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Self Interference of Single Electrodynamic Particle in Double Slit

J.X. Zheng-Johansson

Institute of Fundamental Physics Research, 611 93 Nyköping, Sweden

E-mail: `jxzj@iofpr.org`

Abstract. It is by the long established fact in experiment and theory that electromagnetic waves, here as one component of an IED particle, passing a double slit will undergo self inference each, producing at a detector plane fringed intensities. The wave generating point charge of a zero rest mass, as the other component of the particle, is maintained a constant energy and speed by a repeated radiation reabsorption/reemission scheme, and in turn steered in direction in its linear motion by the reflected radiation field, and will thereby travel to the detector along (one of) the optical path(s) of the waves leading to a bright interference fringe. We elucidate the process formally based on first principles solutions for the IED particle and known principles for wave-matter interaction.

1. Introduction

Since first hypothesised by L de Broglie in 1923[1], it has been overall experimentally demonstrated that all matter particles, like the electrons and atoms, classically pictured as point entities, manifest as also waves, referred to today as matter waves or quantum particles. These particles are capable of producing such wave effects as diffraction and interference entirely in the same way as the ordinary waves do. Overall experiments have subsequently corroborated that the matter waves formally are governed by quantum mechanics, pillared with the Schrödinger equation, or alternatively the Heisenberg equation, and the Dirac equations. Up to the present however it has remained as a basic open question as to what is waving with a matter wave (ψ). Regarding the nature of this wave, the current understanding has been formally rested on an assumption that the complex form of it, $\psi(x,t)$, specifies the physical state of a particle assumed being spatially a point, with $|\psi(x,t)|^2$ describing the probability of finding the particle at location x at time t. This in essence a "statistical point particle" picture has been successful in accounting for some of the basic properties of the quantum particles, in particular in predicting as eigen solutions the quantized dynamical quantities in direct agreement with experiments. This picture however encounters difficulties in accounting for certain other important properties, most notably the superposition, diffraction and interference, of the quantum-mechanical matter particles as well as "photons". The picture becomes paradoxical in the case of explaining the experimentally demonstrated single particle interference (see e.g. the recent reviews in [2, 3, 4]), most simply in a double slit, since a point particle is not capable of entering two slits at the same time. The incompleteness with the current understandings of the matter waves is commonly acknowledged.

From the standpoint of the general physics of particles, the (single) particle interference,

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or also the sometimes joined-in quantum entanglement, as we see, is only one of a range of unsolved "mysteries" in the realm of fundamental physics. By what scheme an electromagnetic radiation is upon absorption or emission converted to or from particle's mass, by a portion or as a whole? What is the origin of mass (m)? Why is mc^2, where c is the velocity of light, equal to the particle's total energy? Why do masses attract one another? And so forth. The eventual answers to these questions in a coherent theoretical framework would demand a realistic particle scheme, or model. Such basic properties of particles as mass, total energy and wave function we know today are each dependent on the particle's motion and these in turn are convertible to and from electromagnetic radiation. This is to say that, the basic particle properties and their relations are interrelated in a dynamical context. A particle scheme or model can not be an ultimate one which facilitates the predictions of some and yet not the overall fundamental properties of particles.

Stemmed from general considerations as underlined above, the author developed in [5a-l] an internally electrodynamic (IED) particle model, which briefly states that *a single-charged material particle, like the electron, proton, etc., is constituted of (i) an oscillatory point charge q (as source) with a characteristic frequency Ω and zero rest mass, and (ii) the electromagnetic waves generated by the charge.* See further a formal outline in Sec. 2. The IED process is governed by a minimal set of well established basic, or first principles laws (for a recent review see e.g. [4], [5j]). A range of basic properties and relations for particles have become predictable in terms the first principle's solutions for the IED process under corresponding conditions; solutions already obtained by the author include those reported in [5a-l]. Based on first principles solutions for the IED particle and the known principles for wave-matter interaction, we formally elucidate in this paper that the IED particle will naturally undergo self-interference in a double slit with a scheme already built-in with the IED process.

2. Wave equations, solutions for IED particle in three dimensions

Consider that a charge q of a zero rest mass and having an initial free-charge kinetic energy ε_q (hence a dynamical inertia) is inserted at position $\mathbf{R}_q$ in the vacuum to which we attach three Cartesian coordinates X, Y, Z. Owing to ε_q, the charge is spontaneously driven into an oscillation (following a mechanical scheme elucidated e.g. in [5j]) of a characteristic frequency Ω, of displacement $\mathbf{u}_q = u_q \hat{u}_q$ along a $\hat{u}_q$ axis about $\mathbf{R}_q(X_q, Y_q, Z_q)$, and in addition, a uniform translation at velocity v in the $+X$-direction. In view of the general validity of the Maxwell's equations for the resulting waves below, u_q may be judged as relatively small and thus has the usual sinusoidal solution (see e.g. [5j]), assuming zero applied force, $u_q(t) = A_q \sin(\Omega t + \alpha)$, with A_q the amplitude and α initial phase. The orientation of $\mathbf{u}_q$, $\hat{u}_q$, may change with time under the influence of random environmental and/or applied fields.

