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Stochastic electrodynamics (SED) without spin, denoted as pure SED, is based on the introduction of the nonrenormalized, stochastic zero-point field (ZPF). It explains some aspects of quantum mechanics (QM), but has four fundamental drawbacks that make it untenable. All the drawbacks are overcome by SED with spin, that allows the derivation of the ZPF and of the Schrodinger equation when the ZPF is not modified, at frequencies smaller than plasma's, because of boundary conditions. In presence of a conducting wall with two slits, an experiment is proposed which could discriminate between QM and SED with spin. In fact, in the case of an electron beam focused on a single slit, no interference pattern due to the other slit is predicted by QM, differently than by SED with spin.

I. ABSORBED AND RADIATED POWERS

The power spectral density of electromagnetic (e.m.) radiation can be represented as

$$\rho(\omega) = \frac{d^4 K}{dV d\omega} = \frac{dU}{d\omega}, \quad (1)$$

with K , V , ω , and $U \equiv d^3 K / dV$ denoting energy, volume, angular frequency, and energy density, respectively. The average force $\langle \mathbf{F} \rangle$ on a charged harmonic oscillator of mass m , electric charge e , having proper angular frequency ω_0 , translating with average velocity $\langle \mathbf{v} \rangle$, and subject to the e.m. power spectral density $\rho(\omega)$, is given by the Einstein-Hopf formula [1]

$$\langle \mathbf{F} \rangle = -\frac{4}{5}\pi^2 \frac{e^2}{mc^2} \langle \mathbf{v} \rangle \left[\rho(\omega_0) - \frac{\omega_0}{3} \left| \frac{d\rho(\omega)}{d\omega} \right|_{\omega=\omega_0} \right]. \quad (2)$$

We notice that only for $\rho(\omega) = A\omega^3$ the force is null for every value of ω_0 , hence allowing a “motion by inertia”, at least for a harmonic oscillator. In particular, as shown by Boyer [1], a density $\rho(\omega) = A\omega^3$ is also the only one relativistic invariant.

Assuming the proportionality constant A as

$$A = \frac{\hbar}{2\pi^2 c^3}, \quad (3)$$

the power spectral density turns out to be

$$\rho(\omega) = \frac{\hbar\omega^3}{2\pi^2 c^3}, \quad (4)$$

coinciding with the zero point field (ZPF) of quantum electrodynamics (QED). However, $\rho(\omega)$ is strongly divergent for $\omega \rightarrow \infty$, so that the ZPF is renormalized in QED. Yet, in presence of a gravitational field, i.e., in a Riemannian space, $\rho(\omega)$ can **not** be renormalized, implying a big trouble for general relativity (GR). In fact, even truncating the ZPF at the minimum possible value, the mass energy density in the universe would be 10^{120} times what observed.

The filament theory (FT), for the time being in progress, leads to a gravitational theory different from general relativity. FT gives the same results of GR up to and including the second order, which is the only one that can be detected at present. But it is radically different, because the ZPF of FT has no effect on gravitation. Consequently, in FT [and in the consequent stochastic electrodynamics with spin (SEDS), that will be studied in Sec. IV of this proceeding] the ZPF is taken as real, i.e., as non-renormalized. We will also see that it has a natural reduction at very high frequencies.

According to classic stochastic electrodynamics (SED), a charged oscillator, as an electron of mass m and electric charge e around an atomic nucleus, classically absorbs a power from the ZPF given by

$$P_{\text{abs}} = 2\frac{2}{3}\frac{e^2}{m}\pi^2\rho(\omega), \quad (5)$$

with $\rho(\omega)$ given by Eq.(4). For simplicity, if we suppose a circular orbit (it is sufficient for our purposes), the electron velocity v is given by $v = \omega R$, and, putting Eq.(4) into (5), it is

$$P_{\text{abs}}|_{\text{circ}} = \frac{2}{3}\frac{e^2}{m}\frac{\hbar v^3}{c^3 R^3}, \quad (6)$$

with the electronic radiated power given by the Larmor

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formula

$$P_{\text{rad}}|_{\text{circ}} = \frac{2}{3} \frac{e^2}{c^3} a^2 = \frac{2}{3} \frac{e^2}{c^3} \left(\frac{v^2}{R} \right)^2, \quad (7)$$

with $a = v^2/R$ as the centripetal acceleration.

Equating the radiated and absorbed powers of Eqs.(6) and (7), we obtain

$$mvR = \hbar, \quad (8)$$

which is the Bohr's condition, allowing the calculation of the most probable atomic radius. Eq.(8) also gives the uncertainty principle.

II. EXCITED STATES

Excited states have never been obtained in SED, and we present them as a new achievement.

