Cytoprotective Effect of Elf-Emf120hz on Early Chemical Hepatocarcinogenesis through Quantum Measurements on Enzymatic Interaction

Juan José Godina Nava[1,3], Eduardo López Sandoval[2], Arturo Rodolfo Samana[2], Paulo Eduardo Ambrosio[1] and Dany Sanchez Dominguez[1]

[1]*Programa de Pós-Graduação em Modelagem Computacional, Departamento de Ciências Exatas e Tecnológicas, UESC, Universidade Estadual de Santa Cruz, km 16 Rodovia Ilhéus-Itabuna, Salobrinho 45662-900 - Ilhéus, BA – Brazil*

[2]*Departamento de Ciências Exatas e Tecnológicas, UESC, Universidade Estadual de Santa Cruz, km 16 Rodovia Ilhéus-Itabuna, Salobrinho 45662-900 - Ilhéus, BA – Brazil*

[3]*Departamento de Física, CINVESTAV-IPN, Ap. Postal 14-740, CdMex, C.P. 07000, México*

Keywords: Extremely-Low Frequency Electromagnetic Fields, Radical Pair Mechanism, Hepatocarcinogenesis.

Abstract: Using the concept of quantum measures, we depict the mechanism in which the cytoprotective effect of ELF-EMF-120Hz on early hepatocarcinogenesis chemically induced in rats matches with the theory. We used the traditional Haberkorn approximation to evaluate the quantum yields at the rate of recombination production of singlet spin state populations, assessing with this information, the magnetic field effect. In this work, we study the system RP-Hepatocyte simply applying dynamic mapping.

1 INTRODUCTION

Nowadays, for all, it is known that both permanent magnetic field (MF) and extremely low-frequency electromagnetic field (ELF-EMF) interact with biological systems (BS) at all levels (Paunesku, 2007). However, there still not exist a precise molecular mechanism for which the ELF-EMF or MF can characterize their therapeutic use, although much research has been performed and reported several effects on BS. The most common report is that an external MF can significantly affect the rates of chemical reactions in BS involving free radicals, impacting the probability of transition between the singlet (S) to the triplet spin state (T), $S \leftrightarrow T$, in the radical pair (RP) largely (Sagdeev, 1973; Maeda, 2011). The hyperfine interaction (HyI) is the responsible for the control of the spin-flip conversion $S \leftrightarrow T$ spin states of the RP permitting to modify it by the application of an external MF. The magnetic energy compared with the chemical energy is 10-100 times smaller, in fact, the newest effect is the magnetoreception in birds (Rodgers, 2008). The RP recombination probability changes in a periodic way whose frequency is determined by the HyI. The origin of the oscillations is the interaction between the one nuclear RP (spin 1/2) and two electrons. In fact, if we start with a singlet correlated-spin state, when HyI produces the oscillations $S \leftrightarrow T$, at the same time determines that be precisely this spin singlet state who through recombination probability oscillate in time (Anisimov, 1983; Maeda, 2011). In a real system, RP has many nonequivalent magnetic nuclei, and in this case, the interaction between RP is management in ensembles by harmonic oscillations, but in this case, the regulation of the system is carried on by a set of complex frequencies that interfere itself and vanishes due to the superposition. The opposite effect, which appears when the magnetic nuclei are equivalent, i.e., the oscillation between *S* and *T* states between differents RP are drafted in a variety of frequencies, whose superpositions appears as beats of the reaction probability. The only condition for their observation is that the ensemble is prepared in a different defined initial spin state and stimulated by light, ionizing radiation or MF.

Facing our limited knowledge and using the available information, we reported the cytoprotective effect of ELF-EMF120Hz on early chemical hepatocarcinogenesis during the enzymatic procarcinogen activation of the Cytochrome P450 (CYP450) by quantum measurements. In the

Godina-Nava, J., Sandoval, E., Samana, A., Ambrosio, P. and Dominguez, D.
Cytoprotective Effect of Elf-Emf120hz on Early Chemical Hepatocarcinogenesis through Quantum Measurements on Enzymatic Interaction.
DOI: 10.5220/0006546401190126
In *Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2018) - Volume 4: BIOSIGNALS*, pages 119-126
ISBN: 978-989-758-279-0

experimental setup, we implementing the modified resistant hepatocyte model with Male Fisher-344 rats exposed them daily to 4.5 mT-120 Hz ELF-EMF during 50 minutes. We analyze the effects performing several biological tests concerning apoptosis, proliferation and cell cycle progression. We found that daily application of ELF-EMF inhibits preneoplastic lesions in both size (56%) and number (58%).

