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Interpretation and Theories of Superconductor-Like Behaviour through Nerves

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Abstract

The present review aim to introduce i) the interpretations of superconductor-like behavior through sciatic nerve and to discuss ii) theories related to superconductor-like behavior in nerves. Recently, histological sections shows Schwann cells number in frog sciatic nerve associated to the amount of myelin and superconductor-like behavior. Several studies have investigated the implication of electrical signals at very low temperature in different nervous system mechanism and algorithm, superconductor-like behavior, in animal species. In the present manuscript, the electric resistivity (R) at different temperatures (T) between 300K to 200K in frog sciatic nerve was explained as semi-conductor- superconductor-like behavior and metallic- superconductor-like behavior. Analysis of electrical properties demonstrates clearly a grade shift in critical temperature (Tc) from poikilotherm to homeotherm; indicating adaptive nerves changes during probably climate changes and animal evolution. Many theories and models were proposed in order to give a good interpretation of the superconductivity in nerves.

Keywords: *Evolution; Climate change; Sciatic nerve; Resistivity; Superconductor-like behaviour; Schwann cells*

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Introduction

In neurophysiological studies, frog nervous system was considered as an important tool in different research (Banasr., *et al.* 2010; Mbainaibeye., *et al.* 2012; Azzouz., *et al.* 2017). Myelin sheath elaborated by oligodendrocytes in the central nervous system and by Schwann cells in the peripheral nervous system could be associated to superconductor-like (Abdelmelek., *et al.* 2017). This organelle, myelin sheaths, consists of a large sheet of plasma membrane that is repeatedly wrapped and very tightly compacted around axons playing a key role in nerve saltation and superconduction (Waxman, 2000; Abdelmelek., *et al.* 2017). It might therefore be expected that natural selection on neuron or nerve conduction could have caused several structural and functional changes; developing new nerve chemical and/or electric conduction mechanism with different algorithm like semi-conductor behaviour, metallic behaviour, and superconductivity (Abdelmelek., *et al.* 2003a; Abdelmelek., *et al*. 2017). In addition, physiological investigations have shown neurochemical and electrical changes in nervous system during globe temperature variations that could be associated with adaptative mechanisms; leading to evolution of species from poikilotherm to homeotherm (Abdelmelek., *et al.* 2003b). Besides the action of monoamines other electrical properties such as action potential or superconductor-like behaviour play a key role in the optimization of nerve network. Moreover, previous studies suggested the presence of adaptative mechanisms involving the spinal cord and the sciatic nerve dopaminergic and serotonergic pathways during acclimation to cold or at low temperature (Hopf & Maurer, 1990; Abdelmelek., *et al*. 2000; Costanzo., *et al*. 2000). By contrast, there are few studies investigating the implication of electrical signals at very low temperature in animal species adaptation. Previous studies reported an increase in myelin sheaths during evolution that could be implicated to the neuromodulation of two components: the neurochemical transmission at low temperature and the adaptative nervous system electrical responses to different environmental stimuli (Azzouz., *et al*. 2017). Mbainaibeye., *et al*. (2012) revealed different electrical responses of frog sciatic nerves during the decrease of temperature and wavelet models. Furthermore, Abdelmelek., *et al*. (2003b) demonstrated that evolution from poikilotherm to homeotherm led to a grade shift in relative “superconducting” transition temperature (Tc).