In the preceding balance $P_{\text{abs}} = P_{\text{rad}}$, that led to Eq.(8), we have considered a pure circular motion, that can not exist because of the random action of the ZPF. Although the ZPF little modifies an orbit during a single revolution, in the long run the orbit becomes elliptical with slow variations of eccentricity, major axis, and even of the orbit plane. The Bohr radius R_1 is only the most probable value to find the electron in a thin spherical shell around R_1 .

Let us now consider the case that a ZPF fluctuation has produced a small variation of an initially circular orbit, transforming it into an elliptical orbit, represented in polar coordinates r (distance) and θ (angle) by

$$r = \frac{R}{1 - \epsilon \cos \theta}. \quad (9)$$

If the eccentricity ϵ is much less than 1, Eq.(9) is equivalent, to within second order terms in ϵ , to

$$\begin{aligned} x &= R \cos \theta + \epsilon R \cos 2\theta, \\ y &= R \sin \theta + \epsilon R \sin 2\theta. \end{aligned} \quad (10)$$

In fact, it is

$$\begin{aligned} r &= \sqrt{x^2 + y^2} = R \sqrt{1 + \epsilon^2 + 2\epsilon \cos \theta} \\ &\simeq R + \epsilon R \cos \theta \simeq \frac{R}{1 - \epsilon \cos \theta}. \end{aligned} \quad (11)$$

In a Keplerian motion there is conservation of angular momentum Γ , so that ω depends only on the distance r , with

$$\omega(r) = \frac{\Gamma}{mr^2}, \quad (12)$$

Putting Eqs.(11) into (12) and defining $\omega_0 = \Gamma m^{-1} R^{-2}$ as the angular frequency associated to radius R , we have

$$\omega = \omega_0 - 2\epsilon \omega_0 \cos \theta. \quad (13)$$

Solving Eq.(13) in an iterative way in θ , we derive to first order

$$\theta = \int \omega dt \simeq \omega_0 t - 2\epsilon \sin(\omega_0 t). \quad (14)$$

Substituting this equation into the polar equation of the ellipse, given by Eq.(9), we obtain the trajectory as a function of time t . Since in Eq.(9) the term $\cos \theta$ is multiplied by ϵ and we are limiting our calculation to first order in $\epsilon \ll 1$, we can neglect the second term.

With $\theta = \omega_0 t$, the first terms at the r.h.s. of Eq.(14) represent the main circular motion, considered as a deferent, on which there is a second circular motion (ϵ time the first one) considered as an epicycle. Since it is $\epsilon \ll 1$, the motion is practically circular, so that the radiated power remains unaltered. What drastically changes is the absorbed power since now there are four harmonic oscillators. The epicycle rotates with angular velocity 2ω in respect of the laboratory. However, since the epicycle rotates around a point that in turn rotates with ω , what is effective for the absorbed power is the relative frequency $2\omega - \omega = \omega$, i.e., the same frequency as the one of the deferent. Consequently, the absorbed power P_{ex} for the first-order excited state can be written as

$$P_{\text{abs}}^{\text{excited}} = n P_{\text{abs}}|_{\text{circ}} \quad (15)$$

with $P_{\text{abs}}|_{\text{circ}}$ given by Eq.(6) and $n = 2$, corresponding to 2 plane motions (hence 4 harmonic oscillators with the same angular frequency ω_0).

The Bohr orbit corresponds to $n = 1$, i.e., to one plane motion (hence two harmonic oscillators). More in general, a periodical elliptical motion can be expanded in Fourier series

$$\begin{aligned} x &= R \cos \theta + R \sum_{n=2}^{+\infty} \epsilon_n \cos(n\theta + \varphi_n) \\ y &= R \sin \theta + R \sum_{n=2}^{+\infty} \epsilon_n \sin(n\theta + \varphi_n), \end{aligned} \quad (16)$$

where φ_n are constant phases. Each additional term corresponds to a circular motion which, being relevant to the same electron, is epicycloidal. If we limit to $n = 3$, we have an epicycle rotating with angular velocity 3ω (in the approximation $\theta = \omega t$) on another epicycle rotating with angular velocity 2ω , in turn rotating on the deferent with angular velocity ω . The relative, effective frequencies for absorption from the ZPF are $3\omega - 2\omega = 2\omega - \omega = \omega$, i.e., the same of case $n = 2$. Being $\epsilon_i \ll 1$ in Eq.(16), the radiated power remains the same as for a circular orbit, i.e., still given by Eq.(7), whence

$$P_{\text{rad}}^{\text{excited}} = P_{\text{rad}}|_{\text{circ}} \quad (17)$$

Equating the absorbed and radiated powers, from Eqs.(6), (7), (15), and (17) we obtain

