Hunting for Snarks in Quantum Mechanics

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“You know, it would be sufficient to really understand the electron!”

Einstein

Santalo 2016
**Snark Hunt**: high stakes search for a *hypothetical physical entity* (**Snark**)!

**Outcomes:**
- **Snark is real!** ⇒ scientific **fame** (Nobel Prize)!
- **Snark is a boojum!** ⇒ scientific **oblivion** (or scorn)!

Some real snarks & boojums with some of their hunters:
- magnetic monopoles (Cabrera, Price)
- neutrinos (Pauli)
- Higgs boson (LHC)
- solar neutrinos (Bachall, Davis)
- gravitational waves (Weber, LIGO)
- EM waves (Maxwell, Hertz)
- tachyons (Sudharshan)
- quarks (Gell-Mann)
- gravitational worm holes (Wheeler)
- blackholes (Hawking)
- cold fusion (Fleischmann & Pons)
- Bose-Einstein condensation

Current popular snark hunts: **string theory**, **dark matter**

Pauli **snark test** (sniff, snicker, snide): “Why it isn’t even wrong!”

Einstein -- the greatest snark hunter of them all!

On **sniffing out a snark**: “I have a good nose!”

His sniffs of quantum mechanics suggest:
"Something is rotten in Denmark"
The Great Debate on the interpretation of Quantum Mechanics is centered on meaning of the wave function $\psi$ and $\psi^* \psi$ as probability density for particle states (Born Rule)

Two major schools:

- The **Copenhagen school** (Bohr, Heisenberg, Pauli, . . . )
  $\psi$ provides a complete description of a physical state.
  Probability is frequency expressing an inherent randomness in nature.

- The **realist school** (Einstein, de Broglie, Bohm, Jaynes, . . . )
  $\psi$ provides an incomplete description of a physical state
  — only a statistical ensemble of similarly prepared states.
  Probability expresses incomplete knowledge about the physical state.
  
  [Bohmian enclave: http://www.bohmian-mechanics.net/]

The **central issue** in the debate was famously articulated by EPR

- Does QM admit an experimentally accessible substructure:
  “elements of reality” (Einstein)
  “hidden variables” (Bell)

- Is there a **snark lurking in Quantum Mechanics?**
The search for hidden structure in Quantum Mechanics
A progress report on the great QM Debate!

- **Pilot Wave Theory** (de Broglie, Bohm): Solutions of Schrödinger’s equation determine probable paths for the motion of the electron.
- **Double solution theory**: de Broglie claims that the same equation may have a **singular solution** describing a definite particle path.
- **Electron clock**: a property of the electron proposed by de Broglie to explain wave properties of the electron.
- **Born–Dirac Theory**: Standard theory of the Dirac equation with the Born Rule for a probabilistic interpretation of solutions.
- **Real Dirac Theory**: Reformulation of the Dirac equation in terms of SpaceTime Algebra reveals hidden geometric structure relating spin, complex numbers, electron clock & zitterbewegung!
- **Maxwell–Dirac Theory**: Singular solutions of the Dirac equation for the electron as a charged hole in the vacuum with spin and zitter.
- **Fusion of Maxwell–Dirac & Born-Dirac Theories**: Complementary ontological & epistemological solutions of the same equation!
Electron trajectories in the double slit experiment
(from the Schroedinger current)

[Phillipidis, Dewney & Hiley (1979), Nuovo Cimento 52B: 15-28]

\[ \psi(x, t) \text{ carries information about electron state!} \]
“relativity is the cornerstone of quantum mechanics.”

Louis de Broglie (according to Georges Lochak)

How reconcile this with standard nonrelativistic QM?!

Two pillars of QM:

- **Planck**: energy is quantized in frequency!
  - of fields or particle sources?!

- **Einstein**: mass is energy!

de Broglie (1924) applied this to the electron:

\[ \omega_B = \frac{m_e c^2}{\hbar} \]

**deBroglie**: mass is frequency!

**Voila!** 

A particle clock:  

\[ \psi(\tau) = e^{i\omega_B \tau} \]

\[ \tau = \tau(x) = v \cdot x \]

\[ p = m_e c^2 v \implies \omega_B \tau = \frac{m_e c^2}{\hbar} v \cdot x = \frac{p \cdot x}{\hbar} \]

Congruence of clocks:  

\[ \psi(x) = e^{\frac{ip \cdot x}{\hbar}} \approx \text{Dirac plane wave!!} \]
de Broglie’s initial theory *coupled internal periodicity of the electron clock to periodicity of an associated wave*.  