It appears when after formation of oxidation state, the electron transfer is involved, and the MF modulates those in the current Haberkorn approach (Jones, 2011; Godina, 2017). The allowed electrophilic reactions that appear in the enzymatic reactions do not require a change of spin because the spin total is zero. Those spin-forbidden reactions, involving paramagnetic participants, can combine their spins freely in any electronic configuration, but it does not mean that all configurations have a chemical reaction. The electron spin is who gives origin to the MF effect (MFE), the magnetic isotope effect and induced nuclear chemical polarization. From all four possible combinations of quantum spin states, only one is useful combining two radicals to become a diamagnetic molecule (Buchachenko, 1995-a; Buchachenko, 2017; Godina, 2017).

The proposal is that when CYP450 metabolizes the xenobiotics used in the experimental setup to induce the chemical hepatocarcinogenesis, such enzymatic proteins act as a molecular motor providing a catalyzing electron that interacts with the RP formed during the oxidative stress generated when the substrate of the enzyme is oxygenated. Since the metabolization is carry on in the liver, the hepatocytes are in contact with the enzymatic protein like in a thermal bath and with a Gibbsian distribution, interacting with the RP like a harmonic oscillator. Employing quantum measurements concepts, we argue the way in which the MF modulates the singlet spin population to diminish the preneoplastic lesion observed during the experimental setup (Jimenez-Garcia, 2010) and theoretically explained in (Lopez-Riquelme, 2015; Godina, 2017). The complete system between RP and electronic configuration of hepatocytes interacting through the hyperfine coupling constant, alter that the quantum spin state removes spin prohibition giving rise to the appearance of new reaction products. Such products in our case, result of the spin selectivity plus HyI action affecting the magnetic properties that impact in the so-called initiated hepatocytes that become later the preneoplastic lesion.

2 RADICAL PAIRS

The main protagonist in this approach is the so-called radical pair (RP), short-lived intermediates that participate in almost all reactions in solution in a correlated way. The RP can recombine or participate in other chemical reactions. They are the responsible for a few phenomena like chemical polarization of electrons and nuclei, and the influence of static and pulsating MF. An RP can decay by recombination, or put apart the radical by diffusion, or react with other radicals. One of the properties of the RP is that recombination probability depends on the spin multiplicity, and it varies during RP lifetime. An interesting detail is that are manifested such variations as dynamic quantum oscillations, the so-called quantum beats between (S, T) spin states of the RP. The quantum beats modulate the probability of appearance of some reaction channels of the RP that at time affect the MF Effect (MFE). By studying these quantum beats, one can reveal valuable information concern the structure, reactions, molecular and spin dynamics of RP (Molin, 1999; Maeda, 2017; Godina, 2017). The RP spin-correlated is formed in the coherent state which oscillates between S and T spin state, an oscillation that depends on of the spin Hamiltonian operator parameters, in particular of the hyperfine coupling constant. The period of the oscillation on organic radicals is in the range of nanoseconds.

3 MAGNETIC FIELD EFFECT

In the first instance, in laboratory conditions, it is possible that we can have significant magnetic field effect (MFE) at low temperatures. There exist other situations where the MFE are essential. In fact, the most exciting possibilities appear when we study the nonequilibrium situation. Thus, when we apart from the equilibrium for a specific quantity, would be involucrated some transport properties, related with the nonequilibrium parameters like electric conductivity, the Hall constant, the thermal conductivity, and the diffusion coefficient (Zeldovich, 1998; Maeda, 2017). The MFE of a magnetic moment of the nuclei is similar to that of an external MF. Other places where we can observe the influence of the weak MF is at the rate of precession of paramagnetic particles like radicals, or electrons, participating in chemical reactions. The main fundament of these effects is the so-called principle of spin selectivity, i.e., that the chemical reactions are

only allowed starting from a definite spin state. For example, the case that happens when is formed an intermediates RP, the radicals in their formation can adopt the singlet or triplet spin state, but the recombination of the RP into a molecule only is allowed through the singlet state, due that the reaction by triplet state is spin-forbidden. When an oxygen molecule meets with the RP, the Hausdorff space spanned by the system of RP-oxygen is formed by two doublets and one quartet state. However, in the doublet is where is constituted the interaction between the radical and oxygen molecule. The central detail into an MFE is that although the MF interactions of spins with external and internal nuclear fields have negligible energies, their effect on chemical reactions is of much strength since those change the spin of the reacting participants promoting new channels of interaction for the spin selection (Zeldovich, 1998; Buchachenko, 2017; Godina, 2017).