Suppose for the present that during a time δt_1, $\hat{u}_q$ is along the Z-axis; $u_q = Z'_q - Z_q$. Owing to its accelerated motion u_q, the charge generates electromagnetic waves of electric fields $\mathbf{E}^j(\mathbf{r}, t)$'s and magnetic fields $\mathbf{B}^j(\mathbf{r}, t)$'s as propagated to position $\mathbf{r}(x, y, z) = \mathbf{R}(X, Y, Z) - \mathbf{R}_q$ in time $t = r/c$, c being the velocity of light and j indicating a source motion effect. The fields are described by the Maxwell's equations given for a specified j, in regions excluding the charge q and assuming no other charge and current, as $\boldsymbol{\nabla} \cdot \mathbf{E}^j = 0$, $\boldsymbol{\nabla} \cdot \mathbf{B}^j = 0$, $\boldsymbol{\nabla} \times \mathbf{B}^j = 0 + \frac{1}{c^2}\partial_t \mathbf{E}^j$, $\boldsymbol{\nabla} \times \mathbf{E}^j = -\partial_t \mathbf{B}^j$. These lead to a wave equation for a jth component wave, denoting for brevity by a dimensionless wave displacement $\varphi^j \hat{\theta} = \mathbf{E}^j / E_q$ in the transverse $\hat{\theta}$ direction, and a corresponding equation for the total wave $\psi = \sum_j \varphi^j$,

$$\partial_t^2 \varphi^j = c^2 \nabla \varphi^j \quad (a), \quad \partial_t^2 \psi = c^2 \nabla \psi \quad (b) \tag{1}$$

The travelling oscillatory charge q and the electromagnetic waves E^j, B^j's, or φ^j's which are continuously generated and therefore in general extend a wave train, make up our extensive IED particle, with the prefix "extensive" unless for emphasis omitted hereafter.

For $\upsilon < c$ (or $<< c$) holds ordinarily, there thus ordinarily exists a brief yet finite time interval δt in which the charge is essentially standing still, at X_q, on the X axis, for which α is a fixed value. So except for a source motion effect indicated by j, the solutions to the Maxwell's equations are of the usual form $E^j = E_q \varphi^j$, where $E_q \doteq \frac{\mu_0 q \omega^2 A_q}{4\pi}$, with $\omega \doteq \omega^j$, and

$$\varphi^\dagger = \tfrac{1}{2}\mathcal{C}_0 \sin(k_p^\dagger r - \omega_p^\dagger t + \alpha), \quad \varphi^\ddagger = -\tfrac{1}{2}\mathcal{C}_0 \sin(k_p^\ddagger r + \omega_p^\ddagger t - \alpha), \quad \text{with } \mathcal{C}_0 = C_0 \sin\theta / r, \tag{2}$$

are two opposite travelling plane waves in the $+r$- ($j = \dagger$) and $-r$- ($j = \ddagger$) directions along a certain radial path $\mathbf{r}(r, \theta, \phi)$ in spherical polar coordinates r, θ, ϕ. In these, $k_p^j = \gamma_p^j K, \omega_p^j = k_p^j c = \gamma_p^j \Omega$ are the Doppler displaced wavevectors and frequencies due to the source motion, with $\gamma_p^\dagger = \frac{1}{1-\upsilon_p/c}, \gamma_p^\ddagger = \frac{1}{1+\upsilon_p/c}$, $\Omega = Kc$, and $\upsilon_p = \upsilon \sin\theta \cos\phi$ being the component velocity of charge q in the $+r$-direction; C_0 is a normalization constant.

Let the IED particle be confined as in later applications between two massive, non absorbing vertical walls here separated at a distance L_ν along the X axis. Its waves φ^j's will travel up to the walls, be reflected, reabsorbed by the charge, partially and most probably after a two-way reflection owing to detailed resonance, and then reemitted, repeatedly, thereby maintaining a constant total energy (ε_{tot}) of the charge and wave system. If the charge has not emitted any radiation, then $\varepsilon_{tot} = \varepsilon_q$. If the charge has emitted its entire ε_q into electromagnetic waves of a mean total length $L_\varphi = \sqrt{L_\varphi^\dagger L_\varphi^\ddagger}$, of a total wave energy $\varepsilon (\equiv \varepsilon_q)$, then $\varepsilon_{tot} = \varepsilon$. In representing a realistic extensive particle able to produce interference at the scale L_ν, L_φ would wind about L_ν in a large $\frac{J_\nu}{2} = \frac{L_\varphi}{2L_\nu}$ number of loops. For this extensive IED particle, there will ordinarily be a portion a_1 of ε_{tot} conveyed by the charge and a_2 by the wave, $a_1, a_2 \leq 1$, and $\varepsilon_{tot} = a_1 \varepsilon_q + \alpha_2 \varepsilon$. For the IED particle in stationary state mainly of our concern later, the rates of emission α^{em}, absorption α^{ab}, and transmission α^{tr} by or passing q need further be in equilibrium, $\alpha^{ab} = \alpha^{tr} + \alpha^{em}$.