**The particle periodicity was discarded almost immediately when Schroedinger introduced his wave equation.**  

*Besides how could one read time on a clock with such a high frequency?*

\[
\omega_B = \frac{m_e c^2}{\hbar} = 0.77634 \text{ Zs}^{-1} \quad \text{Zs}^{-1} = \text{Zetta-Hertz} = 10^{21} \text{s}^{-1} = (\text{zepto-sec})^{-1}
\]

A possibility occurred to **Michel Gouanère** in discussion with **M. Spighel**.  
They engaged an experimental team from Lyon to study “Kumakhov radiation” in the 54–110-MeV region on the linear accelerator at Saclay.  

**Electron Channeling:**  
Electron beam aligned close to a crystal axis.  
Electrons are trapped in orbits spiraling around a single atomic row.  
The atomic row can be approximated as a line charge.  
The orbits are well described by classical physics, especially at high energies.  
Scattering is reduced and transmission is greatly increased.
Michel Gouanèrè argued that, if the electron clock is real, a channeled electron should interact resonantly with the crystal periodicity at some energy.

**Estimate the resonant energy:**

Electron clock in laboratory time $t$: \[ \psi(\tau) = e^{i\omega_B \tau} = e^{i\omega_L t} = \psi(t) \]

\[ \Rightarrow \quad \omega_B \tau = \omega_B \frac{t}{\gamma} = \omega_L t \quad \frac{dt}{d\tau} = \gamma = \frac{1}{\sqrt{1 - v^2 / c^2}} \]

Lab frequency: \[ \omega_L = \frac{\omega_B}{\gamma} = \frac{2\pi}{T_L} \]

Lab period: \[ T_L = \frac{2\pi}{\omega_L} \]

Distance traversed during a clock period:

\[ d = T_L |v| = \frac{2\pi h}{m_e c^2} \gamma \frac{m_e |v|}{m_e} = \frac{hp}{(m_e c)^2} \]

\[ \Rightarrow \quad cp = m_e \gamma |v| = \frac{d(m_e c^2)^2}{hc} = \frac{3.84 \text{Å}(0.511034 \text{MeV})^2}{0.01239852 \text{MeV-Å}} = 80.87 \text{MeV} \]

One day was devoted to the internal clock experiment in 1980, but publication was delayed until corrections could be made to the data!
Crystal thickness = 1\(\mu m = 10^4\) Å (2604\(d\))

Silicon axis: <110>, atomic spacing: \(d = 3.84\) Å

Experimental specifications:

Search for a transmission resonance in a channeled electron beam by scanning a window (±1%) in the momentum range centered at the predicted resonance momentum \(p = 80.87\text{MeV/c}\)

\[ p = m_e \gamma v \]
\[ d = 3.84\text{Å} \]

Experimental result:

8% transmission dip (in the central peak) found at \(p_{\text{exp}} = 81.1\text{MeV/c}\)

\[ \frac{\Delta p}{p} = \frac{p_{\text{exp}} - p}{p} = \frac{0.23\text{MeV/c}}{p} = 0.28\% \]

Estimated calibration error = ± 0.3%

Published: *Annales de la Fondation Louis de Broglie*, 30 (1): 109 (2005)

Impact: NONE!
To get more visibility, Gouanère submitted to *Physical Review Letters* a version of the experiment supported by a phenomenological calculation used as a guide to design the experiment and interpret its results.

**REJECTED!** as physically implausible! January 2007

But one reviewer suggested a possible mechanism for the effect:

**ZITTERBEWEGUNG!**

\[ \omega_z = \frac{2m_e c^2}{\hbar} = 2\omega_B \]

Problems with interpretation the Dirac equation (1928)

- Mixing of positive & negative energy states
- \[ \Rightarrow \] oscillations in particle position (Schroedinger, 1930)
- Spin from circulation of electron mass
- Magnetic moment from circulation of electron charge
- Pair creation — Quantum field theory


What is Zitterbewegung?

