Internally Electrodynamic Particle Model: Its Experimental Basis and Its Predictions

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The internally electrodynamic (IED) particle model was derived based on overall experimental observations, with the IED process itself being built directly on three experimental facts that, a) electric charges present with all material particles, b) an accelerated charge generates electromagnetic waves according to Maxwell’s equations and the Planck energy equation and c) source motion produces Doppler effect. A set of well-known basic particle equations and properties become predictable based on first principles solutions for the IED process; several key solutions achieved are outlined, including the de Broglie phase wave, de Broglie relations, Schrödinger equation, mass, Einstein mass-energy relation, Newton’s law of gravity, single particle self interference, and electromagnetic radiation and absorption; these equations and properties have long been broadly experimentally validated or demonstrated. A conditioned solution also predicts the Doebner-Goldin equation which emerges to represent a form of long-sought quantum wave equation including gravity. A critical review of the key experiments is given which suggests that the IED process underlies the basic particle equations and properties not just sufficiently but also necessarily. (Appeared in: Physics of Atomic Nuclei, 2010, Vol 73, No 3, pp.571-581.)

1. Open questions. The need for a comprehensive particle model

It is well established today that all material particles exhibit a dual wave and particle property, hence described as matter waves, and their motions at quantum scale are governed by the Schrödinger, or alternatively the Heisenberg, and the Dirac equations in the respective velocity regimes. We are also faced today with a range of open questions regarding particles in the realm of fundamental physics. What is waving with the matter wave (ψ) which also dually manifests as a particle? How does a particle interfere with itself say in a double-slit? How is an electromagnetic wave on absorption converted to a portion or the whole of the mass or energy of a particle, and conversely on emission? What is the origin of mass? Why do masses attract one another? How does the gravity enter quantum wave equation? And so forth.

The ultimate answers to the questions inevitably are intimately interconnected. For example, one can not have answered what is waving without answering at the same time how mass enters
in what is waving. The "wave", "relativistic mass", etc. are all quantities in a dynamic domain where a basic rule for all is therefore the consistency in energy, or energy conservation. From an a priori energy consideration we recognize that the matter wave $\psi$ must represent an internal degree of freedom of a particle. In other terms, the waving of $\psi$ can not be the waving of the mass ($m$) of the particle; if it were, the particle would have an excess mechanical energy $m\dot{\psi}^2$ which we know it has not. To answer the various questions we inevitably need a more comprehensive particle model than, approximately speaking, a statistical point particle picture with a given-for-granted mass.

2. The IED particle model: The direct experimental basis

Based on overall experimental observations as input information the author recently developed an internally electrodynamic (IED) particle model [1–10] (earlier termed a basic particle formation scheme) which briefly states: A single-charged material particle, like the electron, proton, etc., is constituted of (i) an oscillatory point charge $q$ of a characteristic frequency $\Omega$ and zero rest-mass, and (ii) the electromagnetic waves generated by the charge and propagated between the charge and reflecting boundaries (Fig.1a). The waves will be subject to a Doppler effect if the oscillatory charge as a whole, the source, is in motion; $q$ is an electric charge in the usual electromagnetic sense and thus obeys the basic laws of electrodynamics; the total energy of the oscillatory charge or equivalently of the electromagnetic waves is associated with a (dynamical) inertial mass obeying the usual laws of mechanics. When going down to a deeper level so as to address the mechanical basis for charge oscillation, the origin of mass, etc., the vacuum is represented as a substantial vacuonic medium, and the charge moving in it will be resisted by a medium force to identify with the usual inertial force.

The IED process is itself built on the experimental facts embedded in the set of established basic laws: (a) all material particles consist of finite amounts of electric charges with accordingly defined spins [11]; (b) an accelerated charge generates electromagnetic waves of electric and magnetic fields $E^j$ and $B^j$ ($j = \dagger, \ddagger$) according to Maxwell’s equations (JC Maxwell, 1873; H Hertz 1888),

$$\nabla \cdot E^j = \frac{\rho_q^j}{\epsilon}, \quad \nabla \cdot B^j = 0, \quad \nabla \times B^j = \mu_0 \partial E^j / \partial t, \quad \nabla \times E^j = -\partial B^j / \partial t,$$

