‘A quantum observation technique;

Quantum decoherence-by-depolarisation-tunnelling in a Spin Polarized Electron Gas,

described by ‘Celalettin’s 1st Paradigm’’

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If an observer detects changes, then I say that this proposal is an observer.

– Metin Celalettin

Notice 3

Doctor of Philosophy Declaration “I, Metin Celalettin, declare that the PhD thesis entitled A quantum observation technique; the ‘Quantum decoherence-by-depolarisation-tunnelling in a Spin Polarized Electron Gas, and: ‘Celalettin’s 1st Paradigm’ is no more than 80,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work”. “I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures

“I hereby release the University from any responsibility should the nominated examiners adversely appraise the thesis”.

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14-05-2021

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Executive Summary

A Spin Polarized Electron Gas (SPEG) will be mathematically modelled to provide a medium in which the phenomenon will occur. Drawing on similar models consistent with the Quantum Monte Carlo (QMC) method, it will result in an equation enabling the medium to leave evidence of a foreign particle attempting to tunnel through it. This meets the objective of this study, quantum measurement. The SPEG's spin exchange energy boundaries and collective electric dipole spin frequencies will enable the required Free Electron Laser (FEL) to be calibrated to the SPEG frequency forming the crux of the proposal. The mathematical model will leverage off investigations that have been performed at the single electron level, such as precession manipulation and application to a SPEG. This research will then present a formula that describes a SPEG pierced by a FEL and producing a resultant tunnel; its walls stoned by spin-flipped electrons. The formula presented will be the energy expression of the tunnel by depolarization.

A superposition of quantum states involving radiation fields with classically distinct phases is modelled and its decoherence is introduced via spin depolarization. The model involves a Spin Polarized Electron Gas (SPEG) interacting with a coherent electron pump trapped in a virtual cavity. SPEG is the equivalent of a particle detection system, providing evidence of a foreign elementary particle though a later collective consideration of flipped spins in the SPEG caused by the electron pump tuned to ω_{Rashba}, described by 'Celalettin's 1st Paradigm'. Once the pump penetrated the SPEG it was found that a tunnel was created, which left evidence of the presence of the foreign particle. This 'spin-flip by depolarization' decoherence phenomenon provided a direct insight into a process at the heart of quantum measurement, which could be exploited in future spintronics' applications.

ii List of Publications

1. Celalettin M, King H (2018) Mathematical Proof of Concept: Celalettin-Field Quantum Observation Tunnel; A Quantum Communication Countermeasure. Sch J Appl Sci Res Vol: 1, Issu: 9. 06-10

2. Celalettin M, King H (2018) A Short Communication on Quantum Radar Obstacles and the Failing ‘Quantum Illumination’ Theoretical solution’. Sch J Appl Sci Res Vol: 1, Issu: 9. 11-12

3. Celalettin M. King H (2018) ‘Mathematical Proof of Concept: Celalettin-Field Quantum Observation Tunnel; A Quantum Communication Countermeasure’. Sch J Appl Sci Res Vol: 1, Issu: 9. 06-10

4. Celalettin M, King H (2019) ‘The Optimal Medium in Which the ‘Celalettin-Field Quantum Observation Tunnel’ Operates: The Polarised Electron Cloud’s Emergence from the Laboratory Based Rubidium-87 to Helium-3; Invizicloud’. American Journal of Engineering and Applied Sciences. 12 (1): 61-66

5. Celalettin M, King H (2019) ‘A Short Communication: Hasret’s Theory; Quantum Observation Caused by the Filling of a Helium-3 Electron Hole in an INVIZICLOUD© via a ‘Celalettin-Field Quantum Observation Tunnel’. American Journal of Engineering and Applied Sciences. 12 (3): 387-390

6. Celalettin M, King H. (2019). The ‘Celalettin-Field Quantum Observation Tunnel’ a Quantum Communication Countermeasure Speculative Structure. American Journal of Engineering and Applied Sciences, 12(1), 111-117

7. Celalettin M, King H (2019) Enabling the ‘Celalettin-Field Quantum Observation Tunnel’ to Develop a Hand-Held Medical Resonance Imaging Device in order to Prevent Paediatric Sedation during Medical Imaging – A Short Communication’. Acta Scientific Paediatrics 2.9

8. Celalettin M, King H. (2020). A Quantum Observation Technique: The 'Celalettin-Field Quantum Observation Tunnel' in an IC-Manifold and the 'Celalettin Tunnel Conjecture'; a Short Communication. American Journal of Engineering and Applied Sciences, 13(1), 56-60

9. Celalettin M (2020) A Paediatric Pulmonary Electron based Magnetic Resonance Imaging Technique Exploiting Electron Orbital Angular Momentum. Spin and the ‘Celalettin Tunnel Conjecture’. Journal of Physics & Optics Sciences. SRC/JPSOS/127

10. Celalettin* M, Celalettin H & King H (2020) ‘The ‘Celalettin Tunnel Conjecture’ and the Recalibration of a Magnetic Imaging Resonance Machine in the Pulmonary Diagnostics of Severe Acute Respiratory Syndrome Coronavirus-2 for Paediatric Patients’. Acta Scientific Paediatrics 3.8

For my wife

iv. List of Figures

ACKNOWLEDGEMENTS

I would like to thank Dr Horace King. Under whose supervision I was pushed beyond the boundaries of extant quantum theory and spintronics knowledge in not a fellowship, but a PhD program. He encouraged me to think so very far outside the box in search of solutions to anticipated future problems with quantum theory. As a result of his courageousness, I have been able to achieve that goal in contributing a proposed new learning in quantum mechanics.

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Chapter 1

1.1 Introduction; Quantum observation techniques

Quantum mechanics is a branch of physics that applies to subatomic particles rather that Newtonian physics or astrophysics. The 'gravity problem' in quantum mechanics is that unlike Newtonian physics or astrophysics, gravity appears to have no effect on individual subatomic particles. The reason for this remains unknown, and significant advancements in string-theory continue to fall short or progress any understanding of the problem. The flagship phenomena in quantum mechanics are superposition and quantum entanglement.

In 1947, Paul Dirac described the superposition principle as follows:

''The general principle of superposition of quantum mechanics applies to the states [that are theoretically possible without mutual interference or contradiction] ... of any one dynamical system. It requires us to assume that between these states there exist peculiar relationships such that whenever the system is definitely in one state we can consider it as being partly in each of two or more other states. The original state must be regarded as the result of a kind of superposition of the two or more new states, in a way that cannot be conceived on classical ideas. Any state may be considered as the result of a superposition of two or more other states, and indeed in an infinite number of ways. Conversely, any two or more states may be superposed to give a new state...

The non-classical nature of the superposition process is brought out clearly if we consider the superposition of two states, A and B, such that there exists an observation which, when made on the system in state A, is certain to lead to one particular result, a say, and when made on the system in state B is certain to lead to some different result, b say. What will be the result of the observation when made on the system in the superposed state? The answer is that the result *will be sometimes a and sometimes b, according to a probability law depending on the relative weights of A and B in the superposition process. It will never be different from both a and b [i.e., either a or b]. The intermediate character of the state formed by superposition thus expresses itself through the probability of a particular result for an observation being intermediate between the corresponding probabilities for the original states, not through the result itself being intermediate between the corresponding results for the original states."*

Quantum entanglement is well described as when two electron particles are entangled when they share the same state after they interact. The quantum states are inter-dependant. There is a correlation between them such that if one of them is in a particular quantum state other one will have the different quantum state. Such that if one particle was in a state of Up-Spin, then the other is in Down-Spin. They are both correlated. The complication in quantum mechanics is such that it is not difficult to comprehend that if the spin of one of the entangled electron particles is observed to be Spin-up or Spin-Down as they are correlated. In the case of quantum particles, it is not that they have their assigned states all the time. However, each of the entangled particles are in a superposition of two of the available states simultaneously and one of the two electrons will choose one of the available states on at the time that it is measured. Prior to being measured, their states had not been determined, therefore when the spin was measured, only at that point was the state determine [1].

In quantum physics, a measurement is the testing or manipulation of a physical system to yield a numerical result. The predictions that quantum physics makes are in general probabilistic. The mathematical tools for making predictions about what measurement outcomes may occur were developed during the 20th century and make use of linear algebra and functional analysis.

Quantum physics has proven to be an empirical success and to have wide-ranging applicability. However, on a more philosophical level, debates continue about the meaning of the measurement concept. The loss of quantum coherence, or the collapse of a superposition; quantum decoherence is a description of the events that occur at the moment of quantum measurement. While coherent, a quantum system can never be observed, neither any particle involved in the system can be measured nor evidence of its presence observed [1].

This irreversible reduction process takes the form that all possible eigenvalues of the system did present simultaneously on a 'preferred' probability index. Once collapsed, these particles can be described classically [2]. Wave function collapse asserts that measurement of a quantum system causes a discontinuous collapse into one of all previously possible eigenstates [3]. The superposition principle is fundamental to quantum mechanics. This phenomenon relates to the Schrodinger equation described by:

$$i\hbar \frac{\partial}{\partial t}|\psi(t)\rangle = \hat{H}|\psi(t)\rangle \tag{1}$$

Where:

H = Hamiltonian

t = time

ψ = the wave function subject to superposition

Where for the quantum entangled system composed of a pair of fermion spin½ particles, we can reduce Equation 1 to:

$$-\frac{\hbar\text{^}2}{2m}\nabla\,\psi(\alpha e) = i\hbar - \frac{\partial}{\partial t}\psi(\alpha e)$$

(2)Where:

αe = eigenvalues of the entangled particles

ψ = the wave function in a superposition

Measuring one entangled particle precludes any possible subsequent measurement of the other however the other particle’s state is opposite [1]. In solid state physics, quantum measurement is almost always achieved by ionization. Gaseous ionization detectors or the more typical semiconductor detectors exploit the ionizing properties of atoms. Confirmation of the presence of matter or the interaction between matter meets the definition of ‘quantum measurement [4].

At the quantum level, it could be scattering. Either an electron or photon with sufficient ionization energy collides with an atom. If the electron or photon’s energy is equal to or greater than the atom’s ionization energy then it will dislodge electrons from the atom’s outer most layer. If its energy is less than the atom’s ionization energy, it will not [5]. Quantum measurement can also be achieved via the photoelectric effect, where the conversion of photons to photoelectrons causes an electric current. In effect, a photon is detected. When relativistic electrons, that is, electrons moving at a speed close to light speed enter a dielectric medium where in the medium of the local speed of light is significantly less than c, the electrons temporarily travel faster than light and as they interact with the medium in slowing down to the local speed of light, they generate a faint light called Čerenkov radiation [6].

The speed threshold for light production, the speed-dependent light output or the speed-dependent light direction of Čerenkov radiation is exploited as it passes through a dielectric medium faster than the phase velocity of light in said medium. The measurement is caused by Čerenkov threshold detectors which discriminate between particles in the medium based on their different masses [4].

A Hilbert space is a Euclidean abstract vector space possessing the structure of an inner product that allows length and angle to be measured within it. A unitary operator is a subjective bounded operator on a Hilbert space. Quantum decoherence processes are usually associated with non-unitary actions and can be modelled as a non-unitary process by which a system couples with its environment [7].

Quantum measurement via particle nuclear spin depolarization could be a non-unitary quantum decoherence causing phenomenon on a quantum system which maps pure states to mixed states [8]. Quantum decoherence by depolarization is caused by the interaction of a particle with fluctuating and/or dissipative force in a magnetic field where condensed matter phase transitions occur [1] [8]. In fact, quantum phase transitions can only be accessed by varying a physical parameter. It is a change in the ground state of a many-body system caused by the system's quantum fluctuations.

These quantum fluctuations are derived from Heisenberg's Uncertainty Principle as the loss of a particle's order. In simplistic terms, this means that when a polarized particle in a superposition is subject to ferromagnetic-paramagnetic transition, loss of magnetic order occurs [9] [10] & [11].

1.2 Scope of thesis

This thesis explores quantum decoherence by depolarization. This is the least understood particle-particle type interaction that destroys a quantum system's coherence aside from amplitude and/or phase damping, affecting both quantum superposition and multipartite entanglement. The reason it is little understood is because most studies are focussed on overcoming quantum decoherence or a solution to it occurring. However, there are reasons why depolarization is beneficial, and one of those reasons is particle detection.

Chapter 2

2.1 The Spin Polarized Electron Gas; Exchange–correlation effects in spin–polarization dependent generalized local fields

2.1.1 Introduction

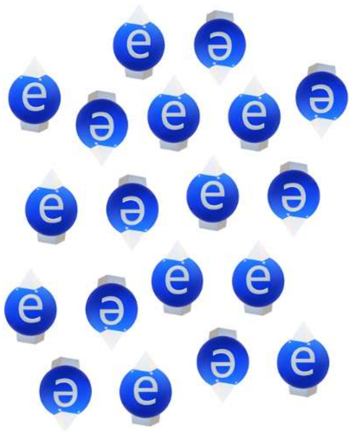

Figure 1: In this conceptual illustration the electrons are aligned vertically, whether they be pointed up or down. This demonstrates a Spin Polarized Electron Gas.
Credit: Celalettin

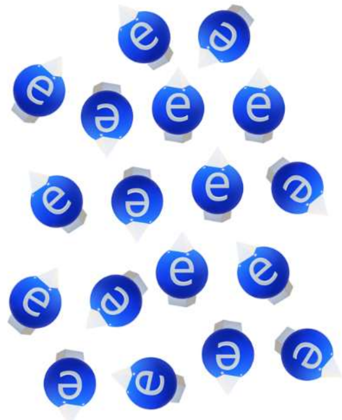

Figure 2: In this conceptual illustration the electrons are not aligned vertically and are arranged chaotically. This demonstrates a polarized electron gas.
Credit: Celalettin

It is virtually impossible to conceptualize a Spin Polarized Electron Gas (SPEG). Figure 1 and 2 show a SPEG, it does not serve a purpose to imagine the model literally. The free electron model, however, can be envisaged as collisions or particles coupling to a field.

Exchange-correlation effects in a SPEG require approximate expressions due to the fundamental uncertainty associated with the medium. This research considers the wave function for a SPEG with a focus on limiting behaviour. This limiting behaviour will sufficiently account for the exchange correlation effects between the SPEG, the dependent local magnetic fields, and the external polarizing field [12].

Corrections due to exchange-correlations will inevitably renormalize the electron mass, the Zeeman energy and the spin polarization degree [11] [12]. Said corrections would therefore modify electron mass, the Zeeman energy and the spin polarization degree. Further, depolarization of affected free electrons in the SPEG will occur via transfer of spin polarization from a non-local spin-active pump via cross relaxation. For a SPEG with a half spin, polarization occurs when spins orient with the field to the spins against the field [13].