$$mv_n R_n = n \hbar, \quad (18)$$

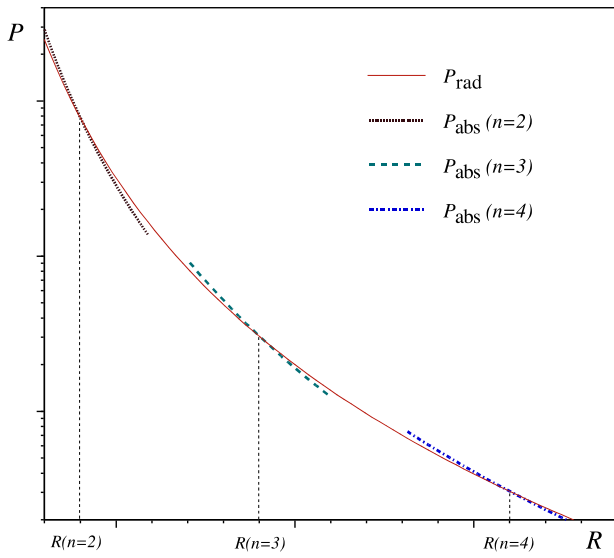


FIG. 1: Radiated power P_{rad} [erg s⁻¹] and absorbed power P_{abs} [erg s⁻¹] vs radius R [cm] of the electron circular orbit. For any number n of plane orbits (in QM terms, n is the principal quantum number) there is a stable point of intersection $P_{abs}(n, R) = P_{rad}(n)$ if the average effect of the zero-point field (ZPF) is considered. The ZPF fluctuations concordant with the radiation damping cause the transition from n to $n - 1$.

i.e., Bohr's condition for quantization.

Let us examine the transition between two states. If the radius R of the orbit changes very slowly, we may consider it in quasi-equilibrium, so that $e^2/R^2 = mv^2/R$, i.e.

$$v = \frac{e}{\sqrt{mR}} \quad (19)$$

Putting Eq.(19) into (15), (17), and using Eqs.(6), (7), the radiated and absorbed powers are given by

$$P_{abs}^{excited} = \frac{2ne^5\hbar}{3c^3m^{5/2}R^{9/2}} \quad (20)$$

$$P_{rad}^{excited} = \frac{2e^6}{3c^3m^2R^4} \quad (21)$$

With a given value of n and for $P_{abs}^{excited} \simeq P_{rad}^{excited}$, as an average effect we have stable equilibrium for a given radius R_n . In fact, if it is $R = R_n + \delta R$ (with $\delta R \ll R_n$), we have $P_{rad}^{excited} > P_{abs}^{excited}$ and radius R decreases. Viceversa, if it is $R = R_n - \delta R$, we have $P_{rad}^{excited} < P_{abs}^{excited}$ and radius R increases, as shown in Fig.1.

There are however the fluctuations of the ZPF (beside its average effect), which can easily destroy the small amplitude $\epsilon_n R$ of one of epicyclic motions. In this case, $P_{abs}^{excited}$ loses two harmonic oscillators (passing from n to $n - 1$) and we have $P_{rad}^{excited}$ sensitively larger than $P_{abs}^{excited}$. As a consequence, the electron motion becomes, on an average, a spiral motion towards the lower most probable orbit $n - 1$.

The net radiated energy is twice the one of the ZPF corresponding to the net observable weighted average frequency $\langle \omega \rangle$.

III. ACHIEVEMENTS OF PURE STOCHASTIC ELECTRODYNAMICS (SED)

The fundamental equation for SED is the Lorentz-Abraham equation of motion with radiation damping

$$m\ddot{\mathbf{r}} - \frac{2e^2}{3c^3}\ddot{\dot{\mathbf{r}}} = e \left[\mathbf{E} + \mathbf{E}_r + \frac{\mathbf{v}}{c} \times (\mathbf{B} + \mathbf{B}_r) \right], \quad (22)$$

in which the actions on the charge e are due to both the external fields (\mathbf{E} and \mathbf{B}) and the random fields (\mathbf{E}_r and \mathbf{B}_r), where the stochastic, or random, electric field of SED can be expressed as the Fourier superposition

$$\mathbf{E}_r(\mathbf{r}, t) = \text{Re} \sum_{s=1}^2 \int \mathbf{E}_k(\mathbf{k}, s, t) e^{i[\omega_k t - \mathbf{k} \cdot \mathbf{r} + \theta_k(s)]} d^3\mathbf{k} \quad (23)$$

of plane waves with random phase θ_k , where the summation is over the two polarizations implied in the e.m. transverse waves, and the Fourier amplitude is $(0.5\hbar\omega)^{1/2} \pi^{-1}$. Using the orthogonal unit vectors $\hat{\mathbf{e}}$ and $\hat{\mathbf{k}}$ in the direction of the electric field and wave propagation vectors respectively, we can write