At any point on a radial path r in $(0, L_\nu)$ there will thus simultaneously prevail the opposite travelling $\varphi^\dagger$ and $\varphi^\ddagger$, newly generated or reflected after round trips, of the IED particle. These superpose into a partial total wave $\psi = \varphi^\dagger + \varphi^\ddagger$, given after direct algebraic operations in complex form as

$$\psi(r, \theta, t)|_{k_{dp}} = \Phi f, \quad \Phi = e^{i[(K + (\frac{\upsilon_p}{c})k_{dp})r - (\frac{\upsilon_p}{c})\omega_p t]}, \quad f = \mathcal{C}_0 e^{i[k_{dp} r - \omega_p t + \alpha_0]}, \tag{3}$$

where $\alpha_0 = \alpha - \frac{\pi}{2}$, $\frac{1}{2}(k_p^\dagger - (-k_p^\ddagger)) = K + \gamma_p \frac{\upsilon_p}{c} k_{dp}$, $\frac{1}{2}(\omega_p^\dagger - \omega_p^\ddagger) = \gamma_p (\frac{\upsilon_p}{c})\omega_p \doteq \frac{\upsilon_p}{c}\omega_p$, $\frac{1}{2}(k_p^\dagger + (-k_p^\ddagger)) = \gamma_p k_{dp} \doteq k_{dp} = \sqrt{(k_p^\dagger - K)(K - k_p^\ddagger)}$, $\frac{1}{2}(\omega_p^\dagger + \omega_p^\ddagger) = \gamma_p \omega_p \doteq \omega_p = \sqrt{\omega_p^\dagger \omega_p^\ddagger}$, with the geometric means being alternative expressions; $\gamma_p = \sqrt{\gamma_p^\dagger \gamma_p^\ddagger} = 1/\sqrt{1 - \upsilon_p^2/c^2}$ or $\gamma_p^2 = 1 + \gamma_p^2(\upsilon_p^2/c^2)$; and

$$k_{dp} = (\gamma_p/\gamma)(\upsilon_p/\upsilon)k_d, \quad k_d = \gamma(\upsilon/c)K, \quad \omega_p = (\gamma_p/\gamma)\omega, \quad \omega = \gamma\Omega, \tag{4}$$

and $\gamma = 1/\sqrt{1 - \upsilon^2/c^2}$. ψ travels in the $+r$-direction at a phase velocity $W_{pp} = \frac{\omega_p^\dagger + \omega_p^\ddagger}{k_p^\dagger + (-k_p^\ddagger)} = \frac{\omega_p}{k_{dp}}$ and group velocity $W_{gp} = \frac{\omega_p^\dagger - \omega_p^\ddagger}{k_p^\dagger - (-k_p^\ddagger)} = \frac{(\upsilon_p/c)\omega_p}{K + (\upsilon_p/c)k_{dp}}$, or

$$W_{pp} = W_p / \sin\theta\cos\phi, \quad W_p = c^2/\upsilon, \quad W_{gp} \doteq \upsilon_p = W_g \sin\theta \cos\phi, \quad W_g = \upsilon. \tag{5}$$

The ψ due directly to the moving source above is seen each r, θ-dependent, or, "polar spherical".

The electromagnetic waves have in terms of the total field $E_q\psi$ an energy density of the usual form $\varepsilon_0 = \epsilon_0 E_q^2 |\psi|^2$, which is transported at the speed of the φ^j waves, $\omega^\dagger/k^\dagger = \omega^\ddagger/k^\ddagger = c$. The intensity of the total wave in relative terms is therefore

$$I(r, \theta) = c\varepsilon_0 / c\epsilon_0 E_q^2 = |\psi|^2 = \mathcal{C}_0{}^2. \tag{6}$$

The ε_0 integrated over total solid angle 4π is $\varepsilon_{0x} = \int_{4\pi} \varepsilon_0 d\tilde{\Omega} = \epsilon_0 E_q'^2 |\psi_x|^2$ where $d\tilde{\Omega} = \sin^2\theta d\theta d\phi$, $E_q' = \frac{2\sqrt{\pi}}{\sqrt{3}} E_q$, and $\psi_x = C_0 e^{i[k_d x - \omega t + \alpha_0]}$ is an apparent plane wave along the X-axis by which ε_{0x}, being a constant, is effectively transported. Along the X-axis $\theta = \frac{\pi}{2}, \phi = 0$, the $\mathcal{C}_0 (= C_0/x)$ and I are a maximum each, $\psi = \psi_x/x$, and the wave variables k_d, ω describe the dynamics of the mass center of the total ψ and hence the IED particle. The X-axis therefore represents a symmetry axis of ψ. The total wave energy across the full wave train $L_\varphi (= J_\nu L_\nu)$ is $\varepsilon = J_\nu \int_0^{L_\nu} \varepsilon_{0x} dx = L_\varphi \epsilon_0 E_q'^2$ provided with the normalisation $\int_0^{L_\nu} |\psi_x|^2 dx = 1$ and thus $C_0 = 1/\sqrt{L_\nu}$. $p = \varepsilon/c$ gives the total linear momentum.

