dit) units, respectively

I	*P(I)*	*R(I),* bit	*B(I),* bit	*N(I),* nit	*D(I),* dit
0	6.900767×10^{30}	102.4446	-	-	-
1	9.704205×10^{29}	99.61452	2.830078	1.961662	0.8519382
2	9.316038×10^{28}	96.2337	3.380821	2.343407	1.017729

Symbols:

I = the index of the "dis-entanglement" stage of the complex system;

P = the product of the virtual populations of the initially empty cells, after the stage "I";

R(I) = $\log_2 P(I)$ = the remaining entanglement degree (bits);

B(I), N(I), D(I) = the information amounts obtained in the dis-entanglement stage "*I*", measured in bits, nits, and dits, respectively.

13. Conclusion

The accomplished study pointed out the main types of entanglements met today in different sciences and proposed a certain type of quantitative evaluation of the entanglement degree.

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