$$\mathbf{E}_k(\mathbf{k}, s, t) = \hat{\mathbf{e}}(s) \sqrt{\frac{\hbar\omega}{2\pi^2}} \quad (24)$$

and

$$\mathbf{B}_r(\mathbf{r}, t) = \text{Re} \sum_{s=1}^2 \int \hat{\mathbf{k}} \times \hat{\mathbf{e}}(s) \sqrt{\frac{\hbar\omega}{2\pi^2}} \times \exp\{i[\omega_k t - \mathbf{k} \cdot \mathbf{r} + \theta_k(s)]\} d^3\mathbf{k} \quad (25)$$

In honour of the authors who first used the above equations intensively, the latter is called the Brafford-Marshall equation. Its application has given results in agreement with those of QM, and even of QED for:

1. The stability of the atoms including the excited states if the e.m. pressure of the ZPF is neglected;
2. The black body spectrum [1, 2]. With the same treatment of Rayleigh-Jeans, but with the inclusion of the ZPF (see Fig.2), the Planck spectrum is found superimposed to the ZPF, i.e.

$$\rho(\omega) = \frac{\hbar\omega^3}{\pi^2 c^3} \left[\frac{1}{2} + \frac{1}{\exp(-\hbar\omega/kT)} \right];$$

3. The intuitive explanation of the Casimir effect [3], i.e., the attraction of two conducting plates (with no electric charge), due to the e.m. pressure of the ZPF, that is larger outside the plates;

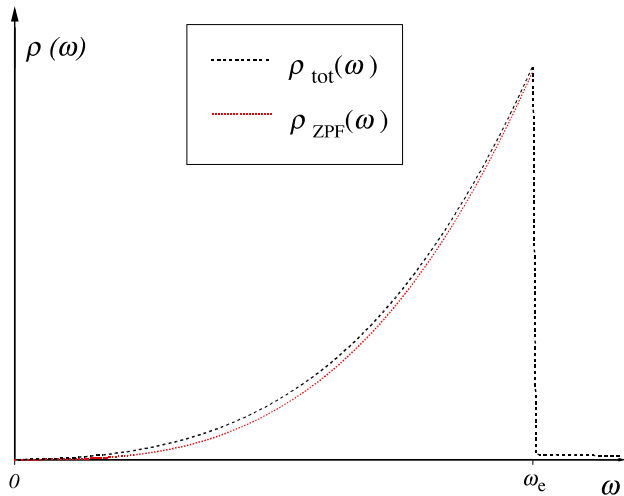


FIG. 2: In SED the Planck spectrum is superimposed to the zero point field (ZPF), represented as $\rho_{\text{ZPF}}(\omega)$, giving the total spectrum $\rho_{\text{tot}}(\omega)$.

4. The Van der Waals forces between macroscopic objects, and between polarizable particles [3];
5. The oscillator and rotator specific heats [3];
6. The fluctuations in thermal radiation [3];
7. The third law of thermodynamics [3];
8. The harmonic oscillator with radiative corrections [4];
9. The diamagnetic susceptibilities [5];
10. The thermal effects of acceleration [6] (the Unruh-Davis effect).

There is also a new result, qualitatively predicted by Rueda [7], i.e., the origin of the extremely high energy tail of the cosmic radiation, which is not contained in usual QED. Indeed, already Einstein showed that the kinetic energy of a particle subject to random impulses increases linearly with time unless a friction force arises, due to the stochastic process itself. But, if the stochastic process is that of the ZPF, the friction force vanishes and the kinetic energy of a charged particle steadily increases until the particle undergoes a collision, which is very rare in the intergalactic space. Thus the huge observed energies of cosmic rays up 10^{21} eV are explained. In this case there is no modification of the ZPF because of the boundary conditions, and that is why QED in the usual time-asymmetric formulation (in which the unmodified zero point is subtracted) does not predict this effect. By SED, Rueda predicted not only the existence of this new effect, but also the correct slope of the very high energy tail of the cosmic ray distribution function versus energy. Unfortunately, the intensity of the acceleration

mechanism turned up to be too intense, so that an electron would become a cosmic ray in an oscilloscope tube [8]!

At the end of the seventies, skilful researchers [9] succeeded to solve nonlinear problems in SED, and then a second big drawback appeared: the solution of the probability density of an electron around a proton tended to be uniform in the long run, and therefore to vanish, thus implying the self-ionization of an hydrogen atom! The stability of atoms was again unsolved, although in the opposite sense to that implied in classical physics (without ZPF), which predicted collapse.