\(c\) being the velocity of light, with the wave’s energy amplitude $\propto \epsilon |E|^2 \ (E = \sqrt{E^\dagger E^\ddagger} \ here) \ being in nature quantized according to the Planck equation [12]

$$\epsilon = n_{ph} \hbar \omega, \quad n_{ph} = 1, 2, \ldots,$$  

\(2\)
FIG. 1: An IED particle consisting of an oscillatory charge \( q(\omega) \), travelling at velocity \( \upsilon \) in +X-direction, and the resulting electromagnetic waves, of electric and magnetic fields \( E^j, B^j \) as in (a), propagated in +X- \((j = \dagger)\) and −X- \((j = \ddagger)\) directions between heavy walls spaced at \( L \). In (b), the \( E^j \) fields are plotted as dimensionless functions \( \phi^j \)'s given by exact solutions (Sec. 3.1); \( f \) is the modulation envelop of de Broglie phase wave \( \psi \) given in (4)'.

(c) the motion of source (the oscillatory charge), at velocity \( \upsilon \), yields a Doppler effect (C Dodpler, 1842; [13, 14]), with the wavevectors and frequencies of the waves generated in the directions parallel \((j = \dagger)\) and antiparallel \((j = \ddagger)\) with \( \upsilon \) displaced from their monochromatic values \( K \) and \( \Omega = cK \) to:

\[
k^j = \gamma^j K, \quad \omega^j = c k^j = \gamma^j \Omega, \quad \gamma^\dagger = 1/(1 - \upsilon/c), \quad \gamma^\ddagger = 1/(1 + \upsilon/c),
\]

and (d) the Newton’s laws of motion and (e) the Lorentz force law in respect to the dynamics of the point charge. (a)-(e) make up the first principles laws here.

Clearly, the finite charge \( q \) in the IED model is a direct mapping of law (a). The zero rest mass of \( q \), being specific with the IED model, ensures that the mass \( m \) of the resulting particle correctly is the dynamical consequence of the IED process and is not endowed twice; this is on equal footing with the well appreciated notion of a zero rest mass of the electromagnetic waves. Laws (b) and (c) are experimentally demonstrated for electromagnetic waves emitted "permanently" from their sources (charged particles), hence appearing "external" to the particles. Yet the same laws (b)-(c) ought naturally to apply to the electromagnetic waves internal of the IED particle since they are emitted by the same charge and propagated in the same vacuum; they appear "internal" only in the way that they are repeatedly re-absorbed by the charge and then re-emitted. Similarly, laws (d)-(e) ought to apply to the charge internal of an IED particle as in practice we commonly apply to other internal charges, like the charges of an atomic electron and of an atomic nucleus.

It suffices to represent the IED wave process [1–6] with the usual electromagnetic fields governed
by laws (b)-(c). Although, a physical construction of the vacuum is compelling for addressing issues like the origin of mass (e.g. in [1, 2, 4]), the mechanical basis of charge and medium oscillations (e.g. in [1–4, 6, 7]) in contrast to an ad hoc imposition, and the cause of gravity[1, 7–9]. Overall experimental observations suggest that [1, 10] the vacuum is filled of electrically neutral but polarisable building entities, called vacuuons (Fig. 2), each composed of a spinning charge $+e$ at the core and $-e$ on the concentric spherical shell bound strongly each other by a Coulomb force, and of spin angular momenta $\frac{1}{2}\hbar$ and $-\frac{1}{2}\hbar$. This vacuum will be polarised about an external charge, building an electrostatic potential in which, in the cage formed by neighboring vacuuons, the charge in turn maintains its oscillation. Ordinarily the vacuuons have each an external-effective spin $-\frac{1}{2}\hbar$ but are opposite aligned with their closest neighbours and yet in an applied magnetic field some of the pairs will be broken into parallel aligned; this vacuum is a magnetically susceptible paramagnetic.

Such a vacuum is in particular pointed to by the observational pair processes taking place at the matter-vacuum interface. In the annihilation of a free electron $e^-$ and positron $e^+$ at rest, $e^- + e^+ \rightarrow 2\gamma$, for example, the energy of the radiated two $\gamma$’s, $2 \times 511$ keV (see Refs. in Sec. 4.3), is converted from only the rest masses of $e^-, e^+$, whereas the Coulomb potential between their charges at a separation distance $r_{+-}$, $V_{+-} = -e^2/4\pi\epsilon_0r_{+-}$ is not released, nor is the energy of the spins. Energy conservation requires that, after annihilation the $V_{+-}$ as well as the spin energy must be conveyed by a certain entity (the vacuuon here) in the vacuum, a point therein yet observationally no different from any other points, whence the vacuuonic vacuum.