2.1.2 Kukkonen and Overhauser technique

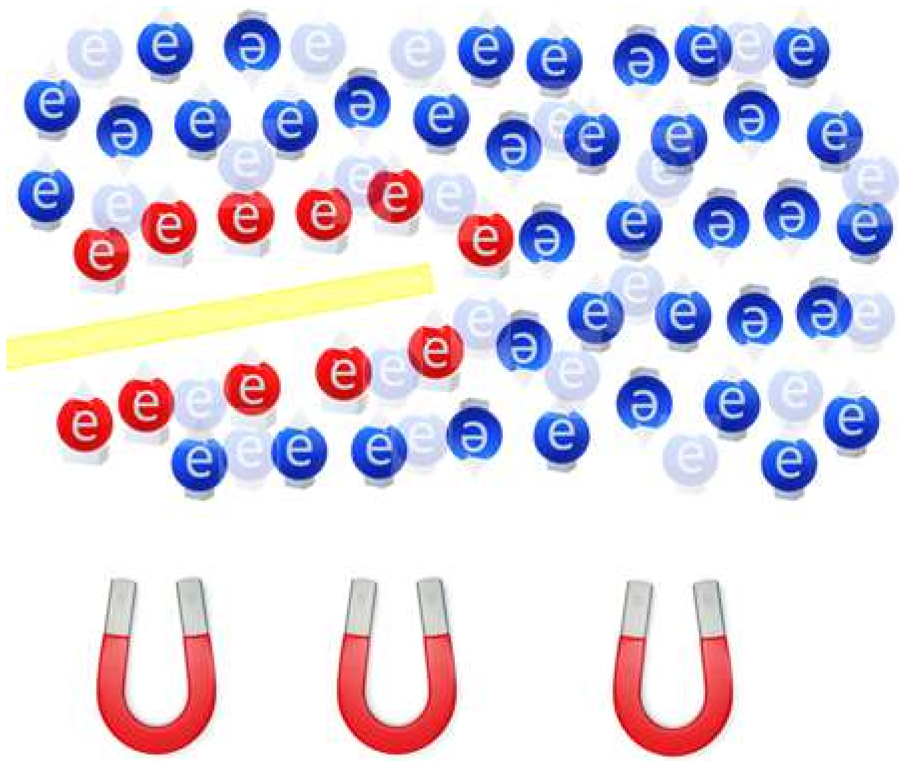

Figure 3: The proposed tunnel made of spin-flipped particles (in red).

Credit: Celalettin.

Figure 3 illustrates the scope of the proposal in this research. As discussed, the Kukkonen and Overhauser analytic method can model interactions between two electrons with spin and accounting for the linear response function. In Figure 3, the Kukkonen and Overhauser analytic method would describe the electron-electron interactions between the spin polarized free electrons in blue.

In particular, the Kukkonen and Overhauser analytic method, or ‘The nuclear Overhauser effect’ is used to model electron-electron interactions particularly when nuclear spin in being considered. Specifically, the Kukkonen and Overhauser effect is the transfer of nuclear spin polarization from one population of spin-active nuclei to another via cross-relaxation. The change in the integrated resonance intensity occurs when and electric field is introduced where a pneumatic ensemble is being considered [14]. The change in resonance intensity is due to an electron being close in space to those directly affected by the electric field. This research considers a SPEG, where the Kukkonen and Overhauser effect will apply to electron-electron collisions within the manifold.

These limiting behaviours are defined with local field functions, a generalized analysis of electron–electron interactions, similar to the linear response method Kukkonen and Overhauser discovered [15]. The Overhauser effect, describes a dipole-dipole interaction between unpaired electrons in dynamic nuclear spin polarization with the nuclear magnetic resonance of a proton half spin particle. Overhauser carried out an experiment to detect an NMR signal from protons in a sample of H_20. The sample was irradiated at the EPR frequency and excited the unpaired electron spins [14] [15].

This research considers a SPEG to be a Fermi gas. This relates the induced charge and spin densities to an external magnetic field; the focus of many studies for several recent years. However, there are many-body problems which pertain to the properties of microscopic systems made of many interacting particles where quantum mechanics has provided an accurate description of the system. Many-body interactions among the SPEG is essential when determining the response of solely an electron-based model [15] [16].

Kukkonen and Overhauser proposed an approximate analytic scheme for calculating the effects of exchange and correlations in an electron gas. Their method accounted for both charge and spin fluctuations [16]. This method is used to represent the auxiliary field produced by said exchange fluctuations and correlations in the gas in mathematically modelling the system. However, a sample of the most dominating interactions will be investigated separately.

The particle interactions that need to be accounted for in this study are wide ranging, complex and in order to increase certainty in a predictive model, proof of modelling the most fundamental interactions is mandatory. However, when it comes to these interactions different studies address different types based on the situation and objective as some of these interactions can be ignored while including others can be vital to a considered investigation.

Kukkonen and Overhauser proposed an approximate analytic scheme that enables the mathematical modelling of the correlations in an electron gas. It accounts for both charge and spin fluctuations, prior to the introduction of the magnet field B, influencing the electron's spin. The benefit of this technique is its simplicity, as there are overwhelming electron interaction types and trying to model all of them would be impossible [16]. Like with any equation, the Kukkonen and Overhauser technique has its limitations, where the two primary restrictions are that it works where the electron gas is of a high density, and the system be of a 2D spin polarized electron gas [15] [16].

The most suitable expression of the aforementioned circumstances using the Kukkonen and Overhauser technique is a model of the total potential by one electron in the 2D SPEG. The spin is dependent on the electron–electron interactions. When accounting for the effects of the Coulomb repulsion the exchange–correlation of free electrons of the same spin Hubbard local field factors will be exploited [16].

The SPEG is based on the concept of quasiparticle pseudo-Hamiltonian. Many-body effects in a 2D SPEG can be calculated. However, it is limited to the many-body local field. This is what led Kukkonen and Overhauser to propose an approximate analytic scheme for calculating the effects of exchange correlations in an electron gas which accounts for both charge and spin fluctuations [17].

As this thesis focusses on building a multilinear mathematical model around the proposed phenomena, the emphasis is to describe the behaviour of local field functions, across the whole range of moments in addition to the electron interactions. The Kukkonen and Overhauser analytic method is referenced as it can model interactions between two electrons with spin and accounting for the linear response function [16].

To begin, an expression for the potential energy of any electron in the SPEG is required. We introduce a spin-down electron ρ ↓:

$$\emptyset\uparrow\downarrow = \mathrm{v(q)}\left\{[\rho\uparrow+\Delta n\uparrow+n\downarrow] - \left[G_{x,\,intra}^{\downarrow\downarrow} + G_{c,\,intra}^{\downarrow\downarrow} + \left(V_{v}-1\right)G_{c,\,inter}^{\downarrow\downarrow}\right]\frac{2\Delta n\downarrow}{V_{v}} - \left[G_{c,\,intra}^{\downarrow\uparrow} + G_{c,\,inter}^{\downarrow\uparrow} + \left(V_{v}-1\right)\right]\frac{2\rho\uparrow+2\Delta n\uparrow}{V_{v}}\right\}$$

Where:

$\Delta n\sigma$	=	linear density fluctuation (±1)
$G_{x(c),intra(inter)}^{\sigma\sigma'}$	=	the appropriate generalized many-body local fields
x	=	to exchange
c	=	correlation
intra	=	intra-valley
inter	=	inter-valley
$\emptyset\uparrow\uparrow$	=	potential
G	=	the many-body local fields

Therefore, an expression for the potential energy of a spin-up electron ρ ↑:

$$\emptyset\uparrow\uparrow = \mathrm{v(q)}\left\{[\rho\uparrow+\Delta n\uparrow+n\downarrow] - \left[G_{x,\,intra}^{\uparrow\uparrow} + G_{c,\,intra}^{\uparrow\uparrow} + \left(V_{v}-1\right)G_{c,\,inter}^{\uparrow\uparrow}\right]\frac{2\rho\uparrow\Delta n\uparrow}{V_{v}} - \left[G_{c,\,intra}^{\uparrow\downarrow} + G_{c,\,inter}^{\uparrow\downarrow} + \left(V_{v}-1\right)\right]\frac{2\Delta n\uparrow}{V_{v}}\right\} \tag{3}$$

As it is a fermion, it is inferred that [17]:

$$G_{x,\,intra}^{\uparrow\uparrow} = G_{x,\,intra}^{\downarrow\downarrow} \tag{4}$$

The Green's function for a spin σ response for a non-interacting electron gas is:

$$g^{\sigma}(\sim p, \omega) \equiv \frac{n^{\sigma}_{\sim p}}{\omega - \epsilon_{\sim p} - i\eta} + \frac{1 - n^{\sigma}_{\sim p}}{\omega - \epsilon_{\sim p} - i\eta}$$

(5)

The correlation effects between two electrons are accounted through spin-flip scattering given by:

$$W^{T} = -2\mu_{B}^{-2}\left[v(q)G^{v}_{-}(\sim p, \omega)\right]^{2} \chi s(\sim p, \omega)$$

(6)

Equal to the scattering matrix elements between two anti-symmetrized states of the interaction potential, where:

χs = spin response

W^{T} = the screened electron-electron interaction

Equation (6) illustrates that the Kukkonen-Overhauser approach can be used to consider the screened interaction between electrons in a SPEG, provided the spin-flip term is considered [14] [15] [16].

2.1.3 Ruderman, Kittel, Kasuya and Yosida (RKKY) technique

The interactions between spin-orbit coupled electrons change energy levels, affected by the spin–orbit interaction. This is due to electromagnetic interaction between the electron's magnetic dipole, its orbital motion, and the electrostatic field of the positively charged nucleus [18]. The exchange interaction between two localized magnetic moments, $S_1\sim$ and $S_2\sim$ are embedded in a host material [16] [17] [18].

Chiral order in magnetic structures have a direct effect on the behaviour of electron-electron interactions. This interaction was originally found by Ruderman, Kittel, Kasuya and Yosida (RKKY). The study compared the RKKY interaction, which refers to a coupling mechanism of nuclear magnetic moments with a Dzyaloshinskii-Moriya (DM) interaction; a microscopic characteristic of interacting spins that occur in a system that lacks inversion symmetry with strong spin-orbit coupling.

It is necessary to understand these two types of interactions in order to model and subsequently predict the strength of spin-orbit coupling under various practical applications [18]. In addition, magneto-chiral dichroism originating in the coupling of their local electric field and the molecular magnetic moments in their host material. This reference is relevant to the proposed model described as the 2D SPEG, an optically dense pneumatic ensemble demonstrating the production of the tunnel magneto-chiral dichroism will affect the frequency depending on the material.

A SPEG can be mathematically interrogated and used to devise a model that can be used to predict electron interaction behaviour under specific circumstances as the standard spin degenerate electron gas. It is for that reason that the DM interactions will be accounted for in this thesis. However, there has been very little focus on decoherence-by-depolarization, leaving a knowledge gap this research aims to contribute to. How the interactions would affect, or be affected by spin polarization transfer will be the focus of this research in order to better understand the phenomenon and its practical application [18].

In order to achieve this it is crucial to understand and model the spin polarization transfer between electrons at different phase states and energy levels. This is in order to predict what occurs when a free electron beam enters a SPEG, and whether a SPEG can detect polarization transfer. Further, a practical application where a spin polarised elementary atomic ensemble can collectively act as a particle detector based on the model.

Compton polarization in the presence of a magnetic field is a classical particle interaction. It is, in effect able to describe the spin polarization of an electron by another electron via a collision. Experimental studies that have investigated photon-electron scattering. However, specific circumstances are introduced for the purposes of simplicity of calculation. The most often constraint is the imposition of ground states for electrons, absolute gas densities, vector fields and induced electric dipole moments [19].

The lowest Landau level approximation to the degenerate electrons in the SPEG is introduced in the modelling. This is to aid in the investigating the plausibility of an external source of radiation depolarizing free electrons in the gas. In modelling the magnetic moments of the electrons as polarized is gravely complex and cannot be explained by classical physics unless a simplification is assumed.

In order to measure the magnetic susceptibility of a free electron we can apply the macroscopic form of Maxwell's equations. This technique allows classical physical laws to predict the magnetic susceptibility of a free electron gas while avoiding the underlying quantum mechanical uncertainty problems [20]. The auxiliary magnetic field H that represents the way B field influences the organization of magnetic dipoles in the spin polarized electron gas, which for the aforementioned purposes will be a model of the interactions covered.

The electric and magnetic fields relate to the electron gas as described by:

$$M = \frac{dm}{dV} \tag{7}$$

Where:

dm = elementary magnetic moment

dV = the volume element

M = the distribution of magnetic moments in the SPEG

2.2 An initial plausibility analysis of the electromagnet physical laws of the proposal

2.2.1 Spin Precession

The net energy of the SPEG correlates to the different spin precession relaxation timings of the material within the sample. In order to polarize a Fermi gas of electrons, a train of continuous RF pulses is required at the resonance (Larmor) frequency of the Fermi gas. At thermal equilibrium, spin precession occurs randomly about the direction of the external applied field, but phase coherence occurs when any of the resultant polarization is created orthogonal to the field [21]. The spin precession and the precession damping are described by the Landau-Lifshiz equation:

$$\frac{d.M'}{dt} = -\gamma M' \times H' + \lambda M' \times (M' \times H') \tag{8}$$

$$M' = -g \,.\, \mu B \,.\, \zeta' \tag{9}$$

$$\frac{d.\zeta'}{dt} = -\gamma\zeta' \times H' - \lambda \,.\, g \,.\, \mu B . \zeta' \times (\zeta' \times H') \tag{10}$$

Therefore, for the z-component:

$$\zeta'(z) = \frac{1}{2}\cos(\theta(t)) \tag{11}$$

Where:

M = Magnetized direction

H' = Effective magnetic field

θ = the angle between M'

ζ' = Spin direction

γ = Gyromagnetic ratio

μB = Bohr magneton

Equation (8) – (11) demonstrates that spin precession is directly proportional to the strength of the electromagnetic field used to polarize the SPEG. Ideally, the gyromagnetic ratio is a measure of the stability of the polarizing process. Therefore, when modelling the SPEG, the electron magnetization and the strength of the electromagnetic field will determine the strength of the electron pump required to cause de-polarization in the SPEG.

A laser is introduced later, where the laser's energy will be greater than H' and able to produce a penetration depth sufficient enough to cause the spins of affected electrons to depolarize via electric dipole spin resonance.

2.3 Spin polarization, cross relaxation and depolarization

The spin polarized electron gas referred to in this thesis is known as a 'Jellium', which is a quantum model of interacting electrons in a solid are uniformly distributed in space; the electron density is a uniform, adhering to the conditions of a Fermi gas [22] [23]. The proposed phenomenon in this thesis is the detection of an external pump beam via the SPEG with cross spin relaxation within the gas producing the evidence.

In order to model such a phenomenon, an interrogation of both quantum and classical physical laws are used. The aforementioned physical laws that describe the electron interactions in the gas that will be explored and will be discussed in detail are the:

- Monte Carlo Method
- Ruderman, Kittel, Kasuya and Yosida Interaction
- Dzyaloshinskii-Moriya Interaction
- Kukkonen and Overhauser

2.4 Analysis of the SPEG interactions

2.4.1 Monte Carlo Method

The Quantum Monte Carlo (QMC) methods provide a reliable approximation of the quantum many-body problem, specifically encompassing the multi-dimensional integrals that arise in its different formulations. The methods allow direct calculations of complex many-body effects in the wave function [24].