A third shortcoming which always troubled the researchers is that SED implies broad spectra for radiation and absorption of rarefied gases, instead of the sharp observed lines! Indeed, according to SED, the quasi-elliptical orbit of an electron around a nucleus undergoes a maximum relative change of 10^{-5} during a revolution, if compared with the corresponding Keplerian orbit. Then, after 10^6 revolutions, the energy and, particularly, the revolution frequency can radically be changed. Although there is average equilibrium between the radiated and absorbed power for orbits not very different from Bohr's orbits, there is a net observable radiation for all the intermediate orbits with their large spread of revolution frequency. For instance, in the passage from the second to the first orbit of Bohr, there is a classical spread of frequency by a factor 8.

A fourth drawback of SED was the impossibility to explain the diffraction of electrons, and the fifth that the Schroedinger equation has been derived in particular cases only. The impossibility to derive the Schoedinger equation by "pure" SED when nonlinear forces are present (as in the case of atoms, where the Coulomb force is highly nonlinear) is related to the above second drawback.

Because of the above five drawbacks, many valid researchers abandoned SED, considering it a curiosity, which gives correct results in the cases of linear systems only. Only few researchers, as Rueda, Puthoff, Spavieri, Tonni, and Bosi, went on working on pure SED. Stimulated by professor L.Bosi, we succeeded to explain an experimental anomaly in the measurements of the maximum limit of the neutrino rest mass [10].

Another long standing problem, i.e., the origin of the electrical noise having power spectral density proportional to $1/f$, received its solution through the introduction of the ZPF. Not only the origin of the $1/f$ noise has been explained, but also a dependence on the electron number density has been found, which allowed an excellent agreement with the experimental results for the purest semiconductors [11].

IV. SED WITH SPIN (SEDS)

Originally, spin was introduced, following Pauli saying, as a "nonclassically explainable two valuedness".

When Goudsmith gave some intuitive model, he meant

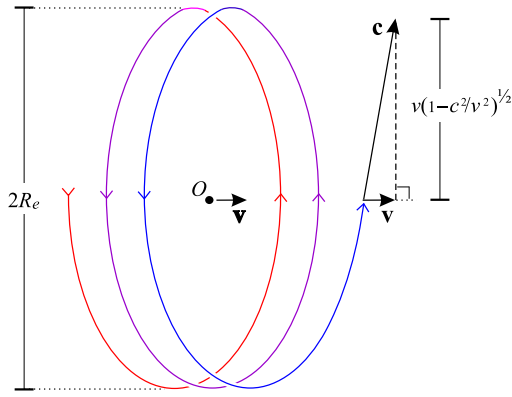


FIG. 3: If the center O of the gyration has velocity \mathbf{v} , the electron moves along a helix. Being c the local velocity of the electron, by the Pythagorean theorem we obtain Eq.(29), i.e., the time transformation of special relativity.

spin as a rotation of an elementary particle around its own symmetry axis. But that is completely wrong, because an electron (or a quark), on the bases of scattering experiments at LEP, has a maximum size less than 10^{-19}m , and with that radius and a peripheral speed equal to that of light, the angular momentum would be less than $10^{-6}\hbar$.

Schroedinger, solving the Dirac equation for an isolated electron, found a motion at the speed of light along a circular trajectory, having the Compton radius

$$R_e = 3.86 \times 10^{-13}\text{m} . \quad (26)$$

Barut and Zanghi [12] showed that the circular motion was the best interpretation for spin. But it seemed a contradiction having a particle moving at the speed of light without having infinite mass, and infinite e.m. radiation.

The complete solution comes from the filament theory [13], where special relativity (SR) is not present at the particle level, but only with respect to the ideal point O around which the particle performs its “spin gyration”.

SR is a consequence of that “gyration” [14]. If the center O of that gyration has velocity \mathbf{v} , the larger is the pitch of the helix, as shown in Fig. 3. Only for a pitch tending to infinity, the speed of O (usually considered as the electron speed) tends to the speed of the light c .

Let us consider a reference frame F' at rest with O . For F' the gyration period is

$$T' = 2\pi R_e / c . \quad (27)$$

For the frame F , at rest with the laboratory, O moves with a velocity \mathbf{v} perpendicular to the plane α of gyration. Since for F the electron moves with speed c along a helix, the period T to traverse a pitch is longer. Precisely, the component c_{\perp} on α of its velocity is

$$c_{\perp} = \sqrt{c^2 - v^2} = c\sqrt{1 - v^2/c^2}, \quad (28)$$

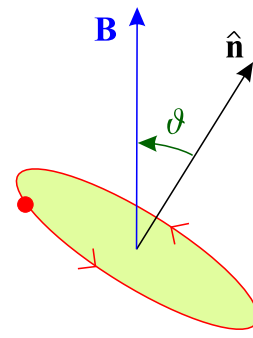


FIG. 4: What is called a “spin up” means a distribution of the spin axis $\hat{\mathbf{n}}$ in a half sphere having \mathbf{B} as a symmetry axis.

so that the period is

$$T = \frac{2\pi R_e}{c_{\perp}} = \frac{2\pi R_e}{c\sqrt{1 - v^2/c^2}} = \gamma T', \quad (29)$$

just as given by SR, but here derived from Galilean kinematics by the Pythagorean theorem.