The key is that those radicals are MF-dependent quantities, and they are controlled by a weak MF ($\leq k_BT$) precisely by their spin correlation, taken as far away from their equilibrium position. Thus, the radical pair mechanism (RPM) is the only plausible theory used to explain the MFE over the reactivity of chemical reactions in BS (Rodgers, 2008; Maeda, 2017; Buchachenko, 2017).

Their importance appears because phosphorylation is the most significant phenomenon for living organisms. For every enzyme or molecular machine, at low energy, appears electron transfer with a high energy nucleophilic reaction. A consensus in the several dissertations is that a weak, steady and pulsating MF can affect the radical concentration affecting the population distribution of nuclear and electronic states, with side effects like interactions on the rate of singlet state decay, affecting the BS.

4 THE MODEL

The MFE is used as a diagnostic tool in search of chemical mechanism of the reaction since they indicate the prominent participation of particular reactants that signal some important chemical transformations of particular radicals. The MFE appear when we have an intermediate RP of paramagnetic particles in a nonequilibrium population of spin states. Can be seen a chemical reaction as a physical process where there are involved a set of regrouping of atoms with the rearrangement of electronic shells of reacting participants, giving place to the generation of new molecular structures called reaction product. The new ways to control chemical reactions have their basis on the selectivity of a process where are involved the spins of molecules, electrons, and nuclei of the reacting participants. For this reason, the rate of spin-selective processes is dependent of MF, whose alter the spins of the participants changing partial or wholly the spin selectivity (Zeldovich, 1998; Buchachenko, 2017; Godina, 2017). Thus, revealed the interaction to explain the cytoprotective effect of ELF-EMF in CYP450, we must define the conditions where is performed the quantum measurement. The first condition is that all quantum states participating in the system RP-hepatocytes in the enzymatic reaction are singlets, for their high reactivity. The second condition is during the enzymatic procarcinogen activation of CYP450 when are metabolized the xenobiotics, in which appear the RP when is generated the oxidative stress. Are produced the intermediaries in this step, and they are the responsible of the insult to hepatocytes and, who will become the future preneoplastic lesions after to finish the chemical induction of hepatic cancer. The third phase is the daily MF stimulation during all chemical process. On the other hand, the spin evolution of RP is driven by the MF through the HyI; is controlled their reactivity by the spin dynamics converting non-reactive triplet into reactive singlets and through quantum measurement. We show the way in which the MF modulates the charges in migration evaluating the recombination probability. At this respect, when the RP interact with another spin electron, this interaction acts as a catalyst increasing the recombination probability accelerating the $S \leftrightarrow T$ interconversion (Buchachenko, 1998; Buchachenko, 2017; Godina, 2017).

4.1 Spin Selectivity

We will use the basic principle of the chemical reactions that those are spin selective. We satisfied the spin angular momentum conservation between reagents and products. The RP acts when there exist $S \leftrightarrow T$ interconversion, and this interaction will generate the MFE (Buchachenko, 1995; Buchachenko, 2017). Also, we use the fact that the spin catalysis consists of changing the spin state of the reactants in a chemical reaction.

In this spin catalysis, those spin states prohibited are stimulated to appear, opening channels that usually do not are open, promoted by the interaction between the RP and the third spin. Such catalytic effect due to the third spin is similar to that of the $S \leftrightarrow$

T interconversion mechanism by the magnetic nuclei of the RP (Gorbunov, 2011).