Alternatively, employing the Planck energy equation for the ψ of a frequency ω, and in turn Newtonian kinetic energy equation for the wave train of ψ which travels rectilinearly at the finite velocity c and accordingly has a finite inertial mass m, we may write down $\varepsilon = \hbar\omega = mc^2$; and $p (= \varepsilon/c) = \hbar k = mc$ (see e.g. [5a,c,e] for a detailed account). Making the expansion $\omega (= \gamma\Omega) = \Omega + \varpi_d$ where $\varpi_d [= (1 + \frac{3}{4}\frac{\upsilon^2}{c^2} + \ldots)\frac{1}{2}(\frac{\upsilon^2}{c^2})\Omega]$, with $\mathcal{E} = \lim_{\upsilon^2/c^2 \to 0} \varepsilon = \hbar\Omega$ and $P = \lim_{\upsilon^2/c^2 \to 0} p = \hbar K$, the differences $\varepsilon_\upsilon (\doteq \frac{1}{2} m\upsilon^2) = \varepsilon - \mathcal{E}$ and $p_\upsilon (\equiv m\upsilon) = \sqrt{p^2 - P^2}$ thus give the kinetic energy and linear momentum of the IED particle. These further lead to $M^2 c^4 + p_\upsilon^2 c^2 = \varepsilon^2$ and the corresponding de Broglie relations

$$\tfrac{1}{2} m\upsilon^2 = \hbar\varpi_d, \quad m\upsilon = \hbar k_d. \tag{7}$$

ψ thus follows to represent a de Broglie phase wave and reduces to a de Broglie wave Ψ (Sec. 4) at a thermal k_d scale, each being polar-spherical. More generally, at the scale k_d equation (1b) reduces to a Schrödinger equation describing the kinetic motion of the particle[5c,j].

From the above follows that $K = Mc/\hbar >> k_d$ holds ordinarily, with $M = \lim_{\upsilon^2/c^2 \to 0} m$ the particle's rest mass. The diffraction and interference effects to be dealt with later will be at the scale k_d, with $\lambda_d = 2\pi/k_d$ the de Broglie wavelength, for which $\Phi \doteq 1$, $\psi \doteq f = \mathcal{C}_0 e^{i[k_{dp} r - \omega_p t + \alpha_0]}$.

3. Optical path of ψ through a double slit. Interference fringes

Suppose that the ψ above, re-denoting now by $\psi(r', \theta', t')$, is first let strike on to an opaque screen D_1 with a narrow slit A of width b, with $b \sim \lambda_d$, at distance x' from q, see Fig. 1a. An effectively plane wave, of a fraction g_A of the integral intensity ($I_{4\pi} = \int_{4\pi} I d\tilde{\Omega}$), only will enter the narrow slit, given by setting $r' = x'$ and $\theta' = \frac{\pi}{2}$ in (3) as $\psi(x', t') = \frac{C_A}{x'} e^{i(k_d x' - \omega t' + \alpha_0)}$, where $C_A = \sqrt{g_A} C_0$. Along the b, the incident $\psi(x', t')$ may be as in the usual approach thought as if regenerated from many (N) small divisions of a width $ds = b/N$ each, into a new wave $\psi_s(r_s'', \theta_s'', t'') = \mathcal{C}_0 e^{[k_d r_s'' - \omega t'' + \alpha_A]}$ along a radial path $r_s'' = r'' + s \sin\beta''$ joining a ds at a vertical distance s from the slit center A to a point P_2 on an image plane D_2, with $r'' = AP_2$ and $\beta'' = \frac{\pi}{2} - \theta''$; $\alpha_A = \alpha_0 + k_d x_A' - \omega t_A$. The total diffracted de Broglie phase wave from b arriving at P_2 at a later time t'', for N being large and x' assumed for illustration large, is given by

$$\psi(r'', \theta'', t'')|_{k_d} = \int_{\frac{-b}{2}}^{\frac{b}{2}} \psi_s(r_s'', \theta_s'', t) ds = \mathcal{C}_A e^{i(k_d r'' - \omega t'' + \alpha_A)}, \quad \mathcal{C}_A(\theta'') = \frac{b\sqrt{g_A} C_0 \sin\eta''}{x'\eta''} \tag{8}$$

$\eta'' = \frac{\pi b \sin\beta''}{\lambda_d}$. ψ has the phase and group velocities W_p and W_g as of $\psi(x', t')$, and an intensity as given after (6) for $\mathcal{C}_A$ here, $I(\theta'') = \mathcal{C}_A^2(\theta'')$.