“The well-known Zitterbewegung may be looked upon as a circular motion about the direction of the electron spin with radius equal to the Compton wavelength \( \times \frac{1}{2\pi} \) of the electron. The intrinsic spin of the electron may be looked upon as the orbital angular momentum of this motion. The current produced by the Zitterbewegung is seen to give rise to the intrinsic magnetic moment of the electron.”

K. Huang, AJP 20: 479 (1952)

This idea originated with Schrödinger (1930)

• Approved by Dirac soon thereafter!
• Duly recounted in textbooks on relativistic QM today!

However, nothing is made of its **staggering theoretical implications**:

• QM has a **particle substructure** generating magnetic moments!
• Substructure **motion is described by the wave function phase**!
• This motion **must generate a fluctuating electric field**!

Is this real Snark?? — or just a Boojum!! — How can we tell??
**SpaceTime Algebra (STA):**

 Generated by a frame of vectors: \( \{ \gamma_\mu \} \)

**STA \( \xrightarrow{\text{matrix rep}} \) (Real) Dirac Algebra**

**Geometric product:**

\[
\gamma_\mu \gamma_\nu = \gamma_\mu \cdot \gamma_\nu + \gamma_\mu \wedge \gamma_\nu
\]

**Inner product:**

\[
\gamma_\mu \cdot \gamma_\nu = \frac{1}{2} (\gamma_\mu \gamma_\nu + \gamma_\nu \gamma_\mu ) = g_{\mu \nu} \quad (\text{metric})
\]

**Outer product:**

\[
\gamma_\mu \wedge \gamma_\nu = \frac{1}{2} (\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu )
\]

**STA basis:**

\( 1, \quad \gamma_\mu, \quad \gamma_\mu \wedge \gamma_\nu, \quad i\gamma_\mu, \quad i = \gamma_0 \gamma_1 \gamma_2 \gamma_3 \)

- scalar, vector, bivector, pseudovector, pseudoscalar

**Vector:**

\( a = a^\mu \gamma_\mu \)

**Bivector:**

\( F = \frac{1}{2} F^{\nu \mu} \gamma_\mu \wedge \gamma_\nu \)

**Unit pseudoscalar:**

\( i \quad i^2 = -1, \quad ia = -ai \quad \gamma_0 i = -i\gamma_0 = \gamma_1 \gamma_2 \gamma_3 \)

**Multivector:**

\( M = \alpha + a + F + ib + i\beta \)

dimensions: \( 1 + 4 + 6 + 4 + 1 = 16 = 2^4 \)

**Reverse:**

\( \tilde{M} = \alpha + a - F - ib + i\beta \)

**Dual:**

\( iM = i\alpha + ia + iF - b - \beta \)
**Real Quantum Mechanics with STA**

**Real** Dirac equation: \( \gamma^\mu \left( \partial_\mu \psi \gamma_2 \gamma_1 \hbar - q A_\mu \psi \right) = m_0 \psi \gamma_0 \)

or: \( \nabla \psi \mathbf{i} \hbar - q A \psi = m_0 \psi \gamma_0 \)

**i** ≡ \( \gamma_2 \gamma_1 \)

\( \mathbf{i}^2 = (\gamma_2 \gamma_1)^2 = -1 \)

**Real** wave function: \( \psi = (\rho e^{i\beta})^2 R = \psi(x) \)

Rotor: \( R = R(x) \quad R\tilde{R} = 1 \)

degrees of freedom: 1+1 + 6 = 8

**Question:** What is the physical meaning of \( \gamma_0 \) and \( \mathbf{i} = \gamma_2 \gamma_1 \) in Dirac eqn?!

**Local observables:** \( \psi \gamma_\mu \tilde{\psi} = \rho e_\mu \) comoving frame: \( e_\mu = R \gamma_\mu \tilde{R} \)

**Dirac current:** \( \psi \gamma_0 \tilde{\psi} = \rho v \) **Answer:** velocity \( v = e_0 = R \gamma_0 \tilde{R} = \dot{x} \)

Particle conservation: \( \nabla \cdot (\psi \gamma_0 \tilde{\psi}) = \nabla \cdot (\rho v) = 0 \quad \Rightarrow \quad \) congruence of Dirac streamlines: \( x = x(\tau) \)

**Answer:** spin \( s = \frac{\hbar}{2} \mathbf{e}_3 = \frac{\hbar}{2} R \gamma_3 \tilde{R} \)

\( S = \frac{\hbar}{2} R \gamma_2 \gamma_1 \tilde{R} = \frac{\hbar}{2} e_2 e_1 = \frac{\hbar}{2} ie_3 e_0 = isv \)