4.2 Haberkorn Approach

Thus, to study the results, involving the information of all parameters employed in the evaluation of MFE, the recombination yield, and the singlet population, is needed the Haberkorn approach; which is the most common theory used for spin dynamics studies. The Haberkorn approach is obtained using the spin density matrix in the framework of the Liouville-von Neumann equation involving the rate at which singlets disappear, and we named k_S; involved in a unnormalized wave function (Jones, 2011; Godina, 2017)

$$\| \psi >= c_S e^{-k_S t/2} \ \| S > + c_T \| T >, \qquad (1)$$

here the amplitudes for the singlet disappears at the rate $-k_S/2$, provoked by the interaction between RP and a third electron coming for the electron configuration of the hepatocytes. With this approach, can be written the standard density matrix (without the third electron) as

$$\hat{\rho}_{in} = \begin{pmatrix} C_S C_S^* e^{-k_S t} & C_S C_T^* e^{-k_S t/2} \\ C_T C_S^* e^{-k_S t/2} & C_T C_T^* \end{pmatrix} \equiv \hat{\rho}_0 \qquad (2)$$

moreover, to satisfied the unicity of the trace in the density matrix, we include the third electron. The so-called reaction products, according to with the rule of conservation of the number of entities participating, i.e., the generation of some product population corresponds to the disappearance of some singlet reactant population (Jones, 2011)

$$\hat{\rho} = \begin{pmatrix} C_S C_S^* [1 - e^{-k_S t}] & \tilde{\emptyset} \\ \tilde{\emptyset}^\dagger & \hat{\rho}_0 \end{pmatrix}, \qquad (3)$$

where $\tilde{\emptyset} = (0\ 0)$ is a null vector.

4.2.1 Quantum Measurements

When we have a chemical reaction involving only singlet spin state as in our case, we can consider it as a quantum measurement (Jones, 2011), where the amplitudes for the singlet disappears at the rate $-k_S/2$ provoked by the interaction of the third spin electron that can be studied.

During the lifetime of the RP, their spin multiplicity can change. Can be seen such changes by electron spin resonance spectroscopy (ESR) studies. The name for such changes in the spin is simply beats, which means, the dynamical quantum oscillation between the $\| S >$ and $\| T >$ spin states of the RP. They are used to study the behavior of the spin dynamics of RP, for example, the rate constants of reaction or the fraction of singlet-correlated pairs, among others. One crucial issue is that RP appears in the coherent state, which permits the oscillations between $\| S >$ and $\| T >$ spin states of the RP, commanding of HyI. At a quantum level, these beats represent the manifestation of the RP. They in ESR studies during the recombination of spin-correlated ion RP were measured. Tacitly, the beats correspond to $S \leftrightarrow T$ spin-flip transitions generated by HyI. The behavior of a unpaired electron under MF, or without MF, determines the influence of HyI so we can measure the MFE.

Eq. 3 express the way at which singlet disappear at desired rate k_S. On the other hand, the off-diagonal terms, represent the coherent superposition terms only decay at a rate $k_S/2$. The corresponding equation of motion for the density matrix with $\hat{H}_{int}$ as the interaction Hamiltonian operator is expressed as (Jones, 2011; Godina, 2017)

$$\frac{d\hat{\rho}}{dt} = -i[\hat{H}_{int}, \hat{\rho}] - \frac{1}{2} k_S (\hat{\rho}\hat{Q}_S + \hat{Q}_S\hat{\rho}), \qquad (4)$$

where $\hat{Q}_S = \| S >< S \|$ is the projection operator onto the singlet state.

The yield of recombination calculated from the singlet state of the RP can be evaluated by

$$\Phi_S = k_S \int_0^\infty Tr[\hat{Q}_S \hat{\rho}(t)] dt, \qquad (5)$$

once that Eq. 4 is solved. Indeed, with this quantity, the MFE is evaluated on the yields of the diamagnetic products involved, and in those RP that does not participate in the recombination process. Furthermore, in the exponential approach, the Φ_S represents, the effect of all re-encounter times for the reencounter probability of a diffusive geminate RP when it is described the time evolution after their formation, and $\tau^{-1} = k_S$ is the average re-encounter time when $k_S = k_T$ (Godina, 2017).

We use as an initial condition the fact that the population is born in singlet state

$\| \Psi(t=0) >= \| S >$, then the evolution time wave function reads

$$\| \Psi(t) > = \sum_n A_{P_n}(t) \| P_n > + A_S(t) \| S > + A_{T_0}(t) \| T_0 > . \quad (6)$$

With this sense, the quantum measurements (Kominis, 2009) give us the formation of products and then the effect of singlets into the hepatocytes with an intensity $\| A_S(t) \|^2$.