Interpretation of superconductor-like behavior through nerves

Different studies indicated that low temperatures induce a striking decrease of nerve electrical resistivity at about 240K in frog sciatic nerve, showing a superconductor-like behaviour. When the electrical contacts were embedded into the nerve, a linear decrease of the sciatic nerve resistivity is observed at $240K < T < 300K$ in frog. This dependence is generally associated with a metallic behaviour. The metallic behaviour exists in materials, usually solid, that can conduct electricity with a very low resistance ($dR/dT > 0$). Then, once the sciatic nerve temperature is driven below 234K in frog, the resistivity decreases abruptly and then it remains constant afterwards. Electrical evolution below 234K can be regarded as a superconductor-like behaviour. The fastest conducting nerve fibers are like wires and have their own insulating sheaths. Thus, the decrease or increase of temperature has a proportional effect on the sciatic nerve resistivity in animal species. By contrast, difference between endotherm (like hot superconductor: rabbit, Tc^{onset}: 300K) and poikilotherm (like conventional superconductor: frog, Tc^{onset}: 250K) could be explained by fundamental anatomical and functional nerves properties related to the development of metabolic function and the development of myelin (Abdelmelek., *et al*. 2003a; 2003b). If we assume the existence of “superconductivity” behaviour in nerves, there is an increasing evidence to attribute this superconductivity to myelin sheaths.

The mechanism of superconductivity and the saltation over the myelin sheathed portions of the nerves showed many similarities. Interestingly, in superconductor materials we found Josephson junction. Josephson Junctions are thin layer of insulating material sandwiched between two superconducting layers. Electrons “Tunnel” through this non-superconducting region in what is known as the Josephson effects (Del Giudice., *et al*. 1973; Waxman, 2000). Moreover, the gradient shift of superconductor-like behaviour in the nervous system from frog to rabbit is correlated with the degree of myelinisation (Abdelmelek., *et al*. 2003b). This recent result on nerve opens up a possible route to new applications in the comprehension of biological systems and to develop an innovative biomimetism mechanism to produce or explain hot superconductors.

Neurophysiological research have shown that changes in plasma or tissues catecholamines levels during cold acclimation could be associated with adaptive changes in interaction with environment and globe temperature (Abdelmelek., *et al*. 2000). Our research group suggests the presence of adaptive mechanisms involving nerve dopaminergic and serotonergic pathways after chronic exposure to cold. In addition to neurochemical adaptation, we have described a procedure for evaluating superconductor-like behaviour in frog and different other animal species (Abdelmelek., *et al*. 2000; Abdelmelek., *et al.* 2017). Analysis of electrical properties demonstrates clearly a grade shift in critical temperature (Tc) from poikilotherm to homeotherm; indicating adaptive nerves changes during probably climate changes and animal evolution.

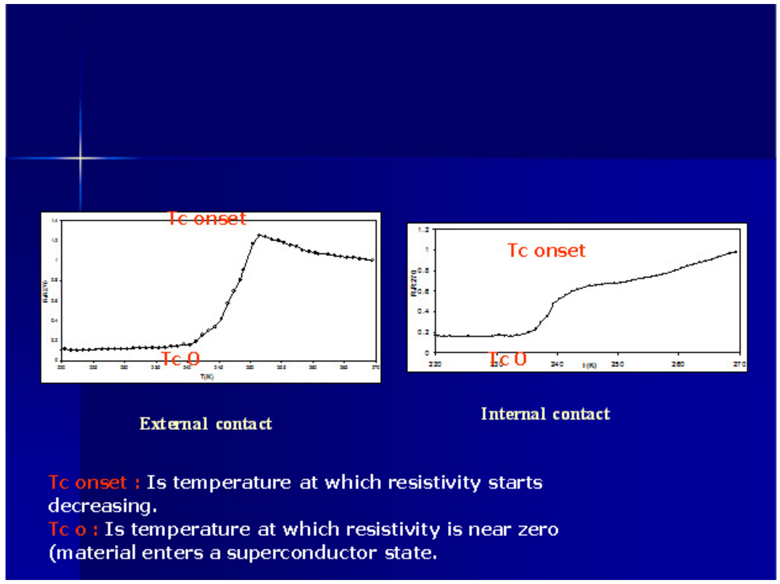

Figure 1: *Evolution of the normalized electric resistance (R/Ra) of the frog sciatic nerve in terms of the temperature T (K) with gold past internal and external recording (Abdelmelek., et al. 2003).*

Many theories and models were proposed in order to give a good interpretation of the superconductivity in nerves as a mechanism developed by adaptation to cold or allow species to resist to cold. The frog's resistance to cold depends perhaps on the state of activity of the nervous system in various tissues at low temperature. According to our findings, the marked decrease of resistivity at low ambient temperature (250K) can be mediated by a mechanism, which has many similarities with inorganic and organic superconductors (Schön., *et al*. 2000). At cold environment, periods of intense heat loss are occurring in all body tissues, that's why animals have to develop a mechanism of energy management.