A homogeneous electron gas interacting via effective spin-dependent many-body potentials is a fundamental aspect to this research. After modelling the scattering potentials, this research predicts an approximation using the QMC method with good accuracy. Many of the electron-electron interactions could be modelled using the homogeneous electron-gas (jellium) model, which is the exact approach this thesis takes [15] [24]. Calculations of spin-averaged pair distributions within multi-dimensional spin polarized electron gas models are presented with results. Many other techniques, including the aforementioned Kukkonen and Overhauser's two body Schrodinger equation, with QMC approach for the evaluation of pair densities provide said results. The most accurate pair density approximation is presented and reveals a model satisfactorily representing a quantitative account of the corresponding data [15].

Whilst this thesis will also cover spin-averaged pair distributions as part of accommodating the H-field, such an investigation is only a means in modelling the gas in preparation for determining the presence of a pump beam. It does necessitate a reliance on Kukkonen and Overhauser's two body Schrodinger equation in the determination of the H-field. A fractional quantum Hall effect (FQHE) is a problem where interacting electrons in a SPEG and Composite Fermion (CF) theory are explored [16] [19] [20]. A spin polarized gas model of electrons in their lowest Landau level will be imposed upon the SPEG model in this research.

It is known that in a strong magnetic field, electron spin degree of freedom is in the magnetic field direction.

For relatively small tilted magnetic field, in which the Zeeman splitting energy is small, Landau level mixing plays an important role in the gas [25]. The most successful theory to explain the partially polarized states is the CF theory, however this thesis will assume that the Kukkonen and Overhauser’s two body Schrodinger equation will account for such interactions as is expected [16] [17] [19] & [25].

A zero-energy scattering Schrodinger equation with an effective potential for a 2D SPEG, including a Fermi term from exchange correlations is in agreement with data from QMC studies particularly for the correlation energy. The occurrence of a quantum phase transition defines coupling strength. [23] [24] [25] & [26].

A differential equation will be presented as formally exact and describes a zero-energy two-body scattering problem in full accordance with Overhauser’s interpretation. It is derived entirely from the available QMC data on the 2D charged-boson gas [27]. To have generated a differential equation fully representative of the QMC data, describing the exchange correlations within the gas is convincing, and as such, this thesis will apply the QMC method to the H field.

2.4.2 The Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction

The RKKY interaction describes the indirect exchange interaction between two localized magnetic moments in a one, two and three-dimensional SPEG. Oscillatory behaviour between two magnetic moments in a SPEG, causes competition between RKKY and DM interactions [24] [25] [26] & [27]. This demonstrates the effect of broken symmetry on the magnetic interaction, caused by time reversal and/or inversion behaviours. The molecular chiral order within the host medium causes this broken symmetry, and for the purpose of this thesis, a Fermi gas is assumed. However, in a real-world situation it cannot be ignored. Kukkonen and Overhauser's two body Schrodinger equation will account for magnetic dipole–dipole interactions, also known as dipolar coupling, which is the direct interaction between two magnetic dipoles. However, when considering a hot material, the degree of magnetic chiral ordering would be directly proportional to the magnetic dipole oscillatory unpredictability [26] [27].

In simplistic terms, the RKKY interaction is a scalar interaction, which means it is an indirect interaction between two nuclear spins arising from hyperfine interactions between the nuclei and local electrons. The DM interaction is a vector and tensor interaction between the two localized moments S_1~ and S_2~ [28]

Tensor interactions are the most significant and provide the most significant attraction in nuclear interactions hence theoretical calculations must include tensor interactions to reproduce the quadrupole moment and binding energy [27] [28]. Crucial to understanding DM interactions is that they are entirely dependent on broken symmetry within the SPEG.

2.4.3 Kukkonen and Overhauser’s model

Kukkonen and Overhauser’s model, or more specifically, the nuclear Overhauser effect is a direct spin-spin interaction where spin is passed on via cross relaxation [14]. The dipolar interaction between two spins is the most important phenomenon in understanding the electron interaction in this thesis as it describes not only further electron interactions but the mechanics behind the proposed particle detector. In 1953, Overhauser described it as a new method for polarizing nuclei, applicable only to metals; and showed that if the electron spin resonance of the conduction electrons is saturated, the nuclei will be polarized to the same degree they would be if their gyromagnetic ratio were that of the electron spin [14] [15] [16]. The most remarkable characteristic of the phenomenon is the description of the hyperfine structure interaction between electron and nuclear spins. The hyperfine coupling between electron spins consists of an exchange interaction and a dipolar interaction.

Localized spin polarized electrons are dynamically nuclear polarized (DNP) via electron-nucleus hyperfine interaction, which can also occur between two electrons in a SPEG where there exists a transient Overhauser field [29]. The DNP time constants attribute to a rapid DNP occurring in the vicinity of donor electrons followed by a delayed nuclear spin polarization between them [29]. Hyperfine coupling causes spin transport amongst electrons and that spin is a non-conserved quantity [30].

While conceptualizing an electron in a SPEG is not representative of a real world scenario, one can move on with the knowledge that spin can be transferred through hyperfine interactions. Therefore it is only logical to infer that the nuclear spin of one external particle can be given to an ensemble of particles where the energy is sufficient to pierce through it.

Subsequentially, it can also be taken away. When dealing with the Overhauser method it is always assumed that there is an external spin polarizing field [15].

In a two-dimensional electron gas (2DEG), the carriers are spin-polarized by a combination of magnetic and electrostatic barriers. The field strength is calculated by considering the pole strength at the gate surfaces and domain boundary. The electrostatic barrier height, Fermi level, and carrier concentration within the 2DEG are calculated using a finite-element Poisson calculation, consistent with the Fermi–Dirac distribution [31].

Using self-consistent simplified mathematical models it is entirely appropriate [and required] to investigate the probability distribution of a Fermi gas under the circumstances within the scope of this research. Particularly as the number of the types of interactions is far reaching. This is the reason 2D free electron gases (Fermi gasses) are used. All can be got from a 2D gas and applied in 3D from a mathematical perspective.

The dielectric permeability tensor for spin polarized plasmas and expressions for the Fermi distribution function and spin distribution function are provided in linear approximations. The dielectric permeability tensor was derived for a spin-polarized degenerate electron gas and the equilibrium distribution function was presented by the spin-polarized Fermi-Dirac distribution [32].

Fermi-Dirac statistics can be expressed as an equilibrium distribution in a linear approximation. This is an approximation of a general function often used in the method of finite differences to produce first order methods for approximating solutions [32].

This approach is also entirely appropriate however the difference between Fermi-Dirac distribution rather than an approximation equation that is the typical approach. This is due to the extreme uncertainty when describing the behaviour of free electrons. In an attempt to stabilise the uncertainty, a linear approximation is presented. The number of variables and considered uncertainty when accounting for a quantum system is endless. The practitioner must then account for what correlations are most likely to achieve the desired result.

The accuracy of the local density approximation (LDA) is based on expressions for exchange and correlation interactions associated with a two-dimensional, spin-polarized dipolar Fermi gas. In order to achieve the objective of this research, the expectations were in achieving an energy expression; a mathematically solvable prediction. Therefore, when two interacting spin-polarized fermions are confined in a two-dimensional harmonic oscillator potential, the most accurate solution would be in a ground state wave function and energy density expressions.

This research imposes a ground state typical of a SPEG study. However, in this thesis only ground states are imposed to describe the SPEG.. Temperature is introduced as it is required when transitioning the model from a theoretical one to one that can be experimentally proven [31].

The Schrodinger equation can be used to solve the eigenvalues. An investigation into the long-range anisotropic nature of the interaction between two dipoles has been researched. A calculation of the dipole-dipole interaction strength is achievable [31]. LDA results for total energy, interaction energy, and eigenvalues can match well with the exact results for smaller values of dipole–dipole interaction strength can be derived from the Schrodinger equation [31] [32].

For higher values of interaction strength, the mathematics falls short solely using the Schrodinger equation because at its very core, it is an approximation equation. This research exploits the Schrodinger equation where the objective is to focus on eigenvalues, however over-arching. The long-range anisotropic nature of the interaction between two dipoles must be accounted for, considering the chaotic interactions in the SPEG. Further, electrostatic interaction that could potentially be modelled more effectively using the Van der Waals force equation [31].

Said model, focussing on eigenvalues yields an exact solution for the time-independent Schrodinger equation for a ground state wave function and the corresponding energy. It can model the SPEG without invoking any approximation either for the form of the two-fermion wave function or for the form of effective potential [26] [31] [32]. However, this is true only by separation of variables and it should be noted, that time-dependant variants still have time dependencies [31].

The behaviour of electrons in a uniform electron gas in understanding the nature of electronic correlations is discussed within this research [33]. The QMC method computes the correlation energy of the fully spin-polarized three-dimensional uniform electron gas [33]. As previously mentioned, the QMC method provides for an accurate approximation of the many-body problem. Suffice to say at this point, the proposed mathematical model harnesses the full potential of a well-informed method of calculating an effective and accurate approximation of the electrostatics [32] [33].

Chapter 3

3.1 Analysis of the dependence on an external field in polarizing the medium

Any charge, within any particle in any momentum of any direction is going to generate an electric field. Applying that line of thought to free electrons in a box, requires the use of reference frames. This is because each electron would be affected every other electron’s magnetic field [20].

We introduce an external field applied to the SPEG. The external field polarizes the electrons making up the SPEG. In understanding how this works, it necessitates a fundamental understanding of what a dipole is. The value of the electron magnetic moment, μ is approximately −9.284 764 × 10^{-24} J / T, given by one form of expression:

$$\mu = \frac{-e}{2m_e} L \tag{12}$$

Where:

m_e = the electron rest mass

L = angular momentum

e = unit of elementary charge

μ = magnetic dipole moment

This expression is limited as it is dimensionless. However, it shows the relationship between charge and angular momentum. It can analyse spin effects in a SPEG. 2D electrons with nuclear spins are presented. The effect magnetic field B and the Dirac equation are manipulated to analyse spin statistics [33] The field is the focus of Zeeman splitting causing an interference pattern of oscillations. The Dirac equation best describes the distribution of the gas with different energy states. In particular, its free form accounts for electromagnetic interactions. Polarization density can be shown using the Maxwell equation:

$$D = \varepsilon_0 E + P \tag{13}$$

Where ε_0 is the electric permittivity of empty space, P is the (negative of the) field induced in the SPEG when the dipoles shift due to field E, and D is the displacement field. The relationship between the magnetic moment of a free electron in a SPEG and its spin can be expressed as [34]:

$$\mu_\zeta = -g_\zeta \cdot \mu_B \cdot \frac{\zeta}{\hbar} \tag{14}$$

Where:

μ_ζ = magnetic moment of a spin polarized electron

μ_B = magneton

$\hbar$ = Plank Constant

A relativistic electron put in the external magnetic field gives interaction energy:

$$-\mu H = -\frac{e\hbar}{2mc}\sigma' H \tag{15}$$

$$\mu = -\frac{e\hbar}{2mc}\sigma' \tag{16}$$

Or,

$$\mu = -\frac{e}{2mc} L \tag{17}$$

This shows that the magnetic dipole moment at any time for an electron is caused by its current intrinsic properties (and associated values for) of spin and electric charge, and that affecting the charge, or energy level of the electron will cause it to flip its spin direction [35].

A spin-flip in a bound electron is much easier to achieve. However regarding a free electron in a Fermi gas it is a little different. Though, it can be achieved by applying a periodic electric field at a specially selected frequency, known as dipole spin resonance [32].

An expression of the SPEG when it is exposed to a magnetic and electric field is:

$$H_1^s(q, w) = \gamma 0 s'.b' + v_0^{ext} + v(q)[\delta n(1 - G_s^+) - s'.\delta m' G_s^-]$$

(18)

Where:

$\gamma 0 \quad = \frac{1}{2} g * \mu_B$

g^* = g−factor

μ_B = Bohr magneton

s' = Pauli spin operator

And:

$$H = H_0 + H_1^s$$

(19)

From Equation (19) the SPEG can be disturbed by electric and magnetic fields if even they are infinitesimally small. In order to account for these disturbances, charge and spin fluctuations are approximated [35].

In order to find the susceptibility functions of the spin–flip processes, it is assumed that the spin–splitting is greater than the Landau level and ignores any degree of orbital quantization. The charge and spin density fluctuations δn(q, ω), δmi(q, ω) (I = z, +, and −) are given, in terms of the effective perturbation $H^1s(q, \omega)$. Δn, δmz, and transverse spin–density fluctuations δm+ and δm− can be expressed by an equation-of-motion density matrix as:

$$\begin{pmatrix} e\delta n \\ \gamma 0 \delta m_z \end{pmatrix} = \begin{pmatrix} \chi^{ee} & \chi^{em} \\ \chi^{me} & \chi||^{mm} \end{pmatrix} \begin{pmatrix} \phi 0^{ext} \\ b0z \end{pmatrix}$$

(20)

$$\begin{pmatrix} \gamma 0 \delta m_+ \\ \gamma 0 \delta m_- \end{pmatrix} = \begin{pmatrix} \boldsymbol{\chi}+^{\mathbf{mm}} & 0 \\ 0 & \boldsymbol{\chi}-^{\mathbf{mm}} \end{pmatrix} \begin{pmatrix} b0^+ \\ b0^- \end{pmatrix}$$

(21)

$b0^{\pm}$ and $\phi 0^{ext}$	= the external electric potential
δm_z	= longitudinal spin–density fluctuation
δn	= charge–density fluctuation
χ	= susceptibility matrix

This matrix shows that the external electric potential corresponds to the external disturbance, reinforcing the aforementioned Kukkonen and Overhauser conclusion at Equation (18). Continuing on from Equation (20) and (21), the Lindhard–type electric susceptibility for the following two equations represents the spin–flip processes:

$X+^{mm(q,\omega)} =$

$$\frac{\frac{1}{2}\gamma 0^{2} \prod_{\sigma\sigma}{}^{0}}{1 + \frac{1}{2}(vG_{\sigma'}^{--} + 4\pi\,\gamma 0) \prod_{\sigma'\sigma'}{}^{0}}$$

(22)

$X-^{mm(q,\omega)} =$

$$\frac{\frac{1}{2}\gamma 0^{2} \prod_{\sigma\sigma}{}^{0}}{1 + \frac{1}{2}(vG_{\sigma'}{}^{--} + 4\pi\,\gamma 0) \prod_{\sigma'\sigma'}{}^{0}}$$

(23)

Equation (22) and (23) represent the Lindhard–type electric susceptibilities, denoting the equilibrium distribution of spin polarised free electrons.