### 3. Solutions for IED particle: an outline

Sections 3.1-3.8 outline some of the key solutions obtained for the IED particle in [1–10].
3.1 Let for illustration a given oscillatory charge \( q \) of a characteristic frequency \( \Omega \) be in contact with a linear chain of the vacuum along the \( X \)-axis, and be oscillating along the \( Z \)-axis about an equilibrium site which moves at velocity \( v \) in \( +X \)-direction. The charge thereby generates two opposite travelling electromagnetic waves in the \( +X,-X \)-directions, given from solving (1) in dimensionless functions as: \( \varphi^{\pm} = C_1 e^{i(k^1x - \omega^1t + \alpha_0)} \) (Fig. 1b) with \( \varphi^{1} = |E^1|/E_q \), \( E_q \) the amplitude of \( E^j \), \( x = X - X_q \), \( \omega^j, k^j \) the Doppler displaced values of \( \Omega, K \) as of (3), and \( \alpha_0 \) the initial phase; \( \varphi^{\pm} \) is as with \( E^j \) a transverse wave displacement in coordinate space along the \( Z \)-axis. The \( \varphi^{\pm} \)'s and the charge \( q \) make up our IED particle; it has a total wave \([1–3]\)

\[
\psi = \varphi^+ + \varphi^-, \quad \phi = e^{i((K+\omega/k_d)x - \omega t/c)} \quad f = Ce^{i(k_d x - \omega t + \alpha_0)}, \quad \text{where}
\]

\[
k_d = (k^1 - k^\perp)/2 = \sqrt{(k^1 - K)(K - k^\perp)} = \gamma K_d, \quad K_d = (v/c)K,
\]

\[
\omega = (\omega^1 + \omega^\perp)/2 = \sqrt{\omega^1 \omega^\perp} = \gamma \Omega, \quad \gamma = \sqrt{\gamma^1 \gamma^\perp} = 1/\sqrt{1 - v^2/c^2}; \quad \text{and}
\]

\[
\lim_{K >> k_d} \phi = 1, \quad \lim_{K >> k_d} \psi = f; \quad \Psi = \lim_{\omega^2/c^2 \to 0, K >> k_d} \psi = Ce^{i(K_d x - \Omega_d t + \alpha_0)},
\]

with \( C = 4C_1 = 1/\sqrt{L} \) from normalization of \( \psi \), and \( \Omega_d \) as expressed after (5) later. From its functional in (4) and the wave and dynamical variable relations (5) below, it follows that \([2, 3]\) \( \psi \) is equivalent to the de Broglie phase wave \([15]\), with \( f \) the modulation envelope (dot-dashed line in Fig 1b); \( k_d \) thus is the de Broglie wavevector and \( \lambda_d = 2\pi/k_d \) wavelength, and \( \omega \) is the total frequency. The \( v^2/c^2 \to 0 \) limit of \( \psi \), \( \Psi \), identifies with the Schrödinger wave function for a corresponding free particle. From (4) further follows that \( \psi \) travels at a phase velocity \( W_p = \omega/k_d = c^2/v \) and group velocity \( W_g = (\omega^1 - \omega^\perp)/[k^1 - (-k^\perp)] \approx v \); the particle’s total energy \( \varepsilon \) and mass \( m \) each travel at the velocity \( W_g \) or \( v \) (elaborated in updated edition of [2], internal).