4.2.2 Dynamical Maps

Since the purpose is to analyze the influence of the ELF-EMF on early hepatocarcinogenesis, in particular, the effect of the singlet-triplet coherent spin-flit conversion of the RP provoked by HyI on hepatocytes by an enzymatic reaction in the liver. We use a quantum mechanical model spin-based with the goal that once is performed the calculation of singlet spin population and determined the MFE, evaluating the quantum yield for the intermediaries RP in the system substrate product of the CYP450, to depict the cytoprotective mechanism.

To study the spin population behavior of the system was applied the Lanczos method to diagonalize the interaction spin Hamiltonian. It was previously rewritten the Hamiltonian in the superstate representation (Godina, 2017). Beyond of the mathematical model, the biology of the problem concerns with the action of the EMF on RP affecting the Hepatocytes during the enzymatic procarcinogen activation of the CYP450, precisely modulating the charges that are in migration during the electron transfer reactions generated by the CYP450 in their substrate producing electrophilic and reactive oxidative species. The intermediaries generated during this process are the source of the first insult to hepatocytes in their way to become preneoplastic lesions in a chemically induced cancer protocol. Are used three assumptions: i) the chemical reactions are spin selective, ii) chemical reactions present nuclear spin selective, iii) chemical reactions are selective with the spin of the electron. Under such circumstances, only the reactions with singlets favored the formation of standard molecules. The reactions with triplet RP are forbidden. Under this outline, the spin of the electron is who controls the generation of the magnetic-spin effects (Godina, 2017). One of the keys of the model is to consider the role for the enzymatic protein as a molecular motor. Their function is supplying catalyzing electrons to the reaction, where take action the RP generated into the substrate of CYP450 when it is metabolizing the xenobiotics used in the hepatocarcinogenic model. Since it is in the liver where the metabolization is performed employing the enzymatic protein, we consider to the hepatocytes harmonically interacting with a thermal bath in a Gibbsian distribution with the RP. Dynamical maps are used to characterize, in a general way, the form in which the interaction affect both the reactive enzymatic system and the hepatocytes (Godina, 2017).

Thus, we study the RP-third electron system, considering that the hepatocytes coupled to the enzymatic reaction system start with some healthy initial cell configuration, $\| 0 >_{Hep}$, and choose a spontaneous decay process (there exist other possibilities) in the recombination dynamics. The system can be described by the following dynamical mapping (Tiersch, 2012; Godina, 2017)

$$\| S >\| 0 >_{Hep} \rightarrow \eta_1 \| P >\| \sigma >_{Hep} + \eta_2 \| S >\| 0 >_{Hep} , \quad (7)$$
$$\| T_0 >\| 0 >_{Hep} \rightarrow \| T_0 >\| 0 >_{Hep} .$$

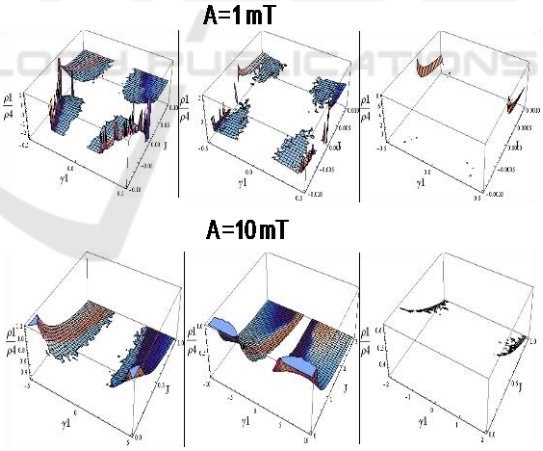

Figure 1: Evolution of the singlet spin population. Here, we note that increasing the hyperfine coupling constant, A, the singlet population is diminishing.

However, we need recover the evolution equation for ρ because the trace should take into account the hepatocytes degree of freedom $\mathrm{Tr}[\widehat{Q}_S \hat{\rho}(t)]$. The trace is evaluated keeping in mind the detailed principle balance.