Where:

$\gamma 0 \quad = \frac{1}{2} g * \mu_B$

$g^* \quad = g-$factor

$\mu_B \quad$ = Bohr magneton

s' = Pauli spin operator

Equation (18) is the generalization of the effective interaction Hamiltonian of the SPEG in the presence of infinitesimal magnetic and electric disturbances. The corresponding matrix elements are then substituted back into the expressions of the fluctuations in Equations (20) and (21) in order to determine the conditions for spin–flips. They are then found to be [23] [35]:

$$1 + \frac{1}{2}(\mathrm{vG}\sigma'^{-} - 4\pi\gamma 0) \prod \sigma\,\sigma' 0 = 0, \tag{24}$$

$$1 + \frac{1}{2}(\mathrm{vG}\sigma'^{-} - 4\pi\gamma 0) \prod \sigma'\sigma 0 = 0, \tag{25}$$

Where:

$G\sigma \pm$ and $\bar{G}\sigma \pm$ = The wave number– and frequency–dependent local fields

The HF approximation in the local fields satisfies the relation $G\sigma + = G\sigma -$. Therefore, the mixed charge–spin response functions become equal (χem = χme). An investigation into the conditions for the spin–flip transverse modes are derived at Equations (24) and (25).

$$X + \frac{mm(q,\omega)}{} =$$

$$\frac{\frac{1}{2}\gamma 0^{\,2} \prod_{\sigma\sigma}{}^{0}}{1 + \frac{1}{2}\left(vG_{\bar{\sigma'}} + 4\pi\,\gamma 0\right) \prod_{\sigma'\sigma'}{}^{0}}$$

(26)

3.2 Hyperfine interactions depolarize SPEG at the local field critical value

When considering the spin-flip criteria energy levels are accounted for. this includes the Zeeman effect, Stark effect, and individual electron energy within the SPEG [36]. The Zeeman effect μ'can be described by:

$$\mu' = -\frac{e\hbar}{2m\check{}e} * \frac{(g.\acute{L} + gs.\zeta)}{\hbar}$$

(27)

$$\mu' = -\frac{\mu B(g.\acute{L} + gs.\zeta)}{\hbar}$$

(28)

Where:

μB = the Bohr magneton,

g = the g-factor,

$\acute{L}$ = Orbital angular momentum and

ζ = Spin.

Individual electron energy within the SPEG is described by the Schrödinger equation:

$$i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle = \hat{H}|\psi(t)\rangle$$

(29)

Where for a free electron:

$$-\frac{\hbar^{2}}{2m}\nabla\psi(r,t) = i\hbar - \frac{\partial}{\partial t}\psi(r,t)$$

(30)

Therefore, the energy component is described by the function:

$$E = \psi(r,t)$$

(31)

Where:

$$E = Ae^{i(k.r - w.t)}$$

(32)

$$E = \frac{Ae^{i(p.r - E.t)}}{\hbar}$$

(33)

$$E = \frac{p^{2}}{2m}$$

(34)

Where ψ is the wavefunction of the particle at r position and t time, and A is Amplitude. Hyperfine electron properties and interactions will be modelled.

Modelling the hyperfine interactions, spin effects in the current-carrying state of superconductor-2D SPEG relies on Zeeman splitting. The hyperfine interaction of 2D electrons with nuclear spins, described by the effective magnetic field B, produce Zeeman splitting. Said Zeeman splitting is significant enough to lead to an interference pattern of supercurrent oscillations over the field [37].

The Zeeman effect is considered a relatively weak magnetic phenomenon. However, this finding is convincing enough to include as a hyperfine consideration. It does coincide with the finding that in a SPEG, Zeeman splitting has to be renormalised as a significant electron interaction that can not be ignored [25].

The reason why the Zeeman effect will have to be included rather than assuming that it be accounted for in the QMC analytical method is because rather than it being an interaction between the electrons, it is an interaction between the electron and the magnetic field. Therefore, it cannot be assumed to be part of the SPEG's radio noise but in addition to it [25] [37].

3.3 Effects on a local magnetic field via free electron beam

In this investigation, a Free Electron Laser (FEL) will be pumped into a SPEG to depolarize electrons in the path of the beam. Therefore, there are three events in the model where electron spin will be manipulated:

1. The first is the initial spin polarization of the electrons in the electron gas.
2. The second event is the ability to keep the SPEG polarized given the nature of cross relaxation occurring through electron-electron transition within the gas.
3. The third is the Compton depolarization of electrons within the gas caused by the FEL pump beam.

Electric polarization is the act of subjecting an electron (in an electron gas) to an external magnetic force. In a thought experiment, 100 electrons are put in a box and an electromagnet on the side of the box, the magnet would cause a slight relative shift of positive and negative electric charge in opposite directions within the electron gas. This is due to distorting the negative cloud of free electrons in a direction opposite to the field. The Fermi energy εF is given by the Fermi wave number and the effective mass m, where:

$$\varepsilon F = \frac{kF^{2}}{2m} \tag{35}$$

The magnetic field applied parallel to the spin polarized electron gas leads to a Zeeman energy ΔE described by [32]:

$$\Delta E = \pm \frac{g.\mu_{B}.B}{2} \tag{36}$$

Where:

kF = the Fermi wave number,

g = the g-factor and

m = the Effective mass,

Then the system will be spin-polarized when:

$$\Delta \mathrm{E} > \varepsilon \mathrm{F}$$

(37)

In order to cause a spin-flip, which is the objective, the FEL is to be tuned to the Combined Resonance (COR) of the SPEG [25] [32]. Its resonance attributes are the:

1. Electric mechanism of its excitation, and
2. Change of the spin quantum state, when the quantum numbers corresponding to the orbital motion do not change.

In this case, the resonance occurs at the electron's spin frequency, namely the Electric Dipole Spin Resonance (EDSR), or electric-dipole-excited electron-spin resonance (EDE-ESR) [25] [32]. Further, the FEL transmits at [25] [29]:

$$\lambda\, \check{}\mathrm{FEL} = \frac{\lambda}{2\gamma(0)} \cdot \left(1 + \frac{\mathrm{K}^{2(0)}}{2} + \gamma^{2(0)} \emptyset^{2}\right)$$

(38)

As discussed, we assume that free electron spin-flipping will occur at individual electron's EDSR within the SPEG by the FEL frequency due to the Rashba effect [32]. The Rashba effect causes electron spin-flips at their intrinsic EDSR. This phenomenon is at the heart of this research.

The Rashba effect does this under certain circumstances:

1. Two fields are applied to the electron,
2. One field is the resonating field and
3. The field oscillates with the electron's Larmor precession [38] [39].

The precession frequency ω, is given by:

$$\omega(\mathrm{Thom}) = \frac{1}{c^{2}}\left(\frac{\gamma}{\gamma+1}\right) a \times v \tag{39}$$

Where:

a = acceleration

v = velocity

γ = gyromagnetic ration

c = speed of light

m = mass

g = g-factor

B = strength of field

e = charge

ω = angular frequency

$$\omega(\mathrm{Thom}) = \frac{g.e.B}{2mc} + (\gamma - 1)\frac{e.B}{2m\gamma} = \frac{e.B}{2mc}\, g - 2 + \frac{2}{\gamma} \tag{40}$$

Where:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\beta^2}}$$

(41)

Therefore, if a free electron in the FEL were resonating at the Thomas precession frequency, as per the following equation:

$$\frac{\lambda}{2\gamma^{2(0)}} = \frac{1}{c^2}\left(\frac{\gamma}{\gamma+1}\right)$$

(42)

Then a free electron will Spin-flip:

$$\lambda\ \check{}\mathrm{FEL}\ \dagger = 2\gamma^{2(0)}\left(\frac{\gamma}{\gamma+1}\right) c^{-2} \quad a\,.\,b$$

(43)

In an attempt to cause an en-masse spin-flip event, it is necessary to model the SPEG and account for interactions with the EDSR frequency.

Where:

e = elementary charge

γ = the Lorentz factor, the g-factor is 2

m = the mass of the SPEG

B = the magnetic field,

v = the relative velocity between inertial reference frames

c = the speed of light in a vacuum

β = the ratio of v to c.

A spin filter method where the acceleration of spin polarized electrons can be beamed directly into a pre-polarized plasma. When a high-intensity particle beam propagates into a pre-polarized target, a 'bubble wakefield' can be used to accelerate the electrons, inside which the spins of the beam particles and those of the plasma cross relaxed [40] [41]. This phenomenon is relevant because this research proposes a particle laser, rather than a stream of photons into the gas.

This mechanism employs an idea to identify subsets of electrons beamed into plasma with low-polarization and filter them out to improve the integrity of the cross-relaxation results. By exploiting the dependence between the initial azimuthal angle and the spin of single electrons during the trapping process, a transverse electron's spin is preserved. Said electron's orientation during injection depends on their relative angle against the polarizing magnetic field [40] [41]. This is of significant relevance to this research as the experimental results confirm beyond a reasonable doubt that an electron's spin polarization can be manipulated using a magnetic field. In addition, their frequencies can be calibrated upon electron-electron collisions.

A precise correlation of the local beam polarization as a function of the electron phase angle, is of particular interest to polarize the FEL beam in its own right [40]. A polarized beam reduces the randomness of results by pre-setting the pre-cross-relaxation angles and enhances the prediction capability of quantum numbers and chiral couplings. Focussing on the azimuthal angle will be included in the model [16] [40] [41].

An examination of the different energies within the 2D SPEG is presented. The Hartree-Fock (HF) energy expression is used to model the SPEG: [12] [23].

$$\mathrm{E}(\mathrm{r(s)},\zeta') = \underbrace{\left|\frac{\varepsilon-2(\zeta)}{\mathrm{r}^{2(\mathrm{s})}}\right|}_{\text{Kinetic Energy}} + \underbrace{\left|\frac{\varepsilon-1(\zeta)}{\mathrm{r(s)}}\right|}_{\text{Exchange Energy}} + \varepsilon(0)(\zeta) + \varepsilon(\ell)(\zeta)\mathrm{r(s)ln.r(s)} + 0.\mathrm{r(s)}$$

(44)

The use of the theoretical SPEG at t = 0 has been a profoundly active area of mathematics over the last half century for its simplicity in understanding different quantum mechanical phenomena. However, almost all models exclude temperature in dictating the terms of the mathematics. A portion of the SPEG with reduced T, can be described by the Kohn-Sham equation [42] [43]:

$$\mathrm{E}(\mathrm{x}\tau)[\mathrm{n}] = \int_{\mathrm{v}} \mathrm{n(q)S(x,\tau)(s)\,dr}$$

(45)

And can be written in the form [42]:

$$\mathrm{E}(\mathrm{x},\tau) = \frac{2.\mathrm{k(F).a(0)}}{\mathrm{x\check{\ }s}} \int_0^{\mathrm{x(s)}} \mathrm{dr(s)} \int_0^{\infty} \mathrm{d(q)}\ \mathrm{S(q,x'(s);\ \tau)} - 1$$

(46)

Where:

$$\tau = \frac{\mathrm{kB,T}}{\epsilon\mathrm{F}}$$

(47)

The coupling parameter is:

$$\mathrm{x}_{\ \mathrm{s}} = \frac{1}{\mathrm{a(0)}\sqrt{\pi\mathrm{n}}}$$

(48)

With the effective Bohr radius:

$$\mathrm{a}(0) = 5.291772109 \times 10^{-11}\ \mathrm{m} \tag{49}$$

And the Fermi wave vector:

$$\mathrm{k}(\mathrm{F}) = (3\pi\hat{}2)^{\frac{1}{3}} \tag{50}$$

Therefore, the energy required for the flip is described by:

$$\mathrm{E}(\mathrm{x}) = \frac{2.\,\mathrm{k}(\mathrm{F}).\,\mathrm{a}(0)}{\check{\mathrm{x}}\mathrm{s}} \int_0^{\mathrm{x}(\mathrm{s})} \mathrm{dr}(\mathrm{s}) \int_0^{\infty} \mathrm{d}(\mathrm{q}); \tau \mathrm{X}(0)(\mathrm{q}, 0; \tau)$$
$$+ \frac{2}{\pi} \int_0^{\infty} \mathrm{dk}\ \mathrm{kf}^0(\mathrm{k}; \tau) \int_0^{\pi} \mathrm{d}\emptyset\ \times \left\{ \coth \frac{\mathrm{q}^2}{2\tau} + \frac{\mathrm{kq}}{\tau} \cos\emptyset \right\}$$
$$- \left\{ \coth \frac{\mathrm{q}^2}{2\tau} + \frac{\mathrm{kq}}{\tau} \cos\emptyset \right\}^{-1} - 1 \tag{51}$$

Like before, this energy level is going to correspond to a new resonating frequency at which the FEL will need to be calibrated. This is to ensure that the electron’s intrinsic spins will flip. We define the SPEG density, and need to confirm that the FEL will propagate through the SPEG sufficiently enough that quantum decoherence-by-depolarisation-tunnelling will occur, rather than only the electrons on the SPEG surface..

The Gaussian beam energy expression is introduced to model the exploitation of spin to demonstrate a depolarization-based particle detector.:

$$E(x,\tau) \; = \; E(0)x'\frac{\omega(0)}{\omega(\tau)} \; \exp\left(\frac{-x^{2}}{\omega(\tau)^{2}}\right) \; \exp\left(-i\left(k\tau + \; k\frac{x^{2}}{2R(\tau)} - \varphi(\tau)\right)\right)$$

(52)

And use the Helmholtz approximation equation:

$$\Psi\varepsilon k(0)^{2} = \frac{1}{r} \cdot \frac{\partial}{\partial r} \cdot \left(r\frac{\partial\Psi}{\partial z}\right) + \frac{\partial^{2}\Psi}{\partial z^{2}}$$

(53)

To solve for k(0):

$$k(0)^{2} = \frac{\omega^{2}}{c^{2}}$$

(54)

Therefore, a complete expression of the lowest order Gaussian can be transformed to:

$$E_{00}\left(r_{T}, z\right) = \varepsilon_{0}\frac{w_{0}}{w(z)}\exp\left[-\frac{r_{T}^{2}}{w^{2}(z)}\right]\left\{\exp - j\left[kz - \tan^{-1}\frac{z}{z_{0}}\right]\right\}\exp\left[-j\frac{kr_{T}^{2}}{2R(z)}\right]$$

(55)

Of which (55) is a snapshot of the Gaussian beam in an electric field, in standard form introduced at (52).

Therefore, the spin precession of an electron in an external electromagnetic field is described by:

$$\frac{da^{\tau}}{ds} = \frac{e}{m} u^{\tau} u_{\sigma} F^{\sigma\lambda} a_{\lambda} + 2\mu\left(F^{\tau\lambda} - u^{\tau} u_{\sigma} F^{\sigma\lambda}\right) a_{\lambda} \tag{56}$$

Where:

a^{τ} = polarization

e = charge

m = mass, and

μ = magnetic moment

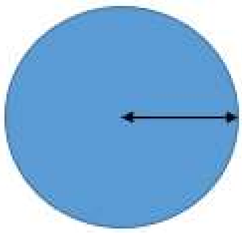

Figure 4: Looking directly into the beam
(Half beam radius defined by arrows).
Credit: Celalettin

The EM wave in the forward direction co-propagates with the electron beam and exchanges energy with the electrons in free space. This research ignores that interaction as there have been other studies that have accounted for that resonance problem [25].