Furthermore, our data suggest the existence of a new electrical conductivity mechanism, which gives the nervous system a real potential to function at low temperature of about 250K (about -23°C). In this case, low resistivity of sciatic nerve can be understood as an adaptive behaviour of the nervous system in order to control energy loss of frogs. Knowledge of changes in frog sciatic nerve conductivity under cold environment is still limited. The difference between endotherms (rabbit, Tc: 300K) and poikilotherms (frog, Tc: 250K) could be explained by fundamental anatomical and functional nerves properties related to the development of metabolic function and the development of myelin. Peripheral nerves are made of bundles of nerve fibres, which can be regarded as living wires. The fastest conducting nerve fibres are like wires and have their own insulating sheaths ((Schön., *et al*. 2000; Stålberg & Erdem, 2000, Rosenthal & Bezanilla, 2000; Abdelmelek., *et al*. 2003).

Nerve fibres conduct nerve impulses very quickly because the myelin sheath has gaps, which allows the nerve impulse to jump from gap to gap and travel faster. The temperature transition (Tc) in the sciatic nerves of frog remains constant and reproducible at 250K. If we assume the existence of "superconductivity" behaviour of the nerve, there is an increasing evidence to attribute this superconductivity to myelin sheaths. Interestingly, numerous studies are dealing with the relationship between structure of the living matter and physical properties as superconductors (Abdelmelek., *et al.* 2017)

Are there certain scales of climatic change that accelerate evolution and improve superconductivity as previously showed between frog and rabbit? The analysis of the meaning of Tc onset could give us an explanation that the Tc probably corresponds to global temperature during the apparition of specie. More investigation must be done in order to confirm these entire hypotheses. Our scientific theories are founded on previous experimental data, and they also lead to new questions as we seek to refine our knowledge based on electrical properties of nerves at low temperature especially superconductor-like behavior in different animal species.

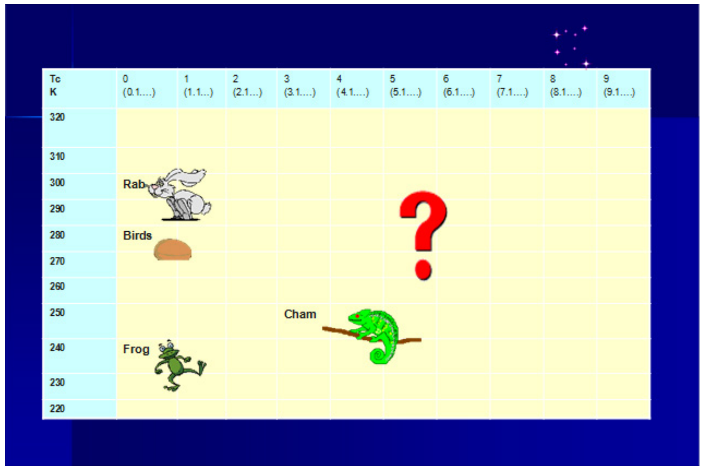

Figure 2: Animal species classification based on superconductor-like behavior in sciatic nerve (Chameleon, frog, bird, and rabbit) inspired from the Mendeleev periodic table methodology (Abdelmelek., et al. 2003b).