Equating the power emitted with the power absorbed because of spin, Bohr’s condition [see Eqs.(6)-(8), with $v = c$ and $R = R_e$] gives

$$mcR_e = \hbar. \quad (30)$$

The spin axis $\hat{\mathbf{n}}$ can assume any direction, as shown in Fig.4. In presence of a magnetic field \mathbf{B} , the spin axes precesses around \mathbf{B} . What is called a “spin up” means an $\hat{\mathbf{n}}$ distribution in a half sphere having \mathbf{B} as a symmetry axis. For “spin down”, the symmetry of the half-sphere is antiparallel to \mathbf{B} . The average value, the only one measurable, is

$$\Gamma_B = \hbar \int_0^{\pi/2} d\vartheta \sin \vartheta \cos \vartheta = \frac{\hbar}{2}, \quad (31)$$

which is the standard value. With the above distribution of $\hat{\mathbf{n}}$, it has been proved by Pitowsky [15] that the procedure used by John Bell to derive its famous inequalities leads to results in agreement with QM, thus eliminating the speculations regarding “superluminal speeds”. The e.m. radiation due to the spin gyration is more than 10^{12} that of an electron whose gyration center revolves around a proton. Consequently, the ZPF is practically due to the spin gyration [14].

As shown in Fig. 5, if all the centers of the electron spin gyrations were at rest with respect to the laboratory, the power spectral density would be a narrow spread around an almost Dirac delta function centered at $\omega_e = c/R_e$. However, if we consider spherical shells concentric with the observer in our expanding universe, the contribution of the shells decreases at the increase of their radii, because of the Doppler-Fizeau effect. The result is $\omega < \omega_e/10$ for $\rho(\omega) \propto \omega^3$.

At the beginning of the universe the particles could be in a steady-state condition because $\rho(\omega)$ did not grow

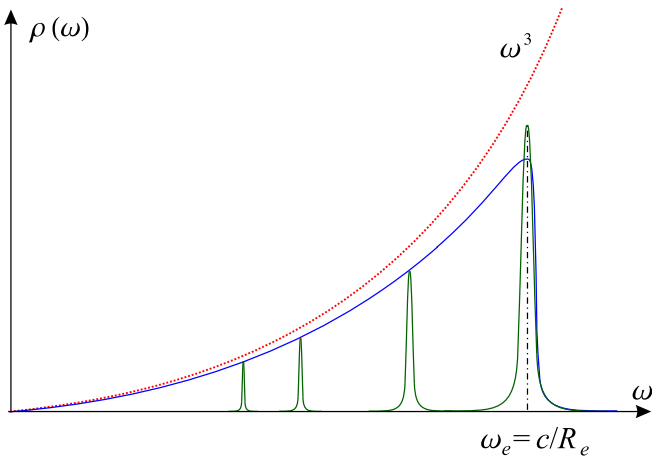


FIG. 5: If all the centers of the electron spin gyrations were at rest with respect to the laboratory, the power spectral density $\rho(\omega)$ would be a narrow spread centered at $\omega_e = c/R_e$. However, ours is an expanding universe, whence, at least for $\omega < 0.1\omega_e$, it is $\rho(\omega) \propto \omega^3$ due to the Doppler-Fizeau effect.

versus ω as ω^3 for $\omega_e/10 < \infty$. Consequently, the spin radius decreased spiralling up to $\sim 10^{-16}$ the present value R_e and $\rho(\omega) \propto \omega^3$ up to $10^{16}\omega_e$.