The interplay of the Lorentz force in the magnetic field and the electric field generated by the electron-electron repulsion, not to mention the dipole-dipole attraction and repulsion, results in an overall frequency that is encompassing simultaneously mitigating forces [32] [44] [45].

3.4 Particle detection by electron-electron cross-relaxation; gyromagnetic nuclear spin in the detection of a sub-atomic; a new phenomenon

Particle detectors can measure particle energy, spin, charge, particle type, in addition to registering the presence of the particle. Most often, this is achieved by ionization. However, there are other methods such as photo-multiplication and photodiodes [46]. In a quantum-entangled system, two entangled particles are said to be in a superposition where a particle in a superposition is in several locations at once [40]. It appears there are several particles. However, that one particle is simply occupying several locations in the universe at once. There is no physical law that says that this cannot happen.

Quantum measurement is the phenomenon described by performing an act on a quantum system and that act causes a collapse of the wave function. The multiple superpositions that the particle was occupying simultaneously, collapse to only one [47] [48]. It is easy to introduce a philosophical debate, as the act of measurement is in many ways akin to defining consciousness. The first influential philosopher to define consciousness was Descartes, who proposed that consciousness resides within an immaterial domain he called res cogitans (the realm of thought).

‘Immanuel Kant’ took the idea further and proposed that space and time are mere "forms of intuition" which structure all experience. His doctrine of transcendental idealism formed the basis of extreme moral goodness in right human action [48]. Examples were telling the truth even if it leads to one’s own death, dedicating one’s life to safeguarding the helpless particularly during times when safeguarding the helpless was not convenient, and never doing any wrong. All based on wilfully and consciously always doing what is right, where goodness and right action is based on how all man perceives the act, from all parties, rather than only a part of society [47] [48]. This philosophical idea is akin to this research where perception determines righteousness.

This brief history of the study of human consciousness shows that it is still a very active area of philosophical debate, and that the act of measuring a particle as part of a particle detector, is potentially subjective. That is, ‘we may use an acceptable detector and we may observe a particle and the particle’s wave function may collapse. Or it may only seem to be so.’ At the quantum level, the Copenhagen interpretation considers a particle measured when an observer (an observer can be a machine), has evidence that there was a particle present at the detection device, although where it came from and where it is going can never be known [47] [49].

Whilst the Copenhagen interpretation provides a set of criteria which when followed, ‘no quantum mechanics experiment has ever failed’, it does have a problem. A problem that seasoned quantum mechanics and string theorists spend their entire academic lives avoiding; the effect quantum gravity has on entangled particles with mass.

If an electron is in a superposition of two locations, then according to string theory there should exist two interacting gravitational fields associated with each electron location. However, this is thought to cause the well-known instability problem of quantum dots [18] [38] [39] & [40]. *“How can there be one electron in a superposition occupying two locations in the universe and at each location it weighs* $9.109*10^{-31}$ *kilograms (being* $1.8218*10^{-30}$ *in total), when in truth, there is only one electron?”* – Celalettin.

The Copenhagen interpretation states that ‘During an observation, the system must interact with a laboratory device. When that device makes a measurement, the wave function of the systems is said to collapse, or irreversibly reduce to an eigenstate of the observable that is registered’. Where an ‘observation’ is defined as ‘the testing or manipulation of a physical system in order to yield a numerical result’ [33] [49].

The conventional method for measuring electron spin in silicon is to convert the spins into charges that can be rapidly detected, which often affects the electron spin during the detection process. However, a new method using Ising interactions enables the electron spins of neighbouring atoms to align. Spin-up Spin-down information can therefore be indirectly accessed, leaving the original spin unaffected.

3.5 The proposal

A SPEG is often used to progress understanding of electron-electron exchange correlations, spintronics, and local field models. They provide a Fermi gas for spin precession studies, interdimensional comparisons and external field related coupling examples. However, not at the time of this thesis has there been an attempt to engineer a SPEG to detect a SPEG-resonant-calibrated-electron-beam in the study of gyro-electromagnetism, a sub-field of electromagnetism. ‘Faraday rotation’ is formally a special-case field of gyro-electromagnetism, used in spintronics research to study the polarization of electron spins in semiconductors [44].

It is best described as a rotation of the plane of polarization which is linearly proportional to the component of the magnetic field in the direction of propagation. By orienting a wave in a superposition’s linear polarization, quantum decoherence can be caused by shifting the wave’s phase [26] [44]. This magneto-optical phenomenon is relevant to this research, as the proposal explores causing quantum decoherence in a scenario of a SPEG in a superposition where the interaction between the magnetic field and synchrotron light. The difference is that the Faraday effect, explores manipulating photon polarity rather than electron polarity [26].

The method of quantum observation proposed in this thesis, is to use a SPEG as a medium in which to detect an external particle $'\rho'$. By capturing the depolarized particles as a single ‘tunnel’ after $'\rho'$ has entered the gas. The collective system of depolarized particles would provide information on, including direction, quantized energy state and spin, akin to the trail of ionized gas particles in a Wilson cloud chamber, reminiscent of the particle it detected [26] [44].

Two-photons confined in a dot experience coherent spin-flips between states of different spin orientation or linear polarization. A polarized and detuned laser beam couples to these states. They can then be used to coherently rotate the spin orientation via a Raman transition [51]. This was shown with photos, however the same can be done with electrons under different circumstances. Particularly, from the Pauli exclusion principle where it is possible only if the state which is to be occupied by the photo-created electron is free [44] [51].

As highlighted in Chapter 2, there has not yet been a fit-for-purpose particle detector that relies on monitoring the spin-flip of an electron. In fact, in an entangled system, a particle’s spin can be spin-flipped without affecting the coherence of the system [40]. Therefore, if a laser could spin-flip an entangled particle in a 2D SPEG, would this even cause decoherence thereby affecting the required detector?

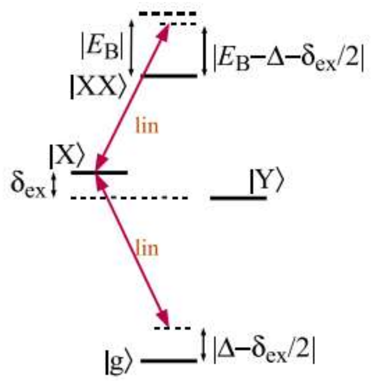

Figure 5: The fine structure splitting of the exciton states
Credit: Machnikowski

In Figure 6, the frequency detuning is Δ, σ are the four-levels in the biexciton system, consisting of the ground state, E_B is the biexciton shift, g is the ground state. |X) and |Y) are the states of the particle and δ is the degree of resonance and exciton shift whilst coupled to the laser.

A pulse of appropriate intensity at normal incidence can be applied to the entangled pair and tuned to the light electron-hole transition, resulting in a linearly polarized state. A pulse traveling in the structure plane can be polarized linearly in the growth direction which would induce a transition [51].

The foundation for this phenomenon is the fact that the laser can be detuned below a frequency that could cause a change in an electron's phase state. It is known that de-phasing an electron, causes quantum decoherence. This is because linear quenching the electron's phase in a spin coherent environment causes decoherence at the time the states change [52] [53]. This research must also consider that the change in linear phase space is distinguished from spin cross relaxation when discriminating between the results.

Chapter 4

4.1 Rationale; quantum observation via depolarization of free particles within the SPEG

Spintronics is a very niche sub-set of quantum physics, which is itself subset of particle physics. However, its applications have changed the world to a point now unrecognisable. This is not because of physics, electronic engineering advancements or better telecommunications system. But directly a result of spintronics, the study of the intrinsic spin echo. A single look beyond this level and the only door that opens is the multi-dimensional multi-universe domain of string theory [54].

That said, in reference to how spintronics has changed the world one must only think of smoke alarms, GPS satellites, Magnetic Resonance Imaging in the medical industry, the speed at which computers operate today, the fact that humans can connect a handheld device to different networks. Even such discoveries as new galaxies and black holes millions of times further out than what we could see before. It is almost impossible to quantify what the study of nuclear spin has done for us, so it's quite a challenge to convey the rationale of this research in a worldly sense when some things as small scale as the effects of spin are responsible for them [55].

The knowledge gap in the study of spintronics is knowing what other macroscopic applications we can get from further manipulating particle spin. This research is exploring the possibility of enabling a beam of electrons from an external source to be detected by a SPEG. The electron laser's signal has caused the spin in the gas to flip, and the gas is permanently changed as a result of this intrusion.

A SPEG could protect a ground-based quantum radar. If a qubit within a quantum radar were to interact with a SPEG, decoherence could inhibit the radar's signal processing ability. This is achieved by the SPEG particle’s spins being flipped, which then causes a reaction with the radar’s signal [56].

4.2 Hypothesis

In this thesis, a polarized electron pump will cause spin transition to free particles in a 2D spin polarized pneumatic ensemble in a localized Euclidean space. This will occur by tuning the pump to resonate with the particle’s EDSR frequency. Therefore, quantum decoherence will occur if the electrons in the SPEG were entangled.

By imaging the ensemble after the beam is introduced, a tunnel will be momentarily present which will show the change in particle orientation, meeting the criteria of a detector. It is proposed that the particles will couple to the pump beam and spin cross relaxation will occur in accordance with the quantum Zeno effect [57]. The quantum Zeno effect is a feature of quantum-mechanical systems allowing a particle's time evolution to be arrested by measuring it frequently enough with respect to some chosen measurement setting [58].

4.3 Methodology overview

The modelling methodology will involve building a complete mathematical model of the SPEG, the interactions and the laser, where it is expected that the FEL will produce the proposed tunnel. Instances where other studies have either overlapped will be referred to or where there are similar studies in which there is a mathematical explanation that is relevant will be produced, with the knowledge gaps provided for with new mathematics.

4.4.1 Two-Dimensional Spin-Polarized Electron Gas; modelling the magnetic interactions

The SPEG has been mathematically modelled several dozen times, and while it is not necessary to model it any different, it is necessary to model it such that it is best engineered for purpose. It must be modelled with, or consistent with QMC results and be prepared ready to be pierced by the Free Electron Laser.

This means that there needs to be an understanding of the proposed quantum decoherence-by-depolarisation-tunnelling proposal in this thesis. The dynamic behaviours are known, in addition to its energy boundaries being known. The reason why is because with time, the EDSR is something that will need to be calibrated against in order to flip the spins of individual free electrons in the SPEG.

When describing a SPEG from a mathematical sense, two predominant behaviours need to be demonstrated. This means that the first step will be broken into two parts:

1. The first part describing the dynamics of the SPEG, and
2. The second part will calculate the energy fluctuations in order to identify a plausible example of the EDSR.

4.4.1.1 Objective

The objective of this study is to effectively model a 2D SPEG using the most recent and accurate techniques in order to ensure subsequent studies will be able to effectively draw upon current proposal to identify the hyperfine interactions and progress the model.

4.4.1.2 Methodology

The starting point is the energy function for an inhomogeneous density profile corresponding to the distribution of the SPEG. The external polarizing agent is described by Hartree and exchange-correlation contributions, with the SPEG defined by the von Weizsacker - Herring term. Any noise will be mitigated by the Hohenberg-Kohn variational principle. The results will then be compared to recent QMC results.

The reason for this approach is because it has a proven record of producing accurate results and is a straightforward approach. A 2D SPEG can be modelled using a similar method to the Bose-Einstein states to model a host liquid [26]. The model in this thesis will model the SPEG strictly as a Fermi gas irrespective of a host.

4.4.1.3 Formulation

In dealing with what is conceptually imagined a gas ensemble, the starting point is at the middle with the energy function for an inhomogeneous density profile defined in (60) below:

$$n(r) = ng(r)$$

(57)

Where:

$n = \left(\pi r_s^2 \alpha_B^2\right)^{-1}$, is the average density for a free electron gas.

(58)

$v(r) = \frac{e^2}{r}$, is the potential energy of our external spin polarizing field.

(59)

Adding the Weizsäcker correction:

$$T_W[n] = \frac{\hbar^2}{8m}\int \frac{|\nabla n(r)|^2}{n(r)}$$

(60)

Substituting it for the inhomogeneous density profile gives:

$$-\frac{\hbar^2}{m}\nabla^2 + v(r) + W_{Fermi}(r)\sqrt{g(r) = 0}$$

(61)

Substituting the W_{Fermi} term in the Hartree-Flock pair distribution function:

$$W_{Fermi}(k) = -\frac{\hbar^2}{m} FT\left[\frac{\nabla^2\sqrt{gHF(r)}}{\sqrt{gHF(r)}}\right] + \frac{\hbar^2 k^2}{4m}\left[\frac{S_{HF}(k) - 1^2}{\sqrt{gHF(r)}}\right]$$

(62)

Which can be reduced to:

$$2S_{HF}(k) + 1 - \alpha\left(r_s\right)$$

(63)

Where:

$\alpha\left(r_s\right)$ = parameter determined by the QMC data

The Born–Oppenheimer approximation is inherently assumed

k = exchange energy

To introduce spin for a single electron only:

$$S_{HF}(k) \sum_{\sigma} [1 + \mathrm{sgn}(\sigma)\zeta] \frac{S_{HF}^{\sigma\sigma}(k)}{2}$$

(64)

$$S_{HF}^{\sigma\sigma}(k) = \frac{2}{\pi}\left[\sin^{-1}\left(\frac{k}{2k_{F\sigma}}\right) + \left(\frac{k}{2k_{F\sigma}}\right)\sqrt{1 - \left(\frac{k}{2k_{F\sigma}}\right)^2}\right]$$

(65)

Where:

$\sigma = \pm$

$\zeta = \dfrac{n\uparrow - n\downarrow}{n}$

$k_{F\sigma} = \sqrt{2}[1 + \mathrm{sgn}(\sigma)\zeta]^{1/2}$

Therefore, the ground energy state of the Jellium is modelled by:

$$\varepsilon\left(r_s, \zeta\right) = \frac{\left(1 + \zeta^2\right)}{r_s^2} + \frac{1}{2}\int_0^1 \frac{d\lambda}{\lambda} \int \frac{dk}{(2\pi)^2} v_k^{(\lambda)} [S\lambda(k) - 1],$$

(66)

a result equivalent to what Davoudi et al found [25], once transformed to the 3D expression. This expression of the ground state potential energy of the SPEG includes the electron-electron interactions, the SPEG density and ideal distribution of electron in the gas.

The ideal-gas kinetic energy has been provided:

$$\varepsilon_0 = \frac{3(1+\zeta)^{5/3} + (1-\zeta)^{5/3}}{10\alpha^2 r_s^2} \mathrm{Ryd}$$

(67)

Where:

$$\alpha = \left(\frac{9\pi}{4}\right)^{-1/3} \mathrm{Ryd}$$

(68)

The exchange correlation, however, can be obtained from Equation (66) [25]:

$$\varepsilon_x = \frac{-3(1+\zeta)^{4/3} + (1-\zeta)^{4/3}}{4\pi\alpha r_s^2} \mathrm{Ryd},$$

(69)

Be $\zeta = 0$, 0.333, 0.667 and 1 over the range $1 \leq r_s \leq 50$.