3.2 Following classical electrodynamics the electromagnetic waves have at every location \( X \) a (mean) energy density \( \varepsilon_1 = (\varepsilon_1)^2 = \varepsilon_0 E_q^2 \) and linear momentum density \( p_1 = \varepsilon_1/c \). For our applications here in general \( \varepsilon_1 \) is significantly lesser than the total energy \( \varepsilon_q \) of the charge which can thus without "refuel" oscillate continuously for a finite time, generating wave trains of a (mean) total length \( L_\varphi >> 2\pi/K \). The particle is as in reality inevitably situated between some massive walls say spaced at distance \( L \) (Fig. 1); its wave amplitude is thereby quantized as \( E_q^2 = n_{ph} E_{q,ph}^2 \) with \( n_{ph} = 1, 2, \ldots \), given as a direct solution for the charge in harmonic oscillation. The total wave energy and linear momentum of the wave train thus are \( \varepsilon (= \varepsilon_q) = L_\varphi \varepsilon_1 = n_{ph} \varepsilon_{ph} \), with \( \varepsilon_{ph} = L_\varphi \varepsilon_0 E_{q,ph}^2 \) an energy quantum; the explicit value of \( \varepsilon_{ph} \) follows from (2), law (b), to be \( \varepsilon_{ph} = h\omega \). We shall below refer to the single charged electron, proton etc. for which \( n_{ph} = 1 \) according to experiments; so \( \varepsilon = h\omega \). In all, the above depicts the IED process in the established unified framework of classical and quantum electrodynamics.
\[ \mathcal{E} = \lim_{v^2/c^2 \to 0} \varepsilon = h\Omega \] gives the ground state of a smallest quantum; thus \( \mathcal{E} \) can not be dissipated except in a pair annihilation. The charge repeatedly re-absorbs the radiation on reflection from the walls and then re-emits, maintaining therefore \( \varepsilon \) constant. The re-absorption of reflected waves \( \varphi^j \)'s, thus \( \psi \), by the charge \( q \) is further ensured by: (i) The \( \varphi^j \)'s are in natural resonance with the source. (ii) At (non-annihilating) massive walls, irrespective of the incident angle the \( \varphi^j \)'s, thus \( \psi \), as a whole will always be reciprocally reflected to the \( q \), via an usual ”temporary absorption and emission” scheme but here by a vacuun; the waves are of too high frequencies \( \omega^j \)'s to be absorbed by a material particle in the wall. The vacuun invariably is polarised in the static field of \( q \), thus bound to the charges in the massive wall and scatters the waves reciprocally on conserving total momentum.

Subtracting the total rest energy and quadratic rest linear momentum from the relativistic ones gives the kinetic energy and linear momentum of the particle \( \varepsilon_v (\equiv 1/2 m v^2) = h(\omega - \Omega) \), \( p_v (\equiv m v) = \sqrt{(h k)^2 - (h K)^2} \). With \( \gamma = 1 + \frac{1}{2} \frac{v^2}{c^2} + \frac{3}{8} \frac{v^4}{c^4} + \ldots \), \( \gamma^2 - 1 = (v/c)^2 \gamma'^2 \), reorganising, these reduce to the usual form of de Broglie relations

\[ \varepsilon_v = h\omega_d, \quad p_v = 2\pi h/\lambda_d \] (5)

where \( \omega_d = \gamma' \Omega_d \), \( \gamma' = 1 + (3/4)(v^2/c^2) + \ldots \), \( \Omega_d = (1/2)(v^2/c^2) \Omega \), \( \lambda_d = 2\pi/k_d \).

3.3 More generally, the Maxwell’s equations (1) in an applied potential \( V_a \) field lead to a wave equation for the total wave \( \psi (c^2 + V_a/m) \nabla^2 \psi = \partial_t^2 \psi \); this at the limits \( v^2/c^2 \to 0 \) and \( K >> K_d \) reduces to an equation governing directly the particle’s kinetic motion[2] which is equivalent to the Schrödinger equation[16],

\[ H\Psi = i\hbar \partial_t \Psi, \quad \text{where} \quad H = -(1/2 M) \nabla^2 + V_a. \] (6)

For two spin half IED particles in region \( v^2/c^2 > 0 \), (1) lead to a Dirac equation[6].

3.4 If an IED particle moving at velocity \( v \) is decelerated to say at rest in the vacuum, then its total wave \( \psi \) of (4) deconvolutes off a thermal mode \( k_d \) into \( \psi_0 = e^{i[Kx - \Omega t]} \), \( \psi \) and \( \psi_0 \) being each the totals of electromagnetic waves regularly comprising the particle in the respective normal states. The deconvolution is an inverse process of the de Broglie wave formation (Sec. 3.1). The oscillation at mode \( k_d \) of the deconvoluted de Broglie wave acts as an apparent source, generating an electromagnetic wave of wavevector \( k_{rad} = K_d (c/v) \); this gives a thermal radiation[5]; and conversely, a thermal absorption.