Climatic changes observed over a few decades are known to correlate with changes in living populations and species especially the nervous system (neurochemical and/or electric properties). Recently, our scientific team used earth magnetic data and globe temperature data to trace how climate has changed at a variety of scales through Earth's histories and their impact on nervous system especially superconductor-like behavior where the Tc temperature could be explained as globe temperature during the evolution of animal species.

Wavelet model and theory of superconductor-like behavior through nerves

Wavelet analysis and characterization of conductivity of frog sciatic nerve

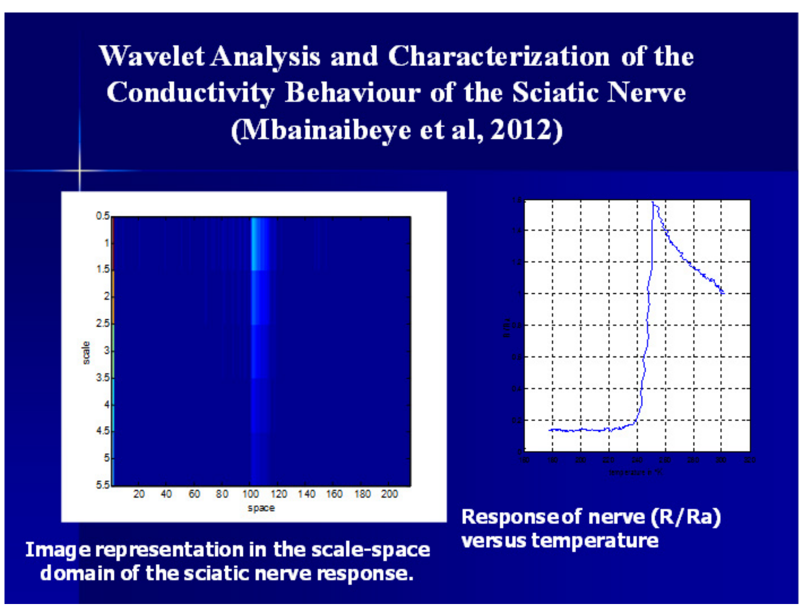

Figure 3: Wavelet analysis and characterization of the conductivity behaviour of the frog sciatic nerve (Mbainaibeye., et al. 2012).

The characterisation of the frog sciatic nerve response by wavelet transform explains that from 300K to 250K, the frog sciatic nerve may be assimilated with the semi conductor for which the resistance grows in this interval. Below 240K, the nerve may be assimilated with a metal for which the resistance is constant and smaller. The interesting information revealed by the wavelet decomposition is the singular behaviour of the frog sciatic nerve between 250K and 240K; in this interval, the resistance of never presents a magnitude discontinuity which is the 0.5 singularity order. This singularity is furthermore characterised by the sensibility of 0.14 K-1.

The analysis by the wavelet transform shows, that between 250K and 240K, the frog sciatic nerve presents a 0.5 singularity order which indicates the magnitude discontinuity in its electrical resistance. We will investigate in the future works, the characterisation by wavelet transform of the electrical conductivity behaviour of sciatic nerves in other species such as chameleon, rabbit and rat...etc (Mbainaibeye., *et al.* 2012).

A new model for the effective superconductivity

The basic finding is that the resistance of the sciatic nerve is reduced by a factor of about ten below a critical temperature at the lower edge of the range of the physiological temperatures. The reduction of the temperature occurs inside a narrow temperature range. This suggests effective super-conductivity. Furthermore, the critical temperature Tc for the breaking of the effective super-conductivity rises from 240K to 300K in the transition from poikiloterms (say frog) to endotherms (say rabbit).