4.4.1.4 Interpretation

At Equation (65) we begin with the exchange energy property of an inhomogeneous electron gas at a jellium surface. The SPEG surface exchange-energy is determined exactly for the calculated set of single-particle wave functions generated within the linear-potential approximation to the effective potential at a surface [24].

When the SPEG density profiles are considered at Equation (69), this universal function varies. For a Hartree-Flock SPEG density increase the surface exchange energy. The local density approximation (LDA) functional of the surface exchange energy is also determined for the same set of wave functions. A study of the inhomogeneous Hartree-Flock and fully correlated systems is also described.

4.4.1.5 Summary Conclusion

The SPEG has been mathematically modelled and engineered to provide the medium in which the phenomenon, is set to occur. This draws upon similar models, and its data is consistent with QMC when modelling the 2D and 3D Jellium. The Fermi gas also meets the definition of a Euclidean space or Euclidean plane in which a quantum event can occur. This is because the spin polarized nature of the Jellium is designed to leave evidence of a foreign particle tunnelling through it. This meets the objective of this study, and a formula has been produced at Equation (109).

4.4.2 Calibrating a FEL to the 2D SPEG electric dipole resonant frequency

Free Electron Lasers are tuneable and use a Direct Current. However, as the electrons in the SPEG are considered free electrons, they do not abide by the same laws that bound electrons do. They can be relied on to predictably describe their ability to leap and spin-flip. The best research that we have regarding the frequency at which the spin of a free electron's spin flips in the EDSR is part of the Rashba effect. Even then, the physics is at best, a guesstimate [59].

Taking into account previous studies, the most likely chance for a free electron manipulation of the precession is the precession frequency, and that precession frequency ratio to the SPEG frequency. Using this technique, all knowledge of spin-flipping frequency will be employed to produce the quantum decoherence-by-depolarisation-tunnelling [21[[59].

4.4.2.1 Objective

The objective of this study is to build upon the 2D SPEG model, investigate the electron precession energy requirement in frequency, and calibrate the FEL to the required variable [23].

4.4.2.2 Methodology

The second study is to consider the SPEG and begin with the electron precession energy requirement for a FEL such that when calibrated to the SPEG's EDSR, it would depolarize affected free electrons in the SPEG. The external polarizing agent remains constant as does the SPEG remain uniform. The Rashba effect will be modelled, as the electric dipole spin resonant frequency has been shown to split electron spin.

4.4.2.3 Formulation

We begin with the energy expression for the SPEG:

$$\varepsilon_x\left(r_s,\zeta\right)=\varepsilon_x^P\left(r_s\right)+\left[\varepsilon_x^F\left(r_s\right)-\varepsilon_x^P\left(r_s\right)\right]f(\zeta)$$

(70)

Where:

$$\varepsilon_x^P\left(r_s\right)=\frac{-3}{2\pi\alpha(r_s)}=\frac{{}_x^P(r_s)}{2^{1/3}}$$

(71)

Where the Seitz radius is:

$$r(s)=(\pi.\rho)^{(-1/2)}$$

(72)

And, assuming $\rho\downarrow \geq \rho\uparrow$, the relative spin polarization ζ is expressed as:

$$\zeta=\frac{\rho\uparrow-\rho\downarrow}{\rho}$$

(73)

With:

ρ = the Local Density Approximation

r(s) = Seitz radius

At this point the model describes the SPEG as an LDA in terms of its energy and to investigate how other interactions will affect that energy value. By using regularized dipole interaction, a 2D dipolar Fermi gas density 'ρ' can be written as [31].

$$\rho=\frac{a,_{dd}}{l_0}.\int\frac{256}{45}\sqrt{\pi}\rho^{\frac{5}{2}}\,dr$$

(74)

And with correlation energy per particle as per the Quantum Monte Carlo:

$$\varepsilon_c(\rho) = -2\pi^2 \left(\frac{a,_{d\ d}}{l_0}\right)^2 . \rho^2 \times \ln\left[1 + \frac{1}{a \curlywedge^{1/2} + b \curlywedge + c \curlywedge^{3/2}}\right]$$

(75)

Where:

$\curlywedge = \frac{a,_{d\,d}}{l_0} . \sqrt{4\pi\rho}$

a = 1.2

b = 1.1071

c = -0.0010

Where the para/ferromagnetic state is [60]:

$$\zeta = \frac{\left[(1+\zeta)^{4/3} + (1-\zeta)^{4/3} - 2\right]}{2(2^{1/3} - 1)}$$

(76)

The paramagnetic coefficients and retrospective spin scalers are at equation (77) and (78) with paramagnetic coefficients [61]. The paramagnetic (ζ = 0) and ferromagnetic (ζ = 0) values are:

$$\varepsilon(-2)(0) = +\frac{1}{2} \qquad \Upsilon(-2)(\zeta) = \frac{\varepsilon - 2(\zeta)}{\varepsilon - 2(0)} = \frac{(1-\zeta)\text{^}2 + (1-\zeta)^2}{2}$$

(77)

$$| \quad \zeta \quad |$$

$$\varepsilon(-1)(0) = +\frac{4\sqrt{2}}{3\pi} \qquad \Upsilon(-1)(\zeta) = \frac{\varepsilon - 1(\zeta)}{\varepsilon - 1(0)} = \frac{(1-\zeta)^{\frac{3}{2}} + (1-\zeta)^{\frac{3}{2}}}{2}$$

(78)

$$\varepsilon_l(1) = \frac{1}{4\sqrt{2}} . \varepsilon_l(0) = -\frac{1}{4}\left(\frac{10}{3\pi} - 1\right)$$

(79)

$$\varepsilon_{\mathrm{l}}(0) = -\sqrt{2}\left(\frac{10}{3\pi} - 1\right)$$

(80)

$= -0.0863136$ induced magnetic moments per particle at the lowest energy boundary for the SPEG.

Gell-Mann–Brueckner formula provides the logarithmic coefficient:

$$\varepsilon\ell(\zeta) = -\frac{1}{12\sqrt{2\pi}}\int_{-\infty}^{\infty}\left[\mathrm{R}\left(\frac{\mathrm{u}}{\mathrm{k}\uparrow}\right) + \mathrm{R}\left(\frac{\mathrm{u}}{\mathrm{k}\downarrow}\right)\right]^{3} \mathrm{du}$$

(81)

Where:

$$\mathrm{R}(\mathrm{u}) = 1 - \frac{1}{\sqrt{1 + \frac{1}{\mathrm{u}^{2}}}}$$

(82)

The Fermi vector is:

$$\mathrm{k}\uparrow,\downarrow = 1 - \frac{1}{\sqrt{1 \pm \zeta}}$$

(83)

Chesi and Giuliani identified a reconcilable spin scaling function:

$$\Upsilon_{\mathrm{l}}(\zeta) = \frac{\varepsilon_{\mathrm{l}}(\zeta)}{\varepsilon_{\mathrm{l}}(0)} = \frac{1}{8}\mathrm{k}\uparrow + \mathrm{k}\downarrow + 3\frac{\mathrm{F}(\mathrm{k}\uparrow,\mathrm{k}\downarrow) + \mathrm{F}(\mathrm{k}\downarrow,\mathrm{k}\uparrow)}{10 - 3\pi}$$

(84)

Therefore, when substituting for the Fermi vector gives the explicit Fourier transformation expression:

$$F(x, y) = 4(x + y) - \pi x - 4xE\left(1 - \frac{y^2}{x^2}\right) + 2x^2 k(x, y)$$

(85)

This allows for the derivation of the wave vector periodic boundary conditions (PBC) which are imposed in both directions due to spin polarization parallel to the field. The spin scaling function:

$$k(x, y) = \begin{cases} \left(x^2 - y^2\right)^{-1/2} \operatorname{arcosh}\frac{y}{x}, x \leq y \\ \left(y^2 - x^2\right)^{-1/2} \operatorname{arcosh}\frac{x}{y}, y > x \end{cases}$$

(86)

From Equation (84) we can deduce the spin scaling function in trivial form:

$$\Upsilon_0^b(\zeta) = \frac{\varepsilon_0^b(\zeta)}{\varepsilon_0^b(0)} = 1$$

(87)

Or:

$$\varepsilon_0(\zeta) = \varepsilon_0^a(\zeta) + \varepsilon_0^b$$

(88)

$$\varepsilon_0^b = \beta(2) - \frac{8}{\pi^2}\beta(4)$$

(89)

Where the spin exchange term can be calculated:

$= +0.114357$ induced magnetic moments per particle.

However, this equation is in open form, while it provides for an expression of the total energy. In order to prove Equation (70), [46], the following double integral would accommodate the expression in closed form:

$$\varepsilon^{a}(0)(\zeta) = -\frac{1}{8\pi^{3}}\int_{-\infty}^{\infty}\int_{0}^{\infty}\left[Q\frac{q}{k\uparrow}\left(\frac{u}{k\uparrow}\right) + Qq/k\downarrow\left(\frac{u}{k\downarrow}\right)\right]^{2} dq\,du$$

(90)

Whereby the steepest known descent:

$$Q\check{}q(u) = \frac{\pi}{q}\left[q - \sqrt{\frac{q}{2} - i.u - 1)\left(\frac{q}{2} - i.u - 1\right)} - \sqrt{\frac{q}{2} - i.u - 1)\left(\frac{q}{2} - i.u - 1\right)}\right]$$

(91)

Is used to substitute for the double integral:

Where:

$\zeta = 0.$

Therefor the transformation:

$$S = \frac{q^{2}}{4 - u^{2}}$$

(92)

And:

$$t = q.u$$

(93)

This gives:

$$\varepsilon^{a}(0)(\zeta) = -\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{0}^{\infty}\frac{1}{\sqrt{s^{2} + t^{2}}} \times \left[1 - \left(\frac{\sqrt{(s-1)^{2} + t^{2}} + s - 1}{\sqrt{(s^{2} + t^{2}} + s}\right)\frac{1}{2}\right]^{2} dt\,ds$$

(94)

Supplemented for coordinates:

$$\varepsilon^{a}(0) = -\frac{1}{2\pi}\int_0^{\infty}\int_0^{\pi}\left[1-\left(\frac{\sqrt{1-2r\cos\theta + r^{2}} - 1 + r\cos\theta}{r(1+\cos\theta)}\right)\right]^{2} d\theta\, dr$$

(95)

$$= -\frac{1}{2\pi}\int_0^{\pi}\left[2.\ln 2 - (\pi-\theta).\tan\frac{\theta}{2} - 2\times\tan^{2}\frac{\theta}{2}\ln\left(\sin\frac{\theta}{2}\right)\right]^{2} d\theta$$

(96)

$= \ln 2 - 1$

$= -0.306853$ induced magnetic moments per particle.

If (ζ = 1):

$$\varepsilon^{a}(1) = -\frac{1}{2}\varepsilon^{a}(0) = \frac{\ln 2 - 1}{2}$$

(97)

=−0. 153 426 induced magnetic moments per particle.

If 0 <ζ< 1:

$$\Upsilon^{a}(0)(\zeta) = \frac{\varepsilon^{a}(0)(\zeta)}{\varepsilon^{a}(0)(0)}$$

(98)

$$\Upsilon^{a}(0)(\zeta) = \frac{1}{2} - \frac{1}{4\pi(\ln 2 - 1)}\int_0^{\infty}\int_{-1}^{\infty} P(k)\uparrow(r,z)P(k)\downarrow(r,z)\frac{idz}{z}\,dr$$

(99)Whereby the steepest known descent:

$$P(k)(r,z) = \left(1 - \frac{\sqrt{(rz-k)^2} + \sqrt{\left(\frac{r}{z}-k\right)^{2}}}{\sqrt{r\left(\sqrt{z}+\frac{1}{\sqrt{z}}\right)}}\right)$$

(100)

And for r:

$$\Upsilon^{a}(0)(\zeta) = \frac{1}{2} - \frac{1}{4\pi(\ln 2 - 1)} \int_{-1}^{1} \mathrm{L(k)} \uparrow (\mathrm{k}) \downarrow (\mathrm{z}) \frac{\mathrm{idz}}{\mathrm{z}}$$

(101)

And for z:

$$\Upsilon^{a}(0)(\zeta) = \frac{1}{2} - \frac{1-\zeta}{4(\ln 2 - 1)} 2\ln 2 - 1$$
$$- \left[\sqrt{\frac{1+\zeta}{1-\zeta}} + \frac{1+\zeta}{1-\zeta} \times \ln\left(1 + \sqrt{\frac{1+\zeta}{1-\zeta}}\right) - \ln\left(1 + \sqrt{\frac{1+\zeta}{1-\zeta}}\right) \right]$$

(102)Which came to 0.9815 average induced magnetic moment per particle, which is consistent with spin exchange term as the upper energy boundary [62].

From there, as the electron is a spin ½ particle, the spin operator can take only two values $S = \pm\frac{\hbar}{2}$ and as the SPEG is affected by an external field, B' the electric dipole spin resonance frequency can be calculated at:

$$\omega_{S} = \frac{g\mu_{B} B'}{\hbar}$$

(103)

Where:

ω = Electric dipole spin resonance frequency

g = g-factor

S = S

μ_B = Bohr magneton

B' = External spin polarizing field

ħ = Plank Constant.

Hence, the correlation energy expansion of the 2D spin polarized electron gas can be found in closed form up to Or(s). In the first part of this study, the electron correlations and polarizing agent is modelled in a manner that involves the solution of a ground state Schrodinger. The Fermi term and the free electron's kinetic energy are the effective potential, with excellent agreement of the stated QMC studies. In contrast, the second part is a vastly different equation which is describing the same event at the same time; a SPEG, in closed form [46] [59].

The second part describes an electron gas from the vantage point of each electron, as they move away from each other without breaking the Pauli exclusion principle. The first part allows us to satisfy the objective by modelling the 2D SPEG and thereby proving that it exists. The second part allows us to understand the polarizing agent's required frequency, such that the FEL is accurately calibrated to the SPEG's EDSR frequency [26] [59].

4.4.2.4 Summary Conclusion 2

The SPEG's spin exchange energy boundaries and collective electric dipole spin frequencies have been calculated. This result enables the required FEL to be calibrated to the SPEG frequency and is the crux of the viability of this proposal. From this point, we reach the boundaries of what is known in spintronics, and what phenomena have been extensively researched.

Equations (94) to (103) progress leverage off investigations that have been performed at the single electron level, such as precession manipulation and application to the SPEG. The model is analysed in an attempt to understand whether or not the tunnel can be produced.