3.5 Whereas equations (4)-(6) convey all the essential wave attributes, these together with the point charge \( q \) convey also all the essential point-like attributes of a particle as observationally
known in three basic ways: (i) The $\varepsilon, p$ contain all the information on the linear dynamics known with a point object. (ii) An IED particle would interact with a detector (e.g. by absorption), or another particle, through its extensive $\psi$ at a fixed interface or through its point charge, each manifesting a spatially point event. (iii) In a condensed matter, each particle (a nuclei, electron, atom, etc.) will be anchored through its point charge, as a mass center, about a fixed position or in a finite region; its waves would typically be confined to a region by reflection from neighbouring particles or by moving in a closed path.

3.6 The wave trains of $\varphi^j$'s in rectilinear motion at the speed of light $c(=\omega_j/k_j)$ resemble each a rigid object and thus obey Newtonian mechanics; given $c$ is finite instead of infinite, the wave trains must have a finite (mean) inertial mass ($m$) instead of zero. From these and the relation $\varepsilon = pc$ earlier, with $p, \varepsilon$ being now the linear momentum and kinetic energy of the rigid wave train, follows (7) below (Newton’s law of inertia); and (7), (2) and (4b) further give (8) below [1, 2, 4]:

$$
p = mc, \quad \varepsilon = mc^2; \quad M^2c^4 + p^2c^2 = \varepsilon^2; \quad (7)$$

$$
m = \gamma M, \quad M = h\Omega/c^2 \quad \text{(for } n_{ph} = 1) \quad (8)$$

with $m$ the relativistic and $M$ the rest mass of the wave train and thus of the particle, noting that rest mass is intrinsic of an object irrespective of in which motion the object is in.

3.7 Two IED particles of masses $M_1, M_2 (= h\Omega_1, h\Omega_2/c^2)$ and charges $q_1, q_2, = \pm e$ here, separated at $r$ apart in a paramagnetic dielectric vacuum are always attracted one another by a Lorentz or attractive radiation force (Fig. 3). This force acting on charge $i$ at time $T$, in charge $i$'s

![FIG. 3: Particle 2 of charge $q_2$ and mass $M_2$ is in the fields $E_{p1}, B_1$ of charge $q_1$ of particle 1, oscillating with frequency $\Omega_1$, acted by an attractive Lorentz force $F_{12}$.](image)

depolarisation field $E_{p1i} = -\chi_{ve}E_i$ and magnetic field $B_i$ is $F_{ii'}(r, T) = q_{i'}\mathbf{v}_{ii'}(r, T) \times \mathbf{B}_i(r, T)$; $F_{ii'} = \int_{0}^{L_{\varphi/1/c}} F_{ii'}dT$ gives the total force due particle $i$ of a wave train length $L_{\varphi/1}$. Here, $\mathbf{v}_{ii'} = \int q_{i'} E_{p1i}/M_{i'}dT$; $\chi_{ve}, \chi_{vm}$ are the electric and magnetic susceptibilities of the vacuum; $E_i = \sqrt{E_i'E_{i'}^d}$, etc.; $\mathbf{B}_i = \mathbf{B}_{gi} + \mathbf{B}_{mi}$, with $\mathbf{B}_{gi}$ applied in empty space and $\mathbf{B}_{mi} = \frac{\chi_{vm}}{\chi_{vm} + 1}\mathbf{B}_i$ induced in vacuum; $i, i' = 1, 2$. The matter-penetrating (due to $\mathbf{B}_{mi}, \mathbf{B}_{mi'}$) mutual mean attractive radiation force is
\[ F = \sqrt{F_{12\phi}F_{21\phi}} = GM_1 M_2 / r^2, \quad \text{where} \ G = \zeta \chi_{vm} \chi_{ve} e^4 / (\chi_{vm} + 1) c_0^2 h^2 \rho_i. \] (9)

\( \rho_i \) is the linear mass density of vacuum; \( \zeta \) is a numerical constant depending on the averaging method, \( \zeta = \pi \) given in [9] (2006) and is being refined. \( F \) is an attraction irrespective of the signs of the charges, is not shielded by matter as the underlying vacuum dipole- and spin- waves are not, and has an inverse square formula; this \( F \) resembles in all respects Newton’s gravitational force.