During the process appears an effective singlet state $\| \sigma >_{Hep}$ describing the degree of freedom of

the hepatocytes, that appears with a probability $\| \eta_1 \|^2$. The triplet state, that appears with a probability $\| \eta_2 \|^2 = 1 - \| \eta_1 \|^2$, does not interact. In fact, both states do not evolve with the interaction Hamiltonian operator $\hat{H}_{int}$, but these probabilities depend on time duration δt of the interaction because they are matrix elements of the time-evolution operator (Tiersch, 2012; Godina, 2017), defining

$$\begin{aligned} {}_{\text{Hep}} < \sigma P \| &= {}_{\text{Hep}} < \sigma \| < P \| , \\ \| S\, 0 >_{\text{Hep}} &= \| S > \| 0 >_{\text{Hep}} , \\ {}_{\text{Hep}} < 0\, S \| &= {}_{\text{Hep}} < 0 \| < S \| , \end{aligned} \tag{8}$$

we can express such amplitudes of probabilities in the form

$$\begin{aligned} \eta_1 &= {}_{Hep} < \sigma P \| \, \mathbb{U}(\delta t) \, \| S\, 0 >_{Hep} , \\ \eta_2 &= {}_{Hep} < 0\, S \| \, \mathbb{U}(\delta t) \, \| S\, 0 >_{Hep} , \end{aligned} \tag{9}$$

generated by the interaction Hamiltonian (Tiersch, 2012; Godina, 2017)

$$\begin{aligned} \hat{H}_{\text{int}} = \eta_0 (&\| P >< S \| \otimes \| \sigma >_{\text{Hep}} < 0 \| \\ &+ \| S >< P \| \otimes \| 0 >_{\text{Hep}} < \sigma \|) , \end{aligned} \tag{10}$$

where $\mathbb{U}(\delta t) = e^{-i\hat{H}_{\text{int}}\, \delta t}$ represent the time evolution operator. A projection over the $S - T_0$ subsystem is precise to obtain the effect on the hepatocytes, but this step leaves without normalization to $\hat{\rho}(t)$. To recover the evolution equation is needed to use an arbitrary pure state

$$\begin{aligned} \| \Psi_{\text{RP}}(t) > = {} & A_S(t) \| S > \\ & + A_{T_0}(t) \| T_0 > , \end{aligned} \tag{11}$$

thus, $\| A_S(t) \|^2 + \| A_{T_0}(t) \|^2 = 1$, and evolving with $\hat{H}_{\text{int}}$ as

$$\begin{aligned} &\left(A_S(t) \| S > + A_{T_0}(t) \| T_0 > \right) \| 0 >_{\text{Hep}} \\ &\qquad \rightarrow \\ &\left(\eta_2 A_S(t) \| S > + A_{T_0}(t) \| T_0 > \right) * \\ &\quad * \| 0 >_{\text{Hep}} + \\ &\quad \eta_1 A_S(t) \| P > \| \sigma >_{\text{Hep}} . \end{aligned} \tag{12}$$

4.2.3 Effect on Hepatocytes

When is done the normalization, the measurement of the generation of some reaction product on the hepatocytes $\| P >$ is represented according to (Tiersch, 2012; Godina, 2017)

$$\hat{\rho}(0) = \begin{pmatrix} \| A_S \|^2 & A_S A_{T_0}^* \\ A_{T_0} A_S^* & \| A_{T_0} \|^2 \end{pmatrix} \rightarrow \hat{\rho}_n , \tag{13}$$

where

$$\hat{\rho}_n = \beta \begin{pmatrix} \| \eta_1 \|^2 \| A_S \|^2 & \eta_2 A_S A_{T_0}^* \\ \eta_2^* A_{T_0} A_S^* & \| A_{T_0} \|^2 \end{pmatrix}, \tag{14}$$

with

$$\beta = \frac{1}{1 - \| \eta_1 A_S \|^2} . \tag{15}$$

The result expresses that hepatocytes can measure the spin nature of the RP that is participating. The spin state of the hepatocyte changes according to the spin nature of the RP that is interacting. During the measurement process, the S and T_0 components do not change, but the hepatocytes change their spin states according to the RP spin character following the dynamical mapping (Tiersch, 2012; Godina, 2017)

$$\begin{aligned} \| S > \| 0 >_{\text{Hep}} &\rightarrow \beta_1 \| S > \| \sigma >_{\text{Hep}} \\ &+ \beta_2 \| S > \| 0 >_{\text{Hep}} , \\ \| T_0 > \| 0 >_{\text{Hep}} &\rightarrow \beta_3 \| T_0 > \| \chi >_{\text{Hep}} \\ &+ \beta_4 \| T_0 > \| 0 >_{\text{Hep}} , \end{aligned} \tag{16}$$