These findings seem to be consistent with the following view.

a) Nerve pulse generation involves a mechanism inducing a flow of ions between axonal interior and exterior and induces at the same time the breaking of super-conductivity (Abdelmelek., et al. 2006; Pitkanen; 2016). At too low temperatures nerve pulses cannot be generated because the breaking of the super-conductivity is not possible. Therefore the critical temperature must be below the range of physiological temperatures.

b) In myelin sheathed regions the breaking of the effective super conductivity does not occur or the critical temperature is higher and the signal carried by the nerve pulse is transformed to an effective or genuine super-current.

c) Poikiloterms can survive only if nerve pulse conduction is possible down to about 240K which represents lower bound for the temperature of environment. Endotherms can keep the body temperature above 300K and so that Tc can be as high as 300K. This is good for survival purposes since high Tc minimizes ohmic losses related to nerve pulse conduction. It is interesting to apply the model for the breaking of super-conductivity in the case of axon (Abdelmelek., *et al*. 2006, Pitkanen, 2016).

d) Understanding the critical temperature

The model for the nerve pulse generation predicts that “bridges” are formed between different space-time sheets making possible the flow of ions between cell interior and exterior. Super-conductivity is broken provided that the temperature is sufficiently high. For electron Cooper pairs the zero point kinetic energy at the cell membrane space-time sheet is from Eq 4

E0 (k = 151) = n1´ 312.25K.

The identification as the critical temperature gives quite satisfactory agreement with the experimental values varying from 240K to 300K. Note that the requirement T > Tc for the physiological temperatures means that k = 151 cell membrane space-time sheet is the effective current carrier in the presence of larger space-time sheets. If the join along boundaries bond connecting k = 169 and k = 151 space-time sheets contains a strong enough transversal electric field, the supra-current can flow only in one direction. It seems that in the case of cell membrane the leakage of electronic Cooper pairs to the negatively charged cell interior is forbidden by this mechanism. The absence of the join along boundaries bonds between cell membrane and cell exterior assumed to be generated during the nerve pulse in the model of nerve pulse in turn implies that the leakage cannot occur to or from k = 169 space-time sheets at all. Therefore both k = 151 and k = 169 space-time sheet might be genuinely super-conducting and only nerve pulse conduction would be accompanied by the breaking of super-conductivity (Abdelmelek., *et al.* 2006, Pitkanen, 2016).

e) Predictions for the critical temperature and resistance fractality allow making definite quantitative predictions for the critical temperature.

f) For k = 163 conductivity the critical temperature is predicted to be by a factor 215-151 = 64 lower than for k = 157 conductivity. This gives Tc (163) = 4.90 K for Tc (157) = 300K. The upper bound Tc = 4K for the critical temperature for super-conductivity in molecular crystals is reported in Schön., et al. (2000). This would correspond to Tc (157) = 240K measured in the case of frog. The predicted lowering of the resistance at this critical temperature for nerve conduction might be testable.

g) Cell membrane thickness L might vary and the natural guess is that the critical temperature is inversely proportional to $1/L^2$. If this is the case, the ratio of cell membrane thicknesses for frog and rabbit should be

$L(frog)/L(rabbit) = [T(rabbit)/T(frog)]^{1/2} = 1.12$
for T (rabbit) = 300K and T(frog) = 240K.

h) A further prediction following from the fractal model for the conductance is that also the k = 157 to 163 at about 4-5K involves a 10-fold reduction of resistance. Also this prediction might be testable for nerves.

i) What happens in saltation?

An interesting question is what happens in the saltation over the myelin sheathed portions of the nerve. According to the model of nerve pulse, a Z0 type ME ("mass-less extremal", "topological light ray" moving with effective velocity equal to the conduction velocity 10 of nerve pulse acts as a bridge between cell membrane (k = 151) and cell exterior (k = 169) space-time sheets and in this manner allows the leakage of ions from cell interior to exterior and vice versa inducing the physiological effects of nerve pulse. Z0 ME could propagate along the myelin sheath rather than along the axon inside. Therefore nerve pulse would not be generated. The following picture about saltation suggests itself.

j) The transformation of the nerve pulse to an electronic k = 151 or k = 169 supra current