Let the D_2 above be an opaque screen containing two narrow slits B, C similarly of a width b each, as in Fig. 1a; and the $\psi(r'', \theta'', t'')$ given by (8), regenerated at A at time $t_0'' = 0$, is incident on D_2. Two of its partial components travelling along the equidistant radial paths $r'' = AB$ and AC at angles $\theta'' = \theta_{AB}$ and θ_{AC} to the Z axis, and of a fraction $g_B = g_C$ of total intensity each, $\psi(AB, \theta_{AB}, t'')$ and $\psi(AC, \theta_{AC}, t'')$ will at a later time t'' $(= AB/c)$ simultaneously arrive at B and C; here they have an identical amplitude $\mathcal{C}_A$ and initial phase α_A. By the standard

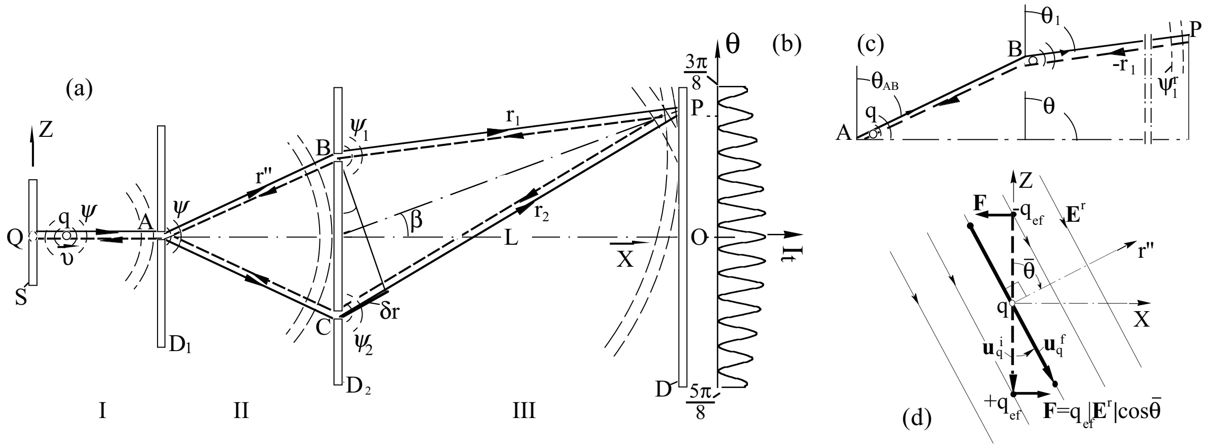

Figure 1. (a) The total electromagnetic wave ψ generated by travelling oscillatory charge q, with ψ, q making up an IED particle, travels through a single slit A and double slits B, C to detector D. (b) Intensity I_t (in units of $1/\mathcal{C}_{B0}$) of wave ψ_t on D calculated from (10) for $b = 1, \lambda_d = 0.5, \ell = 4$, showing two-slit interference fringes. (c) Charge q travels at velocity υ statistically along one optical wave path $(Q)qABP$ through the double-slit up to D. (d) The effective dipole charges $+q_{\rm ef}, -q_{\rm ef}$ associated with the initial displacement $\mathbf{u}_q^{\rm i}$ of q along the Z direction, as at slit A, are acted on a torque $\mathbf{F} \times \mathbf{u}_q$ by the reflected field $\mathbf{E}^{\rm r}$ and turned into aligned with the $\mathbf{E}^{\rm r}$, in the $\bar{\theta}$ direction, with a final $\mathbf{u}_q^{\rm f}$.

notion we know that each electromagnetic wave φ^j will on passing the two slits undergo self interference. The formal conditions for this for the specific de Broglie phase wave ψ here are written down as follows.

The two slits B, C, as two new coherent sources, then regenerate at time $t_0 = 0$ the respective incident waves into two new spherical waves given at location r time t as $\psi_1 = \mathcal{C}_1 e^{i(k_d r_1 - \omega t + \alpha_B)}, \psi_2 = \mathcal{C}_2 e^{i(k_d r_2 - \omega t + \alpha_B)}$ in region III similarly as given by (8), where $\mathcal{C}_i = \mathcal{C}_{B0}\frac{\sin\eta_i}{\eta_i}$, with $i = 1, 2$, $\mathcal{C}_{B0} = \frac{b\sqrt{g_B g_A} C_0}{r''}$, $\eta_i = \frac{\pi b \sin\beta_i}{\lambda_d}$, $\beta_i = \frac{\pi}{2} - \theta_i$. Let at distance L apart in front of D_2 be placed a detector D, and P be a point on D as in Fig. 1a. Two respective partial components of ψ_1, ψ_2 travelling along paths $r_1 = BP, r_2 = CP$ at angles θ_1, θ_2 to the Z-axis, will at a later time t arrive at P, superposing linearly as $\psi_t = \psi_1 + \psi_2$. Assuming as in usual applications $L >> BC$, so for the amplitudes, the two paths r_1,r_2 can be approximated as parallel to each other, of an average distance $r = \frac{1}{2}(r_1 + r_2)$ and angle $\theta = \frac{1}{2}(\theta_1 + \theta_2)$; thus $\mathcal{C}_i \doteq \mathcal{C} = \mathcal{C}_{B0}\sin\eta/\eta$, with $\eta = \pi b \sin\beta/\lambda_d$, $\beta = \frac{\pi}{2} - \theta$. For the phase constants the difference between the optical paths, $\delta r = r_1 - r_2$, yet is nontrivial. Incorporating the foregoing, the summation for ψ_t is algebraically given as