4.4.3 The electric dipole spin resonance particle detection

"Was the wave function waiting to jump for thousands of millions, [or billions of years since the Big Bang] until the ability to register a decision [from superposition] manifested in the universe as a human with the consciousness to do it or for a human to design a detector to detect it?" If not, then how did the wave function jump in the early universe (first 370,000 years)? – John Bell

This question still cannot be answered…

Quantum mechanics is a field of study so profoundly shocking, that at time this thesis begun in 2017, quantum theories then were considered in their infancy. Some quantum theories proposed in 2020 are so philosophical, that it is even more shocking that they actually get traction. One such theory is so incredibly across physics and philosophy is the role consciousness plays in quantum observation / particle detection [63].

Sir Roger Penrose, a Nobel prize in physics laureate claims that 'consciousness' is the result of quantum gravity based on time. Specifically, Penrose explains that the speed of neurons and excitations in the human brain's microtubules is unimaginably slower than the decoherence time. Penrose postulates that consciousness originates at the quantum level inside neurons. [64].

When a bound electron leaps from ground-excited-ground state, the electron dipole spin resonance, it is able to make a calculation by truncating the electron's energy when it reaches the outer electron hole, with the residual energy radiating away as heat. This process causes a spin-flip, as the governance of the electron's energy threshold acts like a reference frame for it to pivot [64].

Conceptualizing a universe where the only matter that exists within it is one electron is almost impossible. As there is no shells or electron holes, then there is no way for it to differentiate its energy between an energy threshold that causes a leap. In this instance, the free electron's precession frequency provides some structure around an incorporeal threshold; the EDSR frequency. That is, it has been proposed that the electron's spin will flip if a pump beam interacted with the SPEG, at the precession frequency [21] [64].

4.4.3.1 Proof of Concept

The objective of this study is to prove that the system has met the criteria of a spin detector and that in detecting the particle's spin, it meets the definition of a particle detector.

4.4.3.2 Methodology

If we consider the magnetic field B~ to be pointing in the z direction, the potential energy E is defined by:

$$E = \mu_z B_z = \gamma . S_z B_z$$

(104)

S_z can only have two values, be is Spin-Up or Spin-Down, therefore the potential energy will have only two values:

$$E = \pm \frac{1}{2} \gamma B_z$$

(105)The difference being:

$$\Delta E = \gamma \hbar B_z$$

(106)Which is the electric dipole spin resonance [32]. If that is applied to the 2D SPEG (ground state),

$$\prod_{0}^{\infty} \frac{(1+\zeta^{2})}{r_{s}^{2}} + \frac{\sqrt{2(1+\zeta}}{r_{s}^{2}} \pm \frac{1}{2}\gamma\hbar B_{z} \int_{0}^{r_{s}} dr'_{s}\, \gamma(r'_{s}, \zeta)$$

(107)Then it is a description of the 2D SPEG with the EDSR frequency incorporated; where a full description of the proposed tunnel would then be:

$$\prod_{0}^{\infty} \frac{(1+\zeta^{2})}{r_{s}^{2}} + \frac{\sqrt{2(1+\zeta}}{r_{s}^{2}} \pm \frac{1}{2}\gamma\hbar B_{z} + \frac{\lambda}{2\gamma(0)} \cdot \left(1 + \frac{K^{2(0)}}{2} + \gamma^{2(0)} \emptyset^{2}\right)$$

$$\int_{0}^{r_{s}} dr'_{s}\, \gamma(r'_{s}, \zeta) \tag{108}$$

The formula, 'Celaletttin's 1st Paradigm', describes a phenomenon where the SPEG encountered by a pump electron beam, pierces it, flipping the spin of affected free electrons. The quantum decoherence-by-depolarisation-tunnel's walls stoned by the flipped spins of electrons in the SPEG provides intelligence on the FEL's transmitted electron. The direction and former position, breaking Heisenberg's uncertainty principle therefore collapsing the wave function, meeting the criteria for quantum observation.

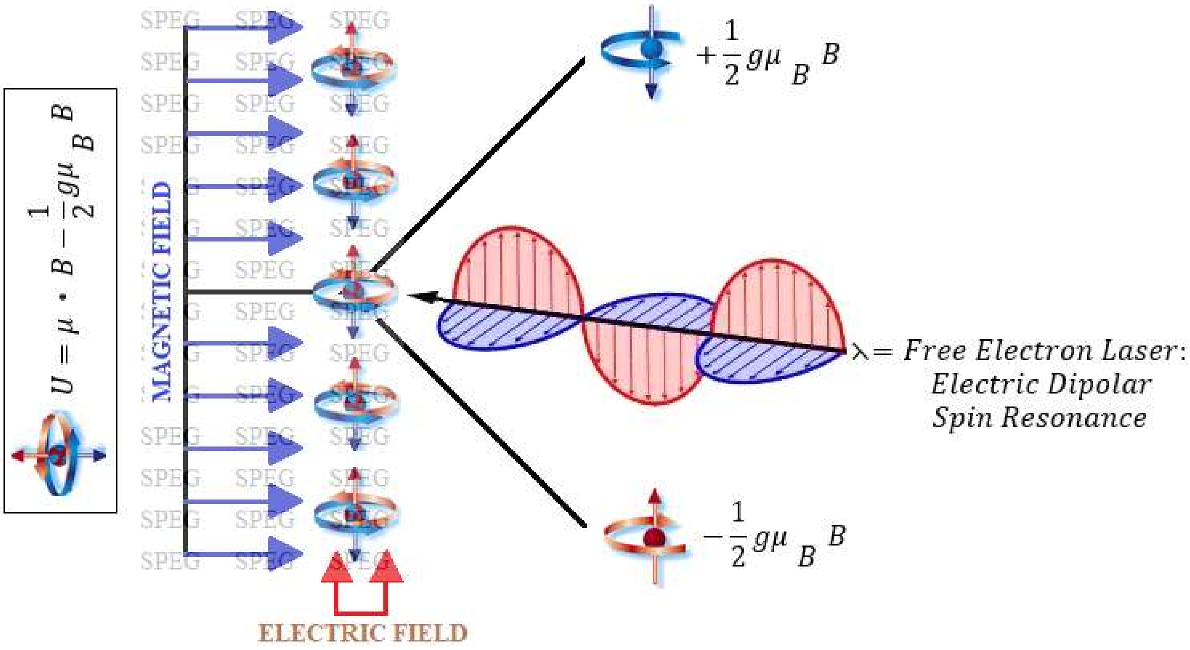

Figure 6: The role of the Free Electron Laser to the SPEG in producing the quantum observation tunnel. The FEL is calibrated to the EDSR, which cause free electrons to collectively ‘observe’ the electron beam.
Credit: Celalettin

This attenuation of the incident electrons in the FEL will result in a phase shift at the time of collision with a SPEG free electron and cause it to spin-flip at the electric dipole resonant frequency [32] [35]. At Figure 6, the interaction between the FEL electrons and the SPEG electrons in a magnetic field is complicated. Both conceptualizing and mathematical modelling, but so incredibly important to understand.

A particle detector is used to detect electron spin in addition to registering the presence of the particle. This is enough to deem it an act of quantum observation [33]. Ferromagnetic spin detectors are the type of detectors that can detect particle spin and are used in the field of medical imaging.

They work through a coupling between the polarizing agent and the matter subject to magnetization through which the electric wave passes. The energy being absorbed by the particle and its Larmor precession into a polarized direction with excess energy lost as heat. So, there is a balance between the precession frequency of the particle and the electric wave's frequency. The computer probes the medium, as the medium's precession is 'given' to the probe [66].

The act of observing (measuring) spin(z) corresponds to J_z can be described by:

Figure 7: Spin selection in Bra-Ket form
Credit: Celalettin

The following experiment would prove this theory:

As in Figure 8, an 8 GeV entangled electron pump beam; a FEL at 1mm diameter, 200nm, using a type-I spontaneous parametric down conversion in a two-crystal geometry with two nonlinear beta barium borate crystals. One of the entangled particles would be directed straight into a first electron capture detector (ECD), while the entangled partner pair directed through a chamber filled with the SPEG.

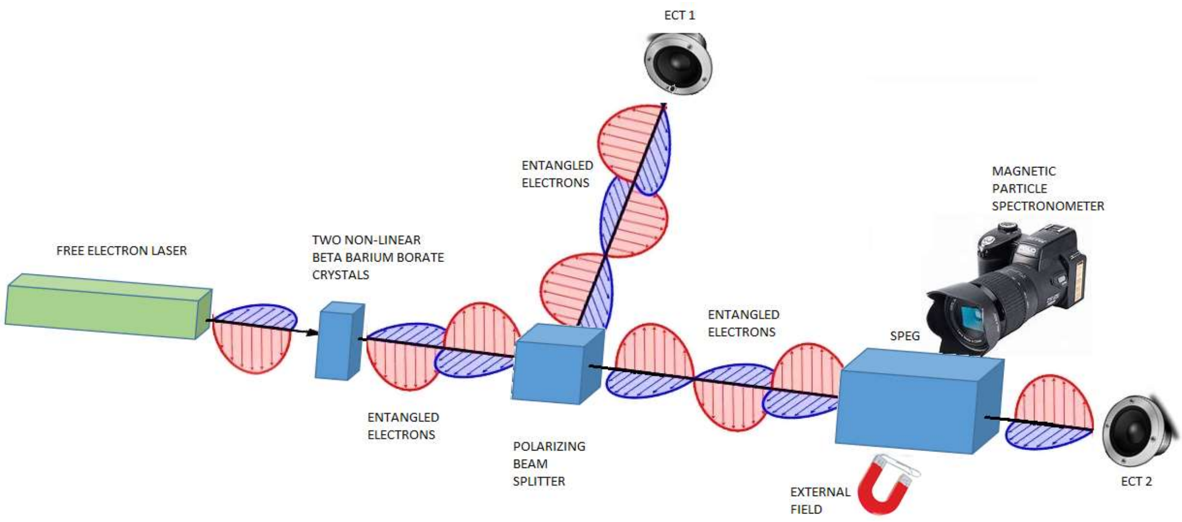

Figure 8: Proposed experiment
Credit: Celalettin

The SPEG with a non-homogenous, vertical magnetic field, effectively polarizing the random electron spin, before continuing into a second ECD. Data on the number of coincidences would be collected through the ECDs. The data would show that the first ECD detects the same spin as the FEL and the second detector is detecting the spin of electrons from the initial pump beam.

The ECD pump would curve through a collimating lens and a blue filter, before a beam aperture, laser polarizer and quartz plate. The mirror would direct the beam through the beta barium borate down conversion crystals where quantum entanglement is achieved.

It would be directed through a first polarizer, Idris diaphragm, red filter, focussing lens, and then through a cage assembly before hitting the first ECD. The second rail would direct the beam through another polarizer Idris diaphragm, red filter, focussing lens and through a cage assembly then directing the beam through the SPEG chamber fitted with a non-homogenous vertical magnetic field before hitting the second ECD.

The two detectors will count the number of coincidences and the data will be used for analytics, using a very simple frequency counts methodology to avoid any human manipulation of the data such as an advanced regression statistical analysis. Rather than count the number of electrons emitted from the laser, the pump will run for a period of time for a number of experiments to assess the consistency of the results. It is proposed that the number of detections at the second detector will be next to zero.

At Figure 9, the electromagnet has been removed, meaning the SPEG is not polarized and is therefore simply an ensemble of non-polarised electrons. This is to test whether it is the quantum decoherence-by-depolarisation-tunnelling (QDDT) through the SPEG that causes quantum decoherence or not. All other features and conditions will be identical with Test 1.

Quantum entangled electron pairs would be generated identically to Experiment 1. One of the entangled particles would be directed into a ECT detector, while the entangled partner pair is directed through a chamber filled with an un-polarized free-electron gas UEG. The results of both tests would be compared and considered. If the SPEG caused decoherence and a UEG did not, then it would provide new knowledge that the proposed tunnel in all likelihood is the cause of quantum decoherence when interacting with a FEL.

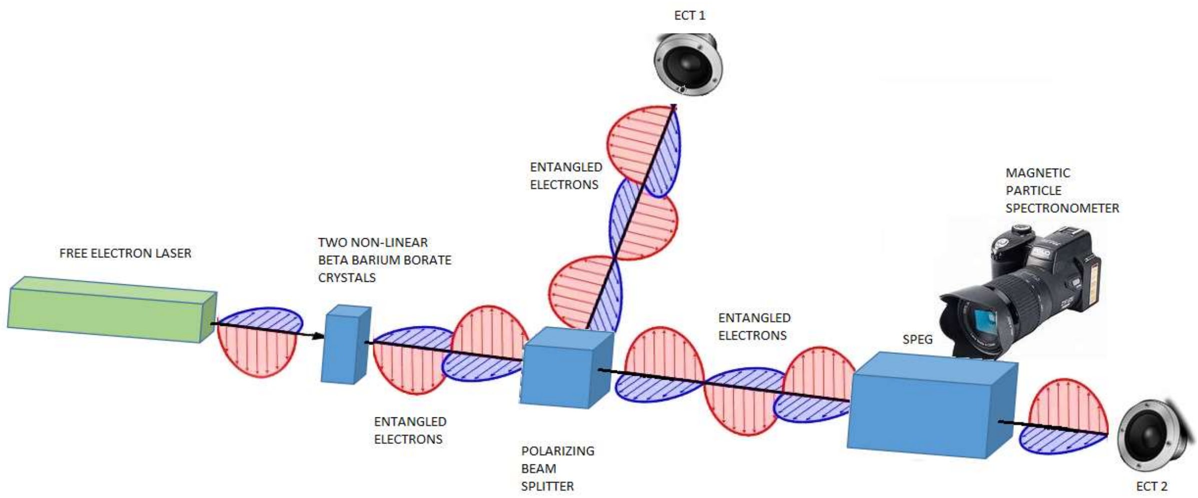

Figure 9: Proposed Control Experiment
Credit: Celalettin

If the ECTs in Experiment 1 consistently find that the SPEG causes quantum decoherence and the UEG does not, then it can be confirmed that the SPEG whereby enabling the production of the tunnel, is a quantum observation technique. This is because when each of the affected (spin-flipped) electrons are considered collectively and imaged using the magnetic particle spectrometer, it will provide local information such as trajectory, direction and evidence of its location.

4.4.3.3 Formulation

This event can be described effectively using Bra-ket notation:

An electron’s spin: |↑|↑

With an observer: |↑|obs|↑|obs

For an entangled quantum system: |↑⟹(|→+|←)/2–√|↑⟹(|→+|←)/2

Where the observer is added: |↑|obs⟹(|→+|←)|obs/2–√|↑|obs⟹(|→+|←)|obs/2

If the observer can measure the state, then the state of the observer changes and the observer can no longer be factored out of the whole state: (|→|obs1+|←|obs2)/2–√(|→|obs1+|←|obs2)/2. The quantumness of |obs1≠|obs2|obs1≠|obs2 describes the electron spin as not acting quantum mechanically as ‘obs’ from this point cannot be removed from the equation, giving it a new permanent state.

4.4.3.4 Summary Conclusion

We present a formula that describes a SPEG pierced by a FEL and producing a resultant tunnel. The tunnel is produced within the SPEGs Euclidean space and its walls stoned by spin-flipped electrons. The formula presented is a product of the SPEGs energy expression, the associated electron interactions and exchange correlations, the EDSR and the energy expression of the FEL.