**Question:** What is the physical meaning of “hidden variable” \( e_2 = R \gamma_2 \tilde{R} \)?!

**Answer:** zitterbewegung!! Along each streamline, \( e_2 \) rotates in the \( S \)-plane with the frequency \( d\phi/d\tau = (2m/\hbar \approx 10^{21} \text{ Hz for a free particle})! \)
Lessons learned from Real Dirac Theory

• **Complex numbers are inseparably related to spin in Dirac Theory.**
  ⇒ Spin is essential to interpretation of QM even in Schrödinger Theory.

• **Bilinear observables are geometric consequences of rotational kinematics.**
  ⇒ They are as natural in classical mechanics as in QM.

• **Spin and phase are inseparable kinematic properties of electron motion.**
  ⇒ Wave function phase is a measure of rotation in the spin plane $S = \psi$.
Say that again!!

The **claim** is that the unit imaginary in quantum mechanics represents a **spacelike bivector**

\[ i\hbar = i\sigma_3\hbar = \gamma_2\gamma_1\hbar \]

specifying **fermion spin**

\[ is = \frac{1}{2} U i\sigma_3 \hbar \tilde{U} = i \frac{1}{2} \hbar U \sigma_3 \tilde{U} \]

*This is kind of idea that can ruin a young man’s career!*  
– so **preposterous** that experts will dismiss it out of hand, usually with a demand for experimental evidence!  
– so **compelling** because it is a mathematical **fact** rather than mere speculation!  

*So the young man had better be careful when and where he mentions it!*  
– One **implication** is that the Copenhagen interpretation cannot be correct, because it does not explain how Planck’s constant in \[ \Delta x \Delta p_x \geq \frac{\hbar}{2} \] is related to electron spin!  
– *Who will believe that?*
Implications of Real Dirac Theory: the geometry of electron motion with de Broglie’s **electron clock** in quantum mechanics!

Dirac equation determines a congruence of streamlines, each a potential particle history
\[ x = x(\tau) \]
with particle velocity
\[ \dot{x} = \nu(\tau) = R\gamma_0 \tilde{R} \]

**Spinning frame picture** of electron motion

Dirac wave function \( \Psi = (\rho e^{i\beta})^{\frac{1}{2}} R \) determines

**Rotor:** \( R = R(\tau) = R[x(\tau)] = R_0 e^{-\frac{i}{2} \varphi \gamma_2 \gamma_1} \)

**comoving frame:** \( e_{\mu} = R\gamma_{\mu} \tilde{R} \)  
**phase** \( \varphi / 2 \)

**velocity:** \( e_0 = R\gamma_0 \tilde{R} = \nu \)

**Spin:** \( S = \frac{\hbar}{2} e_2 e_1 \)

\[ e_2 e_1 = R\gamma_2 \gamma_1 \tilde{R} = R_0 \gamma_2 \gamma_1 \tilde{R}_0 \]

**Plane wave solution:** \( R = R_0 e^{-\frac{1}{2} \varphi \gamma_2 \gamma_1} = R_0 e^{-\frac{p \cdot x}{\hbar} \gamma_2 \gamma_1} \)

\[ p = m_e c^2 \nu \implies \frac{1}{2} \varphi = \frac{p \cdot x}{\hbar} = \frac{m_e c^2}{\hbar} \nu \cdot x = \omega_B \tau \]

\[ \tau = \tau(x) = \nu \cdot x \]

\[ \omega_B = \frac{m_e c^2}{\hbar} = \frac{1}{2} \frac{d\varphi}{d\tau} \]
Dirac Equation in terms of Local Observables

\[ \nabla \psi \mathbf{i} \hbar - \frac{e}{c} A \psi = m_e c \psi \gamma_0 \times \bar{\psi} \]

\[ \hbar \nabla \psi \gamma_2 \gamma_1 \bar{\psi} - \frac{e}{c} A \psi \bar{\psi} = m_e c \psi \gamma_0 \bar{\psi} \]

\[ \hbar \nabla \psi \gamma_2 \gamma_1 \bar{\psi} = \rho P + \nabla (\rho S) \]

\[ \nabla (\rho S) = \nabla \cdot (\rho S) + \nabla \wedge (\rho S) \]