Propagating rapidly through the myelin sheathed portion would make possible a rapid signal transmission without physiological effects. Inside myelin sheathed portions of the axon the leakage to k = 169 space-time sheets would be impossible by the mechanism described above irrespective of the value of the critical temperature.

k) Nerve pulse conduction involves also communication and interaction between different space-time sheets and therefore necessitates the leakage of electronic Cooper pairs from k = 151 cell membrane space-time sheet. Therefore the critical temperature must be below the range of the physiological temperatures. Endotherms have an evolutionary advantage since the higher critical temperature implies that the dissipative effects associated with the nerve pulse conduction are weaker. Whether electronic supra-current in the myelin sheathed portions of the axon propagates along k = 151 or k = 169 space-time sheet or along both plus possibly along some other space-time sheets, remains unclear (Abdelmelek., *et al*. 2006, Pitkanen M, 2016).

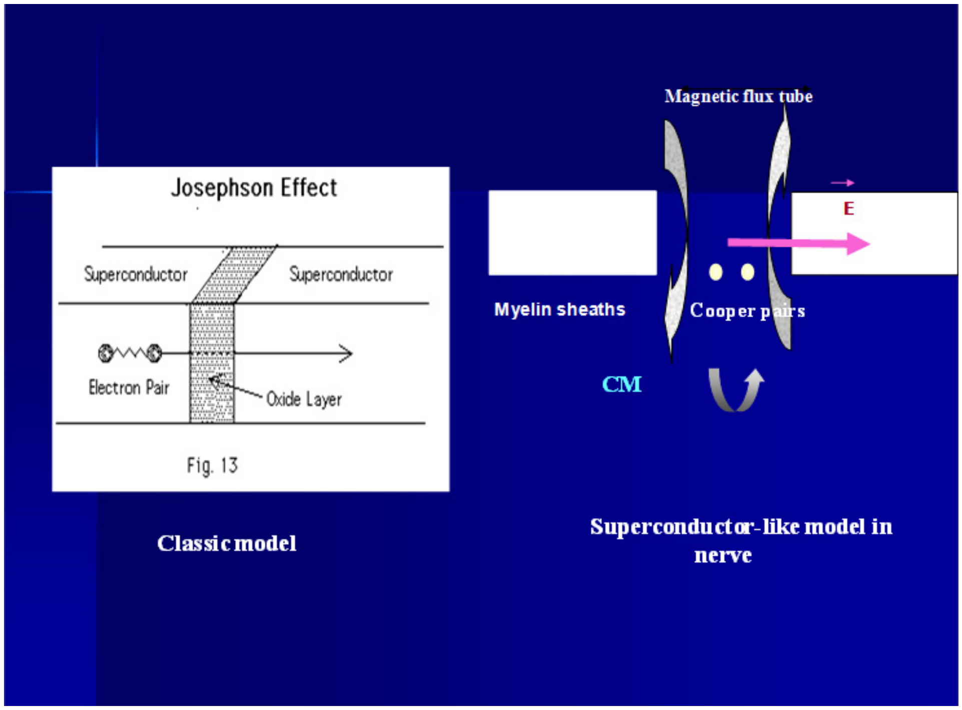

Figure 4: *Sciatic nerve superconductor-like model.*

Conclusion

Our present review represents, for the first time to the best of our knowledge, an exhaustive interpretation and discussion of electric properties of nerves at low temperatures (Semi-conductor, Metallic, and superconductor-like behavior). In addition, we propose theories and models to explain or to understand these exceptional mechanism especially hot superconductors. The mechanism underlying the decrease of resistivity after cold exposure remains to be investigated in different animal species in order to propose animal species classification based on the determination of Tc onset as previously proposed by Mendeleev classification of elements or Mendeleev periodic table. The analysis of climate change impacts on nervous system electric properties at low temperature could be discussed and completed with future investigations. Moreover, the interpretation of the true meaning of Tc in different species could be explained by the values of globe temperature at the apparition or extinction of the species.

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