A spinning particle in a constant field \mathbf{E} lying in the plane of the spin gyration increases the spin radius in a half trajectory and decreases it in the other half. The result is a zero acceleration for O . The particle can therefore accelerate along its spin axis $\hat{\mathbf{n}}$, and the equation of motion, neglecting the self-reaction, is [10, 14]

$$m_* \mathbf{a} = \mathbf{F} \cdot \hat{\mathbf{n}} \hat{\mathbf{n}}, \quad (32)$$

where m_* is the inertial mass when $\hat{\mathbf{F}} = \hat{\mathbf{n}}$ (indeed, in this case, we have $m_* \mathbf{a} = \mathbf{F}$). When an e.m. wave impinges on an electron, the electric field produces a velocity variation $\delta \mathbf{v} \propto \hat{\mathbf{n}}$, so that the additional acceleration due to Lorentz force $\delta \mathbf{F}_L$ vanishes since

$$\delta \mathbf{F}_L \cdot \hat{\mathbf{n}} = e \delta \mathbf{v} \times \mathbf{B} \cdot \hat{\mathbf{n}} \propto e \hat{\mathbf{n}} \times \mathbf{B} \cdot \hat{\mathbf{n}} = 0. \quad (33)$$

Only when $\hat{\mathbf{n}}$ precesses $\delta \mathbf{F}_L$ is no longer zero. The Einstein-Boyer-Rueda mechanism of acceleration of an electron in the ZPF is strongly reduced, since an electron with spin is only sensitive to the ZPF frequency roughly equal to its precession frequency. This mechanism can still justify the existence of the most energetic cosmic rays, but the acceleration requires some thousand (or million) light years in the intergalactic space. The quenching of the mechanism of acceleration due to the component $\mathbf{E}_r + (\mathbf{v}/c) \times \mathbf{B}_r$ in Eq.(22) also explains why good results for the atoms are obtained considering only the effect of \mathbf{E}_r . We have no longer the self-ionization of atoms.

We also overcome the impossibility of pure SED to explain the narrow spectral lines emitted (or absorbed) by gases. The new equation of motion strongly reduces the

random impulses due to radiation pressure of the ZPF, which would vanish in absence of $\hat{\mathbf{n}}$ precession. However, the torque of the extended orbit of spin and due to the atomic nucleus produces a precession of $\hat{\mathbf{n}}$. As a consequence, the ZPF exerts random impulses on the precessing spinning (or better gyrating) electron, which strongly perturbs the regular spiraling motion that there would be if only the classical radiation damping would be present. The actual motion is similar to a spiral-like trajectory with a superimposed rapid diffusion.

In other terms, while the classical spiraling motion requires $\sim 10^6$ revolutions to pass from an excited state (for instance the 2P state of an H atom) to the ground state (the 1S state for H), the rapid diffusion is such that the passage is accomplished in only $\sim 10^2$ revolutions. Consequently, on the average, the complete transition takes $n \sim 10^6/10^2 = 10^4$ passages from one state to the other. The Fourier transform of net radiated electric field is

$$\begin{aligned} \tilde{E}(\omega) &= \frac{1}{2\pi} \int_{-\infty}^{+\infty} dt E(t) \exp(-i\omega t) \\ &= \frac{1}{2\pi} \sum_{s=1}^{n-1} \int_{t_s}^{t_{s+1}} dt E(t) \exp(-i\omega t), \end{aligned} \quad (34)$$

where the time interval $t_2 - t_1$ corresponds to the first passage, and $t_n - t_{n-1}$ to the last passage. If we consider the Fourier transform corresponding to $t_2 - t_1$ only, we have a very wide spectrum, mainly contained between $\omega(2P)$ and $\omega(1S) = 8\omega(2P)$. This would be the spectrum according to pure SED. If we now include the other passages, between the two states, the Fourier transform at a given intermediate ω increases with a factor \sqrt{n} , because the different waves have differently distributed ω values and random phases.

On the contrary, the radiated field $\tilde{E}(\langle \omega \rangle)$, calculated in correspondence of the average value $\langle \omega \rangle$ of each passage, increases as n , because $\langle \omega \rangle$ changes very little between a passage and another passage. The ratio $\tilde{E}(\langle \omega \rangle) / \tilde{E}(\omega)$ is roughly $\sqrt{10^4} = 10^2$ in the considered example. In practice, $\tilde{E}(\langle \omega \rangle)$ is the only one observed, the others $\tilde{E}(\omega)$ being included in the background noise. Obviously, there is a Gaussian spread about $\langle \omega \rangle$, since the average value of each passage is slightly different from the others. But, if we consider \mathcal{N} atoms that radiate, the Fourier transform $\tilde{E}_{\text{tot}}(\omega)$ of all the radiated fields has a still sharper line around

$$\langle \omega \rangle_{\text{tot}} = \frac{1}{\mathcal{N}n} \sum_{s=1}^{\mathcal{N}} \sum_{i=1}^n \omega_{is}, \quad (35)$$

because it corresponds to $\mathcal{N}n$ passages.