**Density:** \( \psi \bar{\psi} = \rho \) if \( \beta = 0 \)

**Dirac current:** \( \rho v = \psi \gamma_0 \bar{\psi} \)

**Spin density:** \( \rho S = \frac{\hbar}{2} \psi \gamma_2 \gamma_1 \bar{\psi} \)

**Momentum density:** \( \rho (P = \hbar \nabla \varphi) \)

\[ \rho = \text{probability density} \]

Gordon Current

**Electron vector potential**

\[ \rho^{-1} = \text{singular vacuum impedance} \]

Born–Dirac

Maxwell–Dirac

\[ \rho P - \frac{e}{c} A \rho = m_e c \rho v + \nabla \cdot (\rho S) \]

\[ = \frac{e}{c} A_C + \frac{e}{c} A_M = \frac{e}{c} A_e = \]

Coulomb

Magnetic
What is free space?

Maxwell’s equation for a homogeneous, isotropic medium

\[ \varepsilon = \text{permittivity (dielectric constant)} \]

\[ \mu = \text{(magnetic) permeability} \]

\[ G = E + \frac{i}{\sqrt{\mu\varepsilon}} B \]

\[ (\sqrt{\mu\varepsilon} \partial_t - \nabla)G = 0 \quad \text{Maxwell’s equation} \]

\[ (\sqrt{\mu\varepsilon} \partial_t + \nabla) \times (\sqrt{\mu\varepsilon} \partial_t - \nabla)G = 0 \]

\[ (\mu\varepsilon \partial_t^2 - \nabla^2)G = 0 \]

\[ (c^{-2} \partial_t^2 - \nabla^2)G = 0 \quad \text{Wave Equation} \]

\[ c = \frac{1}{\sqrt{\mu\varepsilon}} = \text{velocity of light in the medium = free space} \]

D’Alembertian: \( \square^2 = c^{-2} \partial_t^2 - \nabla^2 \) Wave operator

Invariant under Lorentz transformations

\[ \Rightarrow \quad \text{Theory of relativity} \quad \text{But} \quad \sqrt{\frac{\mu}{\varepsilon}} = \rho(x) = ?? \]
Electron as singularity in the physical vacuum

Electromagnetic vacuum defined by: \( \varepsilon \mu = \frac{1}{c^2} = \varepsilon_0 \mu_0 \) (Maxwell)

Vacuum impedance undefined: \( Z(x) = \sqrt{\frac{\mu}{\varepsilon}} = \frac{1}{\rho(x)} \sqrt{\frac{\mu_0}{\varepsilon_0}} \) (E. J. Post)

**Blinder function**: \[ \rho = \rho(x) = \sqrt{\frac{\mu}{\varepsilon}} \sqrt{\frac{\varepsilon_0}{\mu_0}} = e^{-\lambda_e/r} \]

Point charge path & velocity: \( z = z(\tau), \quad v = \dot{z} = \frac{1}{c} \frac{dz}{d\tau} \)

Retarded distance: \( r = (x - z(\tau)) \cdot v \) with \( (x - z(\tau))^2 = 0 \)

Classical electron radius \( \lambda_e = \frac{e^2}{m_e c^2} \)

**Vector potential**: in Maxwell Thry \( \frac{e}{c} A_e = \frac{e^2}{c \lambda_e} \rho v = \rho m_e c v \)

**Momentum density** in Dirac Theory \( \rho = \psi \bar{\psi} \)

Unifies Maxwell & Dirac

Unifies Maxwell & Dirac
What is an electron?!

“It is a delusion to think of electrons and fields as two physically different, independent entities. Since neither can exist without the other, there is only one reality to be described, which happens to have two different aspects; and the theory ought to recognize this from the outset instead of doing things twice!” – Einstein

*Field and particle are all ready unified in the Dirac equation!!*

Dirac equation can be read as an equation for momentum balance:

\[
\rho \left( P - \frac{e}{c} A \right) = \rho m_e c v + \nabla \cdot (\rho S) = \rho p_e = \frac{e}{c} A_e \]

\[
\rho v = \psi \gamma_0 \bar{\psi} \quad \rho S = \frac{\hbar}{2} \psi i \gamma_3 \gamma_0 \bar{\psi}
\]

For ”Pilot Wave Solutions”:

\[
\rho = \psi \bar{\psi} = e^{-\lambda_e / r} \quad \text{Blinder function!}
\]

⇒ Electrons are elementary singularities in the vacuum!