$$\psi_t = \mathcal{C}_t(\delta r) e^{i(k_d r - \omega t + \alpha_B)}, \quad \mathcal{C}_t(\delta r) = 2\mathcal{C}\cos[\tfrac{1}{2}k_d \delta r]. \tag{9}$$

ψ_t, or the field $\mathbf{E}_t = E_q \psi_t \hat{\theta}$ has a relative intensity given similarly as (6) as $I_t = \frac{c\epsilon_0 E_q^2 |\psi_t|^2}{c\epsilon_0 E_q^2}$, or

$$I_t = |\psi_t|^2 = |\psi_1 + \psi_2|^2 = \mathcal{C}_t^2(\delta r) = 4(|\psi_1|^2 + |\psi_2|^2)\cos^2(\tfrac{1}{2}k_d \delta r) \tag{10}$$

where $|\psi_i|^2 = \frac{1}{2}\mathcal{C}^2$, $i = 1, 2$. Now,

$$\text{if} \quad \delta r = 2n\pi/k_d = n\lambda_d, \quad n = 0, 1, 2, \ldots, \quad \text{then} \quad |\mathcal{C}_t(\delta r)| = 2\mathcal{C}, \quad I_t = 4\mathcal{C}^2 \tag{11}$$

are maxima, yielding bright fringes (peaks in Fig. 1b) at distances $PO = L\tan\beta \doteq L\frac{\delta r}{\ell} = n\lambda_d L/\ell$ from O, where $\ell = BC$. Or, if $\delta r = (n + \frac{1}{2})\lambda_d$, then $\mathcal{C}_t(\delta r) = I_t = 0$ yielding dark fringes at distances $PO = (n + \frac{1}{2})\lambda_d L/\ell$ from O on D.

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4. Reflection wave path

A wave ψ (as ψ_1 or ψ_2 here) striking at the detector D, assumed massive and not yet actualised a permanent absorption, will be scattered or reflected back from D, as $\psi^{\rm r}$. In determining the reflection paths, the following basic principles of electrodynamics and wave mechanics (a-c) apply: (a) The scattering of ψ by a scatterer at P may be regarded as a temporary absorption of ψ by the scatterer, and then remission. (b) The amplitude of the absorption will be large if ψ and the scatterer are (nearly) in resonance, or small or zero if otherwise. (c) The orientation of the symmetry axis of $\psi^{\rm r}$ is determined by (c.1) the total linear momentum $p' = \hbar k' = mc'$ of $\psi^{\rm r}$ [after solutions to (1)] and in addition, (c.2) the path which requires the least action (the principle of least action). (d) For elucidating the mechanical scheme for the scattering of ψ in vacuum here, a physical vacuum becomes indispensable which is proposed in [5a,g-h] based on overall experiments as composed of electrically polarisable vacuuons.

For the ψ, vacuum and a massive wall D here we concretely find: (4.1): With the $\omega = \Omega + \varpi_d$ earlier, thus $\psi = \Theta\Psi$, $\Theta = \Phi e^{-i\Omega t}$, $\Psi = \mathcal{C} e^{i[k_d r - \varpi_d t + \alpha_B]}$. This ψ may on the basis of (a)-(b) be scattered separately as Θ and Ψ by distinct scatterers. The scatterer can only be a vacuuon (Fig. 2a-b) for ψ (or Θ alone), whose frequency, ω (or Ω) of the scale of the particle's mass, is too high to be (temporarily) absorbed by a material particle. For Ψ of a thermal frequency ϖ_d, the scatterer may be a material particle, as illustrated in Fig. 2c for a free electron in the wall of a metallic surface. (4.2): The vacuuons will be polarised by the presence of q or also by the passing of ψ, and additionally, when in their proximities by the nuclear charges comprising the wall; they are thereby coupled with each other and in turn to the wall bulk (Fig. 2a). So when