By SEDS (SED with spin) it was possible to derive the Schroedinger equation for a single particle [16] and for many distinguishable particles [17], and the two papers have been positively commented in “*News and Views*” by the then director of *Nature* [18]. Then, a more elaborated derivation of the Schroedinger equation has been given

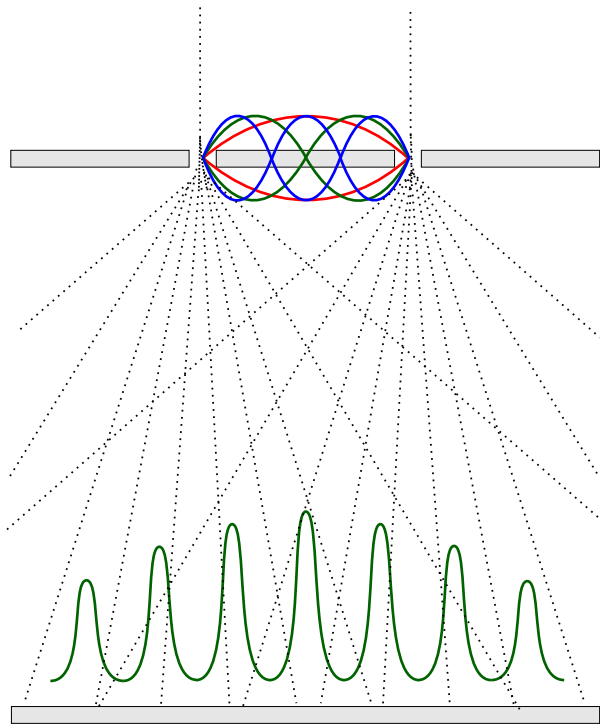


FIG. 6: The diffraction of electrons passing two slits is due to the ZPF modified by the conducting wall up to the plasma frequency of the metal.

[19], where additional, nonlinear terms have been added. The effect of the additional terms was shown to be a correction of $\sim 1\%$ to the Lamb shift [20].

Finally, we explain the diffraction of electrons passing two slits. The ZPF is modified by the conducting wall up to the plasma frequency of the metal (see Fig. 6). The Maxwell equations with $\mathbf{E} = \mathbf{0}$ on the walls and $\mathbf{E} \neq \mathbf{0}$ in correspondence of the slits give a spatial Fourier transform for the ZPF amplitude proportional to $(k_y b)^{-1} \sin(k_y b)$. The corresponding spatial distribution of the energy modes allowed by the slit is proportional to $(k_y b)^{-2} \sin^2(k_y b)$, with intensity maxima for

$$k_y = 0 \quad \text{and} \quad k_y b = \pi(n + 1/2), \quad \text{with} \quad n = 1, 2, 3, \dots \quad (36)$$

These are just the intensity maxima for a plane wave of either e.m. radiation or of a large beam of electrons, ac-

ording to QM. But why does an electron passing through the slit feels only these standing waves of the ZPF far from the slit walls?

The reason is that an electron approaching the walls has a precession of $\hat{\mathbf{n}}$ because of the charges induced on the edges of the slit which it is going to traverse [14]. Then the small range of frequency of the ZPF around the precession frequency ω_n of the electron spin gives a transversal impulse to the electron, expressed by

$$m \langle v_{\perp}^2 \rangle^{1/2} = \frac{\hbar \omega_n}{2c}. \quad (37)$$

If v is the speed of the electron, the consequent deviation is

$$\sin \vartheta = \frac{\langle v_{\perp}^2 \rangle^{1/2}}{v} = \frac{\hbar \omega_n}{2m v c}. \quad (38)$$

Now, ω_n depends on the distance r from the nearest edge and is therefore distributed from zero (for an electron passing through the middle of the slit) to a maximum large value when r is an atomic distance. Consequently, the intensity maxima are practically those of the ZPF, with the boundary constituted by the wall with the slit.

With the use of Eqs. (36) and (38), the intensity maxima are in correspondence of [14, 21]

$$\sin \vartheta_M = 0 \quad \text{and} \quad \sin \vartheta_M = \frac{\hbar \pi (n + 1/2)}{2b m v}, \quad (39)$$

with $n = 1, 2, 3, \dots$

Notice that our explanation holds even though the electron beam is focused on a single slit. On the contrary, in QM the interference term with the other slit should disappear [14, 21, 22]. A relevant experiment could therefore discriminate between QM and SEDS. That has been widely discussed in Ref. [22], where another possibility of discrimination is examined. It consists in performing the Young experiment with an isolating wall (where the two slits are obtained). In that case, even with an electron beam transversally large so as to include the two slits, there should be, according to SEDS, some modifications in the intensities of the peaks after the central one. In fact, the frequency part of the ZPF is not completely cancelled inside the wall (as it is if the wall was made of a conductor). But QM, not being based on the ZPF, makes no difference between either a conducting or an insulating wall.

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