⇒ All elementary particles are topological defects in the vacuum!
Quantization of Stationary States

Split: $z\gamma_0 = ct + \mathbf{r}$

Particle path: $z = z(\tau)$

Period: $z(\tau_n) \cdot \gamma_0 = cT_n$

Periodic orbit: $z(\tau_n) \land \gamma_0 = \mathbf{r}(\tau_n) = \mathbf{r}(0)$

Orbit-clock Resonance

$e_\mu(\tau_n) = R\gamma_\mu \tilde{R} = e_\mu(0)$ \hspace{1cm} $R(\tau_n) = R(0)$

Constant Energy: $E = cP_0 - m_e c^2$

$P = (P \cdot \gamma_0 + P \land \gamma_0)\gamma_0 = (P_0 + \mathbf{P})\gamma_0$

Quantization Condition

$$\oint_0^{\tau_n} P \cdot v d\tau \equiv \oint P \cdot dz = 0$$

$$= P_0 T_n - \oint P \cdot d\mathbf{r} = 0$$

$T_n = \oint_0^{\tau_n} \gamma_0 \cdot v d\tau$

Magnetic flux quantization

$$\oint P \cdot d\mathbf{r} = 2\pi n\hbar = \oint (\mathbf{p} + \frac{e}{c} \mathbf{A}) \cdot d\mathbf{r}$$

F. London

Electroflux quantization

$$P_0 T_n = \oint_0^{\tau_n} \left( p_0 + \frac{e}{c} A_0 \right) dt = n\hbar$$

E. J. Post

Resolves Dirac-Sommerfeld puzzle: $\ell = 0$ \hspace{1cm} s-state

Explains quantum Hall effect
Classical particles with spin (using STA)

Particle history: \( z = z(\tau) \) Parameter \( \tau \) to be determined

Proper velocity: \( u \equiv \dot{z} = \frac{dz}{d\tau} \) constant \( u^2 \geq 0 \) \( \Rightarrow \) \( \dot{u} \cdot u = 0 \)

Particle momentum: \( p = p(\tau) \) Dynamical mass: \( m \equiv p \cdot u \)

Spin (bivector): \( S = S(\tau) \) (Intrinsic angular momentum)

Essential non-collinearity of velocity and momentum:
\( p \neq mu \) because some momentum contained in \( S \).
Hence relation between \( p \) and \( S \) depends on dynamics.

Kinematical constraint: \( S \cdot u = 0 \) (reduces degrees of freedom in \( S \))

Momentum conservation: \( \dot{p} = f \)
Spin conservation: \( \dot{S} = u \wedge p + \Gamma \) \( \Rightarrow \) \( \dot{S} + m = up + \Gamma \)

Orbital angular momentum \( \equiv p \wedge z \) \( \Rightarrow \) Total angular momentum: \( J \equiv p \wedge z + S \)
\( \Rightarrow \) Total angular momentum conservation: \( \dot{J} = f \wedge z + \Gamma \)
Zitter Electron Model

\[ z = z(\tau) \quad u = \dot{z} \quad u^2 = \dot{z}^2 = 0 \]

\[
\begin{aligned}
\dot{u} &= -\omega \hat{r} + \frac{q}{m_e} F \cdot u \\
\dot{p} &= qF \cdot u + \nabla \Phi
\end{aligned}
\]

\[
\omega = \frac{2m}{\hbar} = \lambda^{-1} = |r|^{-1}
\]

\[
\begin{aligned}
\Rightarrow m \equiv p \cdot u &= m_e + \Phi \\
&S = \frac{\hbar}{2} \hat{r} u = m_e r_e u = r_e \wedge (m_e u) \\
&\quad S^2 = 0
\end{aligned}
\]

\[
\dot{S} = u \wedge p + \frac{q}{m_e} F \times S
\]

\[
F \times S = \frac{1}{2} (FS - SF)
\]

**Scale:**
\[
\lambda_e = \frac{c}{\omega_e} = \frac{\hbar}{2m_e c} = 1.93079 \times 10^{-3} \text{ Å} = \frac{\lambda_c}{4\pi}
\]
Zitter in the electron “rest frame”