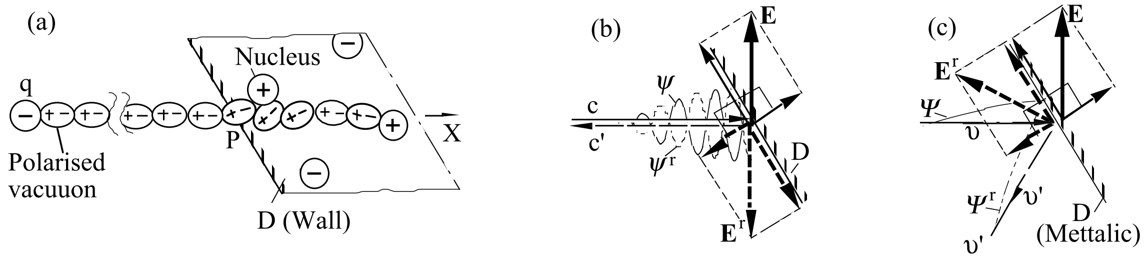

Figure 2. (a) Vacuuons comprising the vacuum are polarised about the charge q of an IED particle, and near P at a massive wall D in turn also by the mutually bound nuclear charges in the wall. (b) Reciprocal reflection of ψ by D. (c) Mirror reflection of Ψ by D.

ψ is incident onto the wall, its field $\mathbf{E}$ acts on a vacuuon scatterer *of an effective charge q_p) at the wall surface a force $\mathbf{F}(= q_p\mathbf{E})$, opposite to which the massive wall acts back a force $\mathbf{F}^{\rm r} = -\mathbf{F}$ (Newton's third law). This gives a reciprocal reflection of ψ, into $\psi^{\rm r}$ of a linear momentum $mc' = -mc$ (Fig. 2b). (4.3): For the ψ_t of (9) striking on D, its reflected wave $\psi_t^{\rm r}$, will be determined by (4.2) to have a linear momentum in the reciprocal $-r$ direction and, while this being met, will however practically choose to retrace along the two separate reciprocal paths $-r_1, -r_2$ that are already (continuously) stretched by the incident waves and thus require a least action. The optical reflection paths for ψ_t from D are therefore for large L equal probably $PBAqQ$ and $PCAqQ$ (Fig. 1a, dashed lines). The reflection "wall" S on the left may in real applications be a particle beam injection "gun"; its mid point Q serves as a virtual source.

5. Motion of q through double slit

Provided that no permanent emission of radiation occurs on its way, the point charge q will, by the repeated radiation reabsorption/reemission scheme (Sec. 2), travel across the double slit. The charge motion in region I is straightforward, and through regions II-III (Fig. 1c) involves re-directions of its linear velocity by the reflected fields. We elucidate the latter process and the physics involved below.

On arriving at the slit A (Fig. 1c), at initial time the charge has a velocity v and symmetry axis in the $+X$-direction, and a $\mathbf{u}_q^{\mathrm{i}}$ and radiation field $\mathbf{E}^{\mathrm{i}}$ which are according to (6) invariably along the transverse, Z- direction. During a dwelling time δt here it will continuously generate radiation field and in turn be met by the reflected field $\mathbf{E}^{\mathrm{r}}$ from either side. By origin of electric field production in general, the field here immediately due to the $\mathbf{u}_q^{\mathrm{i}} = u_q \hat{u}_q'$ at A, $\mathbf{E}^{\mathrm{i}} = \frac{E_q}{A_q}\mathbf{u}_q^{\mathrm{i}}$, may be thought as produced between two effective dipole charges $+q_{\mathrm{ef}}, -q_{\mathrm{ef}}$ separated at a distance $\mathbf{u}_q^{\mathrm{i}}$ pivoted about q (Fig. 1d). So, due to a $\mathbf{E}^{\mathrm{r}}$ in a certain $\bar{\theta}$- direction the two dipole charges will be acted by two forces $+\mathbf{F}, -\mathbf{F} = q_{\mathrm{ef}} E^{\mathrm{r}} \cos\bar{\theta}$, hence a torque $\boldsymbol{\tau} = \mathbf{u}_q^{\mathrm{i}} \times \mathbf{F} = \boldsymbol{\mu}_{q_{\mathrm{ef}}} \times \mathbf{E}^{\mathrm{r}}$, with $\boldsymbol{\mu}_{q_{\mathrm{ef}}} = q_{\mathrm{ef}} \mathbf{u}_{\mathbf{q}}^{\mathrm{i}}$, until after an relaxation time δt_1, its axis $\hat{u}_q{}'$ is turned into $\mathbf{u}^{\mathrm{f}} = u_q \hat{u}_q''$ in $\bar{\theta}$-direction (Fig. 1b). (We may comprehend the microscopic physics as that, the vacuum is a dielectric[5] and is produced with a polarization $\mathbf{P}_{\mathrm{v}}$ about q for q at each fixed position, and an altered $\mathbf{P}_{\mathrm{v}}$ on deformation due to $\mathbf{u}_q^{\mathrm{i}}$, hence the $+q_{\mathrm{ef}}, -q_{\mathrm{ef}}$, and in turn due to the $\mathbf{E}^{\mathrm{r}}$; the latter passes on no energy but a turn in the dipole axis only.) Accordingly, the charge will then be (re-)directed to travel along the radial path r'' perpendicular to $\mathbf{u}_q^{\mathrm{f}}$.