3.8 Similar to the gravity in Sec. 3.7, an IED particle is always attracted by a Lorentz force \( F^j \) (Fig. 4) acting on its own charge \( q \) in the \( E_j^p, B_j^p \) fields induced by \( q \) itself in a dielectric medium; \( j = \uparrow, \downarrow \). The net force \( F^\uparrow - F^\downarrow \) presents a frictional force [7] \( f = (b_1/L^j\psi)d\psi/dT \) opposing the particle’s motion, with \( b_1 \) a constant of the medium and charge \( q \); when the medium identifies with a dielectric vacuum, \( f \) depicts a self gravity on the particle. The wave equation in the presence of \( f [7] \) is equivalent to the Doebner-Goldin equation predicted by H.-D. Doebner and G.A. Goldin in group theoretical terms[17]:

\[ (H + iDhG)\Psi = i\hbar \partial_t \Psi, \quad G = \nabla^2 \psi + |\nabla \psi|^2 / |\psi|^2, \] (10)

with \( D \) depending on \( f \), and \( H \) the usual Hamiltonian operator as in (6). (10) precedes a ”grand unified” wave equation including gravity between particles.

4. Validating the IED model: the solutions and experiments

Equations (4)–(10) are exact predictions of a set of familiar basic equations of particles in contemporary physics, originally proposed by several individual physicists on hypothetical or phenomenological basis; (4)–(9) and the associated properties (Secs.3,4) have long been broadly experimentally corroborated or demonstrated. We below review the key experiments, and underline their specific indications of the IED model and also the insufficiency of otherwise pictures if in question.
4.1 A wave characteristic of the material particles as of (4)-(6) is broadly experimentally established today for electrons[18, 19], atoms and molecules [20], neutrons[21–23], and large molecules[24]. In the first historical experimental demonstrations [18, 19], electrons of well controlled kinetic energy ($\varepsilon_v$) were let stricken on to a crystal at angle $\theta$ from its planes spaced at $b_0$. These produced diffraction fringes (Fig. 5a) according to (i) Bragg formula $2b_0 \sin \theta = n\lambda_d$ (cf. Fig. 6) in the same way as the light waves and ordinary elastic waves do, and (ii) the de Broglie relations as of (5), $\lambda_d = h/\sqrt{2m_e\varepsilon_v}$ (solid line, Fig. 5b). For the high velocity ($v \sim 9.4 \times 10^7$ m/s) electrons used in [19], a relativistic $\lambda_d(=\gamma 2\pi/K_d)$ was obtained, indicating a full wave function as of $\psi$ in (4), $\Psi$ being thus its $v^2/c^2 \to 0$ limit.

![Graph](image)

**FIG. 5:** (a) Diffraction fringe intensity v.s. azimuth angle ($90^o - \theta$), and (b) de Broglie wavelength $\lambda_d$ v.s. velocity $v$, circles, for electrons diffracted from a crystal grating measured in [18]. Solid line in (a) is after the IED solutions for de Broglie relations given in (5).

Although the stationary wave $\psi_i$ will upon detection (at D in Fig 6) be generally "collapsed" by e.g. emitting radiation, however the coherent interference producing the diffraction fringes can only have occurred before the collapsing and between two stationary-state electron waves $\psi_i$'s, Fig. 6. Therefore the diffraction fringes inform that a wave $\psi$ as of (4) presents regularly with a stationary-state electron.

The diffraction fringes need necessarily be produced by the interference between two *travelling plane waves*, as illustrated in Fig. 6 a,b for two Bragg diffractions at angles $\theta_a, \theta_b$. The IED particle at scale $k_d$, the $f$ or $\Psi$ of (4)', is a travelling plane wave in a self-sufficient way; its "particle"
attribute is facilitated by the IED model itself (Sec. 3.5). Alternatively, as a practical means today, a "particle" attribute is attached to the Schrödinger plane wave by dispersing (supposing a physical basis exists) it into a wave packet; the latter is no longer a plane wave and, as shown by the thick arrows in Fig. 6a,b, would not produce diffraction fringes.