‘Celalettin’s 1st Paradigm’ expressing the tunnel energy and be described by:

$$\prod_{\lambda=\Gamma} \left| e^{\frac{\uparrow\downarrow \,|\, \downarrow\uparrow}{\Gamma}} \right| \left| \hbar \right| \left| \lambda\!\!\!^{-} \right| \qquad (109)$$

And:

Γ = The SPEG EDSR frequency

⋋ = FEL frequency

T = Tunnel

ƛ = Number of Spin-flipped electrons in the SPEG caused by ⋋

To interpret this equation, it states that the Hamiltonian for a QDDT is described per electron in the SPEG. Where, the FEL flips the spin of those electrons whose frequency was tuned to the EDSR frequency, which collectively describes a tunnel. This research proposes that the tunnel would cause wave function collapse, because those spin-flipped electrons are considered collectively.

The method's criteria for decoherence that this phenomenon meets, is 'decoherence by depolarization'. This is a non-unitary transformation on a quantum system mapping pure states to mixed states. It is a non-unitary process, because any transformation that reverses this process will map states out of their respective Hilbert space [59].

5. General Discussion

This thesis covers the time it takes the FEL to pierce a SPEG; this entire body of investigation takes place in 0.0000000033 seconds. Just to put that in context, there would need to be just over 33 million sequential repetitions of the same process to encompass a complete single one second in time.

This thesis proposes that when a gas ensemble is pierced by an electron pump at the gas' electric dipole spin resonant frequency, a tunnel will momentarily be produced; its walls stoned with spin flipped electrons. These spin-flipped electrons enable the electrons that form the tunnel to be differentiated from the other electrons in the gas. All the events pertaining to re-polarizing the spins of affected electrons are outside the scope of this research.

The knowledge gap that this research contributes to is in quantum measurement. The current understanding of quantum measurement, or quantum observation is based on the premise that a quantum system ceases to exist once either the system experiences quantum measurement or causes quantum measurement. The sub-specific area of quantum mechanics that this research directly relates to is ‘quantum systems as measuring devices’.

The new learning that this research contributes to quantum theory is that spin angular momentum can be cross relaxed, and solely the resultant particles can identify the incident beam. The way in which it can do this is best explained broken into two parts:

- The mathematical modelling of the tunnel phenomenon
- A philosophical discussion on the considering of all effected electrons as a single quantum system.

In the literature review, it was found that the most suitable method in which a feasible mathematical model of the spin polarized electron gas being subject to a high-power laser, or FEL would produce a tunnel in a Fermi gas medium. This medium in which the laser as a vector could be measured, meets the criteria set by the Heisenberg uncertainty principle for an observer [49].

It was established from the Rashba studies that in trying to flip the spins of free electrons, first there needs to be an energy boundary in which the electron knows that whatever function it performs next will affect its spin. That energy boundary can take two forms, and it depends on how they are considered in determining their frequency.

- Electron precession frequency, or
- Electron dipole spin resonant frequency.

It is paramount to note that for a single free electron, the electron dipole spin resonant frequency is the electron precession frequency. Each of these values is dictated by one event: an electron spin flip. Such an event is much easier to model for a bound electron as it can be argued that it is simply the electron-shell energy quantity threshold, However, for a free electron it is not so easy. The electron will continue to exist with a linearly increasing energy value 0→∞ and experience no quantization or quantum leap as it would if it were bound to an atom. This is because it is not subject to electron hole.

Rather, the only way for it to recognize that its energy level has changed, is the Rashba effect, also called the Bychkov–Rashba effect, which is a momentum-dependent splitting; the splitting is a combined effect of spin–orbit interaction and the orientation of the two interacting electrons prior to them experiencing each other. Incident beams are most often prepared divergent to the SPEG as at that angle of incident the most amount of divergence is possible [32].

Electron spin resonance Γ is described by:

$$\Gamma = \frac{1}{2\pi}\gamma B_z \tag{110}$$

Where:

B_z = is the field.

In the general sense, electron spin resonance is described by:

$$H_{SOC} = \alpha\left(\sigma_x k_y - \sigma_y k_x\right)$$

(111)

Where:

α = intensity of Spin Orbit Coupling

σ_x = vector of the Pauli Matrices

σ_y = vector of the Pauli Matrices

k_x = electron wave vector

k_y = electron wave vector

Equation (111) shows that the spin orbit coupling to the FEL or to the SPEG provides the electric dipole spin resonant frequency. In the most simplistic description of what spin orbit coupling is, regarding an electron; it merges spin and momentum. It would be analogous to a gluon binding two quarks. Spin orbit coupling is paramount to the ability of the FEL being tuned to the SPEG’s electric dipole spin resonance [30].

An electron pump matching the energy difference of an electron in a uniform field with spin up or down causes its spin to flip. When the frequency of the second magnetic field is close to the precession frequency, the magnetic axis of the electron will flip to oppose the main magnetic field [31].

$$\Gamma = \left(\frac{geB}{2mc} + (\gamma - 1)\frac{eB}{2m\gamma}\right) \cong J_{SPEG}$$

(112)

The above equation is for one electron only, and in Chapter 4 in Study 2, the SPEG's electron spin resonance frequency was calculated. For the SPEG, Equation (113) describes the total energy:

$$E\left(r_s, k\right) = \left\{ \frac{\left(1+\zeta^2\right)}{r_s^2} \left[\pm\frac{1}{2} \left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \right) B_z \right] \right\} + \frac{1}{2}\int_0^1 \frac{d\lambda}{\lambda} \int \frac{dk}{(2\pi)^2} v_k^{(\lambda)} S_\lambda(k) - 1$$

(113)

Longitudinally polarized electrons can be delivered to three experimental halls. The degree of longitudinal polarization has been described. A divergent incident beam of polarized electrons deliver a high degree of longitudinal polarization. Further, it improved the degree of longitudinal polarization by redistributing the energy gain of the CEBAF linacs while keeping the total energy gain fixed [21].

The similarity between this research and Higginbotham's research was that he caused electron-electron spin cross relaxation on one electron. The SPEG would be analogous to one fish swimming being described by:

$$h(t) = 3cos\left[\left(\frac{\pi}{7}\right) \times t\right] - 6$$

(114)

Figure 10: Sphere or individual schooling fish
Credit: Sailors for the Seal

In Figure 10 there is approximately 1000 fish. However, if they are considered collectively then it could be considered a single fixed sphere, where the sphere

$$\Gamma = -\propto \left[\frac{1}{\left(\frac{\left\| x_i - x_j \right\|}{r} \right)^{p}} + \frac{1}{\left(\frac{\left\| x_i - x_j \right\|}{r} \right)^{q}} \right] \left(x_i - x_j \right)$$

(115)

This demonstrates an equation that collectively describes individual entities, behaving as one system, similar to the proposed tunnel. Higginbotham's equation describes the spin precession of one electron.

(116)

Where, the expression for solely the tunnel when considered a single quantum system, is at Equation (109). One can see how the example at Equation (115) describes the way the sphere moves as if it was a single organism. It is comparable to Equation (109) which describes the free electrons which define the proposed tunnel. When considered collectively, they are simply free spin-flipped electrons. However, when considered as a single entity, the electrons define the tunnel. They also enable the direction, and frequency of the Free Electron Laser to be determined.

It was assumed that electron-electron interactions could be thought of as collisions or particles coupling to a field. Exchange-correlation effects in spin polarized electron gas required approximate expressions due to the fundamental uncertainty associated with the medium. This research considered the wave function for a SPEG with a focus on limiting behaviour sufficiently accounting for the exchange correlation effects between the SPEG, the dependent local magnetic fields, and the external polarizing [68].

Corrections due to exchange-correlations renormalized the electron mass, the Zeeman energy and the spin polarization degree [68]. They would therefore modify electron mass, the Zeeman energy and the spin polarization degree. Depolarization of affected free electrons in the SPEG occurred via transfer of spin polarization from a non-local spin-active pump via cross relaxation [13] [68].

These limiting behaviours were constructed with local field functions and a generalized analysis of electron–electron interactions [15]. The Overhauser effect, described a dipole-dipole interaction between unpaired electrons in dynamic nuclear spin polarization with the nuclear magnetic resonance shown in the model.

A SPEG with a uniform positive charge background related the induced charge and spin densities to an external magnetic field. It is a phenomenon that has been the focus of many studies for several recent years. As stated, the many-body problem pertains to the properties of microscopic systems made of many interacting particles where quantum mechanics has provided an accurate description of the system. Many-body interactions among the spin polarized electron gas was essential when determining the response of solely an electron-based model [27]

Kukkonen and Overhauser’s proposed an approximate analytic scheme for calculating the effects of exchange and correlations in an electron gas accounted for both charge and spin fluctuations in the model. This method was used to represent the auxiliary field produced by said exchange fluctuations and correlations in the gas in the model [16] [17].

The particle interactions that needed to be accounted for in this study were wide ranging and complex. Proof of modelling the most fundamental interactions is in the analysis of other methods and the findings that total kinetic energy and exchange correlations must include the hyperfine, and so it did. Different studies addressed different types based on the situation and objective as some of these interactions could be ignored while others can be vital to a considered investigation.

Compton polarization, or cross relaxation described the spin polarization of an electron by another electron via a collision, which affected its precession [19]. We introduced the lowest Landau level approximation to the SPEG so that we had a predetermined beginning that was going to drive the way the model looked at rest. This aided in the investigating the plausibility of an external source of radiation depolarizing free electrons in the gas.

In order to measure the magnetic susceptibility of a free electron we applied the macroscopic form of Maxwell's equations to avoid the underlying quantum mechanical uncertainty problems [20]. The auxiliary magnetic field H that represents the way B field influences the organization of magnetic dipoles in the spin polarized electron gas, which for the aforementioned purposes was a model of the interactions covered in the studies.

The QMC method provided a reliable approximation of the quantum many-body problem, specifically encompassing the multi-dimensional integrals that arose in the various modelled formulations. The methods allowed direct calculations of many-body effects in the wave function which were used to check the accuracy of some predictions given by the model, where consistency with QMC was mostly used as a modelling guide [24].

The objective was to present calculations of spin-averaged pair distributions within multi-dimensional spin polarized electron gas models. Once that was done, they were compared against many other techniques, including the Kukkonen and Overhauser's two body Schrodinger equation. Zeeman splitting energy was found to be small, consistent with similar studies where the Kukkonen and Overhauser's two body Schrodinger equation accounted for such interactions as was expected [15] [16] [17].

Understanding an electron's role in a SPEG renders knowledge hyperfine interactions. Electron spin can be manipulated in a SPEG through spin exchange optical pumping [15]. The field strength can be calculated by considering the pole strength at the gate surfaces and domain boundary [70]. This research however, calculated the electrostatic barrier height, Fermi level, and carrier concentration within the 2DEG using a finite-element calculation, consistent with the Fermi–Dirac distribution.

The mathematics illustrated that any charge, within any particle in any momentum of any direction generated an electric field, consistent with known phenomenon. When that was applied to free electrons, the models showed that two electrons affected each other's magnetic field [20]. In progressing the models, an external field was applied to the SPEG. The external field spin polarized the gas. However, the model exposed its limitations as it is dimensionless showed the relationship between charge and angular momentum.

Flipping the spin of a free electron is no new learning. However, when applied to a SPEG, it is a relatively new field of study. The Rashba effect enabled a free electron in a Fermi gas' spin to flip by applying a periodic electric field at a specially selected frequency [32]. However, it is in further exploiting Rashba's research where a proposed tunnel can be produced in a SPEG by an incident beam provided by a FEL.

The model then investigated the susceptibility functions of the spin–flip process. Those susceptibility studies all albeit in a fractured and fragmented way, propose that a free electron's spin will flip at the electric dipole resonant frequency. This then reinforces the proposal that a Free Electron Laser could provide the required wattage to lever an electron's spin from one state to the other.

The way in which the results of the model relate to the extant position on decoherence by depolarization is significant and the reason why is due to the lack of research into this specific method. Current studies are limited to studying the implications in a loss of purity during the evolution of a quantum system. Specifically, decoherence due to depolarization is typically modelled as a correlation between depolarization and dephasing.

This research has modelled a plausible phenomenon where a pneumatic ensemble can be engineered to cause decoherence. The implications of being able to control such a phenomenon, could aid in quantum illumination studies. This is because extant quantum computing advancements are hindered by qubit coherence decay due to quantum discord [71].

The proposed decoherence causing tunnel describes a quantum observation technique, as it could detect the presence of a particle after it shows any evidence of a spin-flip. The more spin-flips that occur in the SPEG, the stronger the case builds for evidence of the presence of a foreign particle. The theory describes the phenomena, future research could look into an experiment [72].

6. Conclusion

In this research the properties of the spin polarized electron gas when pierced by an electron pump were modelled as and proposed as a way in which to detect an electron. The SPEG is simply an instrument in solid state physics upon which when reconciling the theoretical equations, it provides an effective starting point. Researchers interrogate the free electron model in order to ascertain the plausibility of progressing their investigation to apply to explore real-world scenarios. Both the 2D and 3D SPEG have been covered, without significant differentiation between the two, as the SPEG and its attributes have already been investigated.

The primary difference between the two is that the jellium is characterized by a density $\rho = \rho\uparrow + \rho\downarrow$, where $\rho\uparrow$ and $\rho\downarrow$ are the densities of the spin-up and spin-down electrons, respectively. For this reason, most of the modelling has been in 2-dimensions as any future research progressing the proposal in this thesis would likely focus on entanglement. This is because quantum observation describes a quantum system losing coherence. In a 2D SPEG the electrons are assumed to be embedded in a uniform background of positive charge and it is well researched that there is an intimate connection between a Jellium and quantum dots.

The Hartree-Fock method of approximation determines the wave function and the energy of a quantum many-body system in a stationary state. Therefor this method was used to describe the SPEG. A Jellium was primarily used, and results from a 3D SPEG calculation were given also. At this point, the SPEG was described which encompassed both hyperfine and exchange correlations. The most important attribute was the fact that the ensemble was spin polarized. The reason why is because to attribute spin polarization to all electrons in the gas provides for a medium of Euclidean space in which the direction and position of a particle can be measured, in breach of the Heisenberg uncertainty principle thus causing wave function collapse.

The Electron pump, when added to the SPEG was shown to have caused the pins of effected electrons within the SPEG to flip when tuned to the electric dipole spin resonance frequency via the Rashba effect. This crucial element within the scope of this thesis provides for the proposed tunnel. The model showed this by first calculating the total power of the SPEG, which then enabled the electron dipole spin resonant frequency for the SPEG to be calculated.

In applying that frequency to the free electron pump, it can be logically assumed that the mathematical model’s description of a tunnel walled by spin flipped electrons would be produced when the pump is beamed into the SPEG. Therefore, the proposed tunnel; the QDDT’s feasibility cannot be denounced, until the proposed guide to an experimental apparatus is progressed and the theory is tested.

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