Charge current: \( J = q\dot{z} = q(\dot{x} + \dot{r}) = q\dot{x} + \dot{d} \)

\[
\begin{align*}
\bar{J} &= q\dot{x} \\
\bar{d} &= q\omega \times r
\end{align*}
\]

\[
\begin{align*}
|\omega \times r| &= \omega\lambda = c = 1 \\
\bar{d} &= 0
\end{align*}
\]

Spin-Zitter Uncertainty Relations

\[
\Delta x = \lambda_e = \frac{\hbar}{2 m_e c}
\]

\[
\Delta p_x = m_e c
\]

\[
\Delta x \Delta p_x = m_e c \lambda_e = \frac{\hbar}{2}
\]

Zitter frequency & QM phase

\[
\omega = \frac{d\varphi}{d\tau} = \omega_e + \frac{2}{\hbar} \Phi = \frac{1}{\lambda}
\]

\[
m = m_e + \Phi = \frac{1}{2} \hbar \omega
\]
**Experimentum crucis**: The zitter model explains all results of Gouanère’s electron clock channeling experiment!!

(Foundations of Physics (2008) **38**: 659-664)

The detailed explanation:

- Provides *equations of motion* for channeled electrons with zitter
- Explains the clock *interaction mechanism* as resonance with a circulating electric dipole
- Calculates *resonant energies* and explains why \( \omega_z = \frac{2m_e c^2}{\hbar} = 2 \omega_B \)
  Parametric resonance!
- Calculates the *width* of the lowest resonance
- Explains the *shift* in resonance energy
- Predicts *spin effects* at higher resolution

The experiment should be refined and repeated to confirm predictions!

**References**:


CONCLUSION

Is the electron really a vacuum singularity with clock & zitter?

Is it a Snark!

or a Boojum?

BEWARE the consequences!
Described in the immortal words of LEWIS CARROLL: (1875)
“The Hunting of the Snark”
as an allegory of scientific research:

The project leader (the *Bellman*)
organizes a scientific team and
defines the research objective: To discover a Snark!

The poem personifies the excitement and perils of
scientific search and discovery

With the frightening prospect that
the Snark might turn out to be a *Boojum*!
whereupon the hunter
“softly and silently vanishes away.”
(into scientific oblivion!)
“The Hunting of the Snark” (edited) — Lewis Carroll

“Just the place for a Snark!” the Bellman cried,
  As he landed his crew with care;
Supporting each man on top of the tide
  By a finger entwined in his hair.

“Just the place for a Snark! I have said it twice:
  That alone should encourage the crew.
Just the place for a Snark! I have said it thrice:
  What I tell you three times is true.”

... Each thought he was thinking of nothing but “Snark”
  And the glorious work of the day;
And each tried to pretend that he did not remark
  That the other was going that way.

... They sought it with thimbles, they sought it with care
  They pursued it with forks and hope;
They threatened its life with a railway share;
  They charmed it with smiles and soap.

... You boil it in sawdust: you salt it with glue:
  You condense it with locusts and tape:
Still keeping one principal object in view—
  To preserve its symmetrical shape.
(That’s exactly the method,” the Bellman bold
In a hasty parenthesis cried,
“That’s exactly the way I have always been told
That the capture of Snarks should be tried!)

“But oh, beamish friend, beware of the day,
If your Snark be a Boojum! For then
You will softly and suddenly vanish away,
And never be met with again!”

“There is Thingumbob shouting!” the Bellman said.
“He is shouting like mad, only hark!
He is waving his hands, he is wagging his head,
He has certainly found a Snark!”

Erect and sublime, for one moment of time,
In the next, that wild figure they saw
(As if stung by a spasm) plunge into a chasm,
While they waited and listened in awe.
“It’s a Snark!” was the sound that first came to their ears,
    And seemed almost too good to be true.
Then followed a torrent of laughter and cheers:
    Then the ominous words It’s a Boo——

Then, silence. Some fancied they heard in the air
    A weary and wandering sigh
That sounded like”——jum!” but the others declare
    It was only a breeze that went by.

They hunted till darkness came on, but they found
    Not a button, or feather, or mark,
By which they could tell that they stood on the ground
    Where the Bellman had met with the Snark.

In the midst of the word he was trying to say,
    In the midst of his laughter and glee,
He had softly and suddenly vanished away——
    For the Snark was a Boojum, you see.
The End

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