4.2 Experiments for electrons using certain kinds of a double slit since the 1970’s [25, 26], and for neutrons from the very first experiments using crystal diffraction [21, 22] and using double slit, as a hitherto most precise realisation for matter waves, in 1988 [27] as judged by the generally low neutron flux intensity [27, 28], have shown that, the interference pattern (as in Fig. 7 [25]) is just as well produced when only one particle passes through an interferometer at a time. That is, each particle interferes with itself.

Self interference, such as in a double slit (Fig. 8) requires each particle passes two slits at the same time. —For a statistical point particle this is a logical impossibility. The IED particle ($\psi$) naturally has this ability since its each constituent electromagnetic wave ($\varphi^j$), hence the total $\psi$,
will in an open vacuum medium disseminate itself in all possible directions, which is based on observational fact and also the understood principle for medium waves. As illustrated in Fig. 8, the total wave ψ of an IED particle arriving at narrow slit A will be regenerated, by Huygens’ principle or as solution to (1) in three dimensions, as a spherical wave ψ(r, T); two of the partial components ψ(AB, T), ψ(AC, T) along equidistance paths AB, AC will enter the two slits B, C at the same time. The resultant two split waves ψ1(r1, T) and ψ2(r2, T) will traverse distances r1 = BP and r2 = CP, rejoin at point P on a photographic plate D as ψtot = ψ1 + ψ2, and will superpose with constructive interference into a peak if Δ = r1 − r2 = nλd, with n an integer. Or else they annul each other. If a thermal mode of the ψtot peak is absorbed by a molecule at P in D, a detection (excitation) signal will be produced without the arriving of q. The charge q, if finally arriving at detector D too, is propelled forward at velocity v by a repeated re-absorption/re-emission of ψ travelling at the enormous phase velocity c^2/v, >> v, by Sec. 3.1. The so driven charge will definitely first travel to A, then statistically take a radial path, say AB, and on exiting B, continue along BP only if P is a diffraction peak which feeds the charge with a linear momentum kd. Or else, the charge gets no feed of kd and will stray off the course (detailed treatment given in internal report). The self interference is one of the critical tests that point to the IED model is not just sufficient but also necessary.

In theory, interference is understood to be the (only feasible) result of superposition of vector fields, here the E_i’s or ψ_i’s (= E_i/E_q), at any point (or oscillator) in the medium; in contrast, two identical fermionic particles as a whole tend to repel each other (Pauli principle). This tends to suggest that, even in a many-particle beam as in [18, 19], diffraction is predominantly the result of self-interference of each individual particle in an afore-discussed fashion.

4.3 The various pair production and annihilation experiments of elementary particles provide a most direct revelation that, apart from charges, electromagnetic waves actually constitute the
material particles as stated by the IED model. In the same example as in Sec. 2, an electron $e^-$ and positron $e^+$ [29–31] can annihilate into (typically in a condensed matter) two gamma rays $\gamma$'s, $e^- + e^+ \rightarrow 2\gamma$, with the two $\gamma$'s being emitted [32–35] in opposite directions and carrying a total energy $\varepsilon_{2\gamma} = 2\hbar\omega \approx 2 \times (511.0031 \pm 0.0032) \text{ keV}$ (precision Ge(Li)- scintillation data from [35]). This $\varepsilon_{2\gamma}$ value equals twice the electron rest mass $M_e$ times $c^2$, $2 \times M_e c^2 = 2 \times 510.9989 \text{ keV}$ (CODATA, 1998), with which the IED solution (7) directly agrees.

When emitting the radiation, the annihilating particles $e^-, e^+$ are not undergoing any accelerations inasmuch as is externally observable; rather, most favourably they are at rest as indicated by the peak position at 511 keV in Fig. 9. However, electromagnetic theory requires the charge must undergo acceleration ($> 0$ or $< 0$) to emit radiation. Inevitably then, the emitted $\gamma$- electromagnetic waves ought to have been as stated by the IED model regularly generated by the oscillation of charge within each normal-state particle; and upon annihilation these waves are no longer re-absorbed by the charges which have now neutralised one another into the vacuum.