instituted by the interaction (Tiersch, 2012; Godina, 2017)

$$\hat{H}_{in} = \{ \eta_S \| S >< S \| \} \otimes [\| \sigma >_{\text{Hep}} < 0 \|$$

$$+ \| 0 >_{Hep} < \sigma \|] + \{\eta_{T_0} \| T_0 >< T_0 \|\} \otimes [\| \chi >_{Hep} < 0 \| + \| 0 >_{Hep} < \chi \|], \quad (17)$$

here, η_S and η_{T_0} give us the strength of the interaction of the hepatocytes with RP spin character, appearing the new term, $\beta_3 \| T_0 > \| \chi >_{Hep}$, without $\| P >$ states.

In this case, the probabilities $\| \beta_1 \|^2$ or $\| \beta_3 \|^2$ express the appearance of a $\| S >$ or $\| T_0 >$ spin states, represented by $\| \sigma >$ and $\| \chi >$ (Godina, 2017). They measure the fraction of singlets transformed into a reaction product or transformed cell. It is precisely this kind of product formation which change the electronic configuration of the hepatocytes, as we claim. The result is evident from Figure 1, where we note that increasing the hyperfine coupling constant, A, the singlet population is diminished. Thus, once the hepatocytes interact during δt with the CYP450 by the enzymatic reaction, they change their spin states by the effect of the application of the selective spin operator. For each time interval δt will be applied the dynamical mapping to each new healthy hepatocyte in the tissue $\| 0 >_{en}$ incorporating them into the enzymatic reaction which provides of catalyzing electrons during the metabolization of xenobiotics (Godina, 2017)

$$\| \Psi(\delta t) >_{s\,en} = \mathbb{U}(\delta t) \| \Psi(\delta t) >_0 = e^{-i\hat{H}_{in}\delta t} \| \phi_0 >_s \| 0 >_{en}. \quad (18)$$

Also, neglecting the memory effects due to the previous results with other singlets, which are diminishing as is evidenced by the quantum measurement $\| \beta_1 \|^2 = k_S \delta t$, changing the electronic configuration of the hepatocytes when it converted the RP in a reaction product by the recombination kinetics.

5 CONCLUSIONS

In this work, we studied a simple quantum mechanic model to describe the interaction RP-Hepatocytes following the typical Haberkorn approach for spin dynamics. Was taken the quantum yields, MFE and spin population from previous theoretical studies (Lopez-Riquelme, 2015; Godina, 2017) to explain the experimental one (Jimenez-Garcia, 2010).

In (Godina, 2017) is investigated in details the calculations regarding the spin relaxation effects, and also other forms of coupling to hepatocytes.

We evaluated the MFE due this is the diagnostic tool for measure the efficiency in the conversion of triplet spin state in reactive singlet spin state interacting with hepatocytes. We evaluated it employing the Eq. (5), subtracting the corresponding contribution $\Phi_S(\vec{B} = 0)$ from that part of the magnetic field and establishing the rate dividing by the contribution without the field, and multiplying all by 100%. The calculated MFE is an acceptable result compared with the experimentally obtained value (61% compared with 56% (size) - 59% (number) of preneoplastic lesions) (Godina, 2017). The idea of this research note is to obtain an explanation of the way in which hepatocytes can modify their electronic structure when is in interaction with the RP which come from the enzymatic reaction. Our proposal includes the use of the CYP450 as a molecular motor of electron spin catalysis when is oxygenated during the electron transit by the enzyme substrate during the process of metabolization of the xenobiotics employed in hepatic cancer induced chemically. The result gives us a more knowledge respect the way in which MF modulate the electrons which come from the oxidative stress (cytoprotective effect) generated in the reactive system RP-Hepatocyte in the liver, with the finality of understanding carcinogenesis.

ACKNOWLEDGEMENTS

One of the authors (J.J.G.N.) would like to acknowledge the financial support to Universidad Estadual de Santa Cruz, UESC-BA-Brazil (Programa Nacional de Pós-Doutorado PNPS/CAPES).

REFERENCES

Anisimov, O. A., Bizyaev, V. L., Lukzen, N. N., Grigoryants, V. M., & Molin, Y. N. 1983. *The induction of quantum beats by hyperfine interactions in radical-ion pair recombination*. Chemical physics letters, 101(2), 131-135.