In practice, ψ^{r} is reflected from all $\bar{r}$-directions, and thus with a $\mathbf{E}^{\mathrm{r}}$ in all $\bar{\theta}$-directions in a statistical manner; $|\mathbf{E}^{\mathrm{r}}|$ also varies with time. The probability for $\mathbf{u}_q^{\mathrm{i}}$ to be turned to a $\mathbf{u}_q^{\mathrm{f}}$ parallel with a particular $\mathbf{E}^{\mathrm{r}}(\bar{r}, \bar{\theta}, t'')$ is apparently in direct proportion to the intensity of $\mathbf{E}^{\mathrm{r}}$, $I(\bar{\theta})$ given in (6); with ψ of (8) in it here we have $\mathcal{P}(\bar{\theta}) = |\psi^{\mathrm{r}}(0, \bar{\theta}, t'')|^2 = \mathcal{C}_A^2(\bar{\theta})$. We suppose in the following that, by a probability $\mathcal{P}(\theta_{AB})$, the charge q at A has been re-directed to travel in the AB- direction and $\hat{u}_q{}''$ along the transverse θ_{AB}-direction, and at a later time t'' enters B as in Fig. 1d.

Similarly, at B the charge, with an initial $\mathbf{u}_q^{\mathrm{i}}$ in the θ_{AB} direction, is statistically subject to a torque due to a certain reflected field, which according to (4.4) is a projection of a total $\mathbf{E}_t^{\mathrm{r}}$ onto $\bar{\theta} = \theta_1$ or θ_2 perpendicular to $\bar{r} = -r_1$ or $-r_2$. Particularly here, $\mathbf{E}_t^{\mathrm{r}}$, as the incident $\mathbf{E}_t (= E_q \psi_t \hat{\theta})$, has peaked intensities $I_t^{\mathrm{r}}(\bar{\theta}) = I_t(\theta)$ given by (11); and its projection on θ_i, with $i = 1, 2$, is $I_1^{\mathrm{r}}(\bar{\theta}_i) = \frac{1}{2} I_t^{\mathrm{r}}(\bar{\theta})$ following from the effectively symmetric geometry of P relative to B, C for large L in region III, and $I(\theta''_{AB}) = I(\theta''_{AC})$ in region II. The probability for $\hat{u}_q{}''$ to be turned to $\hat{u}_q$ parallel with $\bar{\theta}_i = \theta_i$- direction perpendicular to $\bar{r}_i = -r_i$, $i = 1$ or 2, in an individual measurement is thus given by

$$\mathcal{P}_i(\theta_i) = \tfrac{1}{2}\mathcal{P}_t(\theta) = \tfrac{1}{2}(|\psi_1|^2 + |\psi_2|^2) 4\cos^2(\tfrac{1}{2}k_d \delta r) = \tfrac{1}{2}|\psi_1 + \psi_2|^2, \quad i = 1, 2. \tag{12}$$

(12) implies that, in each individual measurement the point charge q has definitely, equally probably travelled through either slit B or C before striking on D. The detection signal produced directly by the striking of q however does not inform which slit is passed by q. A determination of which slit can be prevented, not in principle but in common practice. If for example one attempts to determine which slit by blocking one of the two, say C, then the intensities of the incident and reflected waves and of the so navigated q will each be of a pattern of single-slit diffraction. This feature has been well demonstrated in matter-wave double-slit experiments.

A detection signal at D may be directly due to the impingement of q or ψ_t (in the latter case the slow moving q may not have entered D), of an identical intensity I_t given by (10) or (12). Either will inform the self interference of the IED particle. From either (10) or (12), the two probabilities $|\psi_1|^2, |\psi_2|^2$ for the single particle passing two slits add up to the total I_t in the manner of $|\psi_1 + \psi_2|^2$, and not $|\psi_1|^2 + |\psi_2|^2$. This predicts an important characteristics of quantum probability as has been demonstrated by overall matter-wave interference experiments. This way how the intensities add up is completely the same as how the intensities of an elastic or light wave add up; and we have in fact just obtained (10) naturally for the IED particle for its constituent electromagnetic waves φ^j's, or "light" rays of far-above ultra violet frequencies.

An incident IED particle with a low enough energy will knock a point-like absorber in D into excitation of one energy quantum $\hbar\varpi_d$ at a time, producing a detection signal appearing as a

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spatial point on the D plane. When this is directly due to a (thermal) absorption of the extensive (Ψ off from) ψ), we can think of the wave as (conveying) an energy flux and its each wave front as an equi-energy surface S. An energy will first of all be transported to P longitudinally through the propagation of ψ at the speed c. In the meantime, a sudden drop of energy at P (upon onset of excitation) creates an energy potential against other points on the S intersecting with P, driving therefore a lateral energy flow toward P at a speed which may be expected to be high since no time is wasted in undulation.

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