4.4 If the particles $e^-, e^+$ are during annihilation in motion, then according to the IED model their constituting electromagnetic waves should be subject to a Doppler effect, law (c). This effect indeed is directly revealed by the commonly observed unusual broadening in the annihilation radiation intensity profile, as shown in Fig. 9 as a function of differential wavelength $\lambda - \lambda_0$ measured in [14] using a crystal spectrometer, $\lambda_0 = \hbar/M_e c$ being due to electron rest mass $M_e$. It was historically first shown in [14] that a residual broadening $\delta(\lambda - \lambda_0) \sim 0.096 \text{ x.u.} \quad (\sim 0.0958 \text{ A})$ retained after subtracting an instrumental cause and was identified to result from the Doppler effect from the thermal motion, of a velocity $\sim 16 \text{ eV}$, of the recombining positron-(conduction) electron pair in the metal specimen.

4.5 The IED solution (8) for mass v.s. velocity, $m = \gamma M$ (solid curve, Fig. 10a) predicts exactly the well-known empirical formula concluded originally from a series of experiments on electrons

![Radiation Intensity](image)

**FIG. 9:** Experimental $e^-, e^+$ annihilation radiation intensity v.s. wavelength displacement[14].
during 1901-15 [26-28]. There, electrons are driven into motion at a given velocity ($v$) in an applied magnetic field ($B$) perpendicular to the electron motion plane (Fig 10b), and are thus subject to a Lorentz force $F_m = -euv \times B$; the equation of motion is $F_m = mv^2/R(y,z)$. A measurement of their coordinates $y, z$ gives then an in situ, non-destructive determination of the $e/m$ ratio, hence the $m$ value, v.s. $v$ (circles, Fig 10a).

The exact prediction by (8) of the experimental relation $m = \gamma M$ points to an unique underling IED process in two major ways: (i) From its relation to total energy ($\varepsilon$), the IED represents a unique feasible microscopic process (Sec. 3.6) for yielding the exact solution relation (7), $\varepsilon = mc^2$, where the $v$-dependence of $\varepsilon$, hence $m$, results automatically from this process owing to a Doppler effect which separately is an experimental law, (c). The relation $\varepsilon = mc^2$ originally was a postulate by A Einstein (1905), being aware of the experiments of [36], and up to the present it has not been understood why total energy $\varepsilon$ equals mass $m$ times the square of the velocity of light $c^2$.

(ii) Observationally[36–39], an electron in macroscopic uniform circular motion emits radiation statistically, so sometimes it appears not radiating; also, an orbiting atomic-electron in a stationary state does not radiate. The above thus appears paradoxical to the electromagnetic theory by which the charge under constant centripetal acceleration ($a_R$) should be constantly radiating. This paradox presents not with an IED electron whose oscillatory charge emits electromagnetic radiation ($\varphi^j$’s) all the time and the acceleration $a_R$ additionally bends its radiation wave path from linear into circular. It is self-evident that, the radiation as emitted by a circulating electron is not due to the centripetal acceleration, but rather is due to the sudden deceleration associated with a mass reduction, $(m - M)c^2$, accompanying which the electron falls onto a smaller-radius orbit if no
energy compensation.

4.6 The inverse square formula of gravity as of (9) was originally an empirical law discovered by I Newton (1687) based on the then available observational astronomical data. Since the first "torsion balance" determination of $G$ value by H Cavendish (1798), the constancy of $G$ and the inverse square behaviour of $F$ have been repeatedly experimentally (terrestrially) validated with ever improving accuracy [40]. The cause of gravity is up to the present yet not understood. Gravity, as a fundamental force universally exerted between all masses at all distances, is as intrinsic a property as the wave function, mass and charge of a particle, so that a particle model could not be said to be adequate without a built-in scheme for this force, the gravity. The IED model uniquely has such a scheme and predicts a precise inverse square formula (9), with its constant $G$ being expressed by only fundamental constants and constants of the vacuum.

5. Concluding remarks

A set of well known basic equations embedding our present-day essential knowledge of particles can be derived based on solutions for the IED process governed by a minimal set of long established basic or first principles laws (a-e). These equations and the closely related particle properties have long been broadly experimentally validated; the present critical review of several key experiments suggests that the underling IED process is not just sufficient but is also necessary. An otherwise particle picture would not yield all of the predictions or just some of these without some kind of clashes.

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