Buchachenko, A. L. 1995a. *The nuclear-spin selectivity of chemical reactions.* Russian Chemical Reviews, 64(9), 809-816.

Buchachenko, A. L., & Berdinsky, V. L. 1998. *Spin catalysis as a nuclear spin selective process.* Chemical physics letters, 298(4), 279-284.

Buchachenko, A. L., Ruban, L. V., Step, E. N., & Turro, N. J. 1995. *Spin catalysis of the radical recombination reaction.* Chemical physics letters, 233(3), 315-318.

Buchachenko, A., Lawer, R.G. 2017. *New possibilities for Magnetic Control of Chemical and Biochemical Reactions*. Acc. Chem. Res., 50(4), 877-884.

Godina-Nava, J.J., Torres-Vega, G., López-Riquelme, G.O., López-Sandoval, E.,Samana, A.R., García-Velasco, F., Hernández-Aguilar, C., Domínguez-Pacheco, A. 2017, *Quantum mechanical model for the anticarcinogenic effect of extremely-low-frequency electromagnetic fields on early chemical hepatocarcinogenesis*. Phys. Rev. E 95, 022416.

Gorbunov, O. A., & Purtov, P. A. 2011. *Manifestation of the exchange-relaxation mechanism of spin catalysis*. Chemical Physics Letters, 507(1), 178-180.

Jiménez-García, M.N., Arellanes-Robledo, J., Aparicio-Bautista, D.I.,Rodríguez-Segura, M.A., Villa-Treviño, S., & Godina-Nava, J.J. 2010. *Anti-proliferative effect of extremely low frequency electromagnetic field on preneoplastic lesions formation in the rat liver. BMC cancer*, 10(1), 159.

Jones, J. A., Maeda, K., & Hore, P. J. 2011. *Reaction operators for spin-selective chemical reactions of radical pairs*. Chemical Physics Letters, 507(4), 269-273.

Kominis, I. K. 2009. *Quantum Zeno effect explains magneticsensitive radical-ion-pair reactions*, Phys. Rev. E80, 056115.

López-Riquelme, G.O., López-Sandoval, E., Vera-Aguilar, E., & Godina-Nava, J.J. 2015. *Modulation of radical pairs dynamics immers*ed in an ELF-EMF: The effect on hepatocarcinogenesis. In Journal of Physics: *Conference Series* (Vol. 582, No. 1, p. 012048). IOP Publishing.

Maeda K., Neil, S.R.T., Henbest, K.B., Weber, S., Schleicher E., Hore, P.J., Mackenzie, S.R., and Timmel, C.R. (2011). *Following Radical Pair Reactions in Solution: A step Change in Sensitivity Using Cavity Ring-Down Detection*. J. Am. Chem. Soc., 133(44), 17807-17815.

Yu, N. M. 1999. *Quantum beats in recombination of spin-correlated radical pairs*. Bulletin of the Korean Chemical Society, 20(1), 7-15.

Paunesku, T. & Woloschak, G.E. 2007. *Effects of Radiofrequency and Extremely Low-Frequency Electromagnetic Field Radiation on Cells of the Immune System. In Biological and Medical aspects of electromagnetic fields*, Barnes, F.S. & Greenbaum, B. (Eds.), Taylor & Francis, Bocca Raton, FL, USA, 465.

Rodgers, C. T., & Hore, P. J. 2009. *Chemical magnetoreception in birds: the radical pair mechanism*. Proceedings of the National Academy of Sciences, 106(2), 353-360.

Sagdeev, R. Z., Molin, Y. N., Salikhov, K. M., Leshina, T. V., Kamha, M. A., & Shein, S. M. 1973. *Effects of magnetic field on chemical reactions*. Magnetic Resonance in Chemistry, 5(12), 603-605.

Tiersch, M., Steiner, U. E., Popescu, S., & Briegel, H. J. 2012. *Open quantum system approach to the modeling of spin recombination reactions*. The Journal of Physical Chemistry A, 116(16), 4020-4028.

Zel'dovich, Y. B., Buchachenko, A. L., & Frankevich, E. L. 1988. *Magnetic-spin effects in chemistry and molecular physics*. Soviet Physics Uspekhi, 31(5), 385-408.