Effective Biological Alpha: Unifying the Fine-Structure Constant α and Life as an Electromagnetic Phenomenon

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Article

Effective Biological Alpha: Unifying the Fine-Structure Constant α and Life as an Electromagnetic Phenomenon

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Abstract

The Electron-Ion Interaction Potential (EIIP) is an empirically derived descriptor introduced through pseudopotential theory, representing the effective interaction between conduction electrons and atomic cores. Remarkably, EIIP depends solely on the atomic number Z, positioning it as a direct function of the periodic system. This paper revisits the theoretical foundation of EIIP and demonstrates its proportionality to the fine-structure constant $\alpha \approx 1/137$, revealing a universal relationship that bridges quantum electrodynamics and the periodic architecture of matter. We show that EIIP can be expressed as $EIIP = f(Z) \cdot \alpha$, where f(Z) is a periodic function empirically determined from spectroscopic data. This insight establishes EIIP as a structural descriptor with broad applicability across physics, chemistry, and biology. Extending this framework, we introduce the concept of an effective biological fine-structure constant α_{bio}, which quantifies the degree of electromagnetic coherence in living systems. Life is viewed as a resonant electromagnetic phenomenon, where molecular recognition and energy flow depend on synchronized electron and photon exchange. We define α_{bio} in terms of dielectric and charge-transfer properties of biological media, and propose its deviation from α as a marker of aging and decoherence. By unifying EIIP and α_{bio}, we establish a theoretical foundation for Electronic Biology, linking atomic periodicity with biological vitality through a shared electromagnetic language.

Keywords: electron-ion interaction potential; biological fine structure constant; electrodynamics; electronic biology; aging

1. Introduction

The periodic table is one of the most profound organizational structures in science, reflecting the quantum mechanical nature of atoms through the discrete progression of atomic number Z. At the same time, the fine-structure constant α governs the strength of electromagnetic interactions and appears ubiquitously in atomic and molecular physics. The convergence of these two quantities—Z and α—within the framework of the Electron-Ion Interaction Potential (EIIP) suggests a deeper structural connection between atomic identity and fundamental physical laws.

EIIP, originally introduced through pseudopotential theory [1], has found applications in solid-state physics, bioinformatics, and materials science [2]. Its dependence solely on Z makes it a powerful and transferable descriptor of electron-ion interactions. In this work, we explore the theoretical basis for EIIP's proportionality to $f(Z) \cdot \alpha$, and examine its role as a bridge between quantum electrodynamics and the periodic system.

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2. Materials and Methods

2.1. Coulomb Interaction and the Role of α

The Coulomb potential between an electron and a nucleus of charge Ze is given in atomic units by:

$$V(r) = - Z\alpha/r \quad (1)$$

where, $\alpha=e^2/(4\pi\varepsilon_0\hbar c)$ is the fine-structure constant—a dimensionless quantity that characterizes the strength of electromagnetic interactions, and natural units ($\hbar$=c=e=1) are used, as originally formulated in the relativistic quantum theory of the electron [3]. This constant appears ubiquitously in quantum electrodynamics and sets the scale for atomic energies, radii, and transition probabilities [4].

Since pseudopotentials are constructed to approximate the Coulomb interaction and incorporate exchange and correlation effects, α is inherently embedded in the formulation of EIIP—even if not explicitly stated. The effective interaction energy between valence electrons and the ion core, as captured by EIIP, reflects this fundamental scaling.

2.2. EIIP as a Scaled Coulomb Descriptor

The pseudopotential model proposed by Veljković and Slavić [1], which builds on earlier formulations of core–electron interactions developed within pseudopotential theory [4], expresses the electron–ion interaction through a simplified form factor derived from spectral spectroscopic data:

$$(k+q|w|k) = B_1 \sin(2\pi B_2 n)/(2\pi n), \quad n = q/(2k_F) \quad (2)$$

where B_1 and B_2 are parameters fitted to experimental data, and k_F is the Fermi momentum. The product B_1B_2 is constrained by the Fermi energy E_F, which itself depends on the electron density and effective mass—both influenced by α through quantum electrodynamics [5,6].

Although EIIP is empirically defined, its strict dependence on Z and its compatibility with the electromagnetic scaling governed by α suggest a deeper theoretical significance. This motivates the generalized expression:

$$EIIP = f(Z)\alpha \quad (3)$$

where f(Z) is a periodic function reflecting electronic configuration. In this form, EIIP serves as a structural descriptor that encodes both atomic identity and the universal scaling of electromagnetic interaction.

3. Results

3.1. Periodicity and Quantum Structure

The periodic variation of pseudopotential parameters, such as B_1, mirrors the quantum shell structure and electronic configuration of atoms. Given that the atomic number Z changes discretely across the periodic table while the fine-structure constant α remains invariant, the composite term αZ^2 emerges as a quantum-electrodynamic signature of elemental identity [1]. Through this scaling, EIIP effectively captures periodic trends—including ionization potential, electronegativity, and bonding characteristics—in a compact and predictive framework grounded in fundamental physics.

Moreover, the periodic modulation of EIIP across groups and periods reflects the quantum mechanical filling of electron shells, reinforcing its role as a structural descriptor rooted in universal principles.

3.2. Similar Connections Between α and the Periodic System

While EIIP provides a direct and elegant link between α and the periodic table, other connections do exist—though typically in more complex or indirect forms:

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- **Ionization Energies and Rydberg Formula**: The Rydberg constant R_∞ is proportional to α^2, and ionization energies of hydrogen-like atoms scale with Z^2 [3].
- **Atomic Radii and Bohr Radius**: The Bohr radius sets the scale for atomic size. Periodic trends in atomic radii are influenced by this fundamental length scale [3].
- **Spectroscopic Fine Structure**: The splitting of atomic energy levels due to relativistic effects is directly proportional to α, and varies with $Z^4\alpha^2$, especially in heavy elements [7].

However, these relationships are typically limited to specific atomic models or require detailed quantum mechanical calculations. EIIP, by contrast, offers a universal and transferable formulation that applies across all elements and disciplines.

3.3. Extending α to Biology: Definition of α_{bio}

In living systems, energy flow and molecular recognition are mediated by coherent electron and photon exchange. Szent-Györgyi described life as "an electron looking for a place to rest," [8] emphasizing that biological organization depends on continuous redox gradients and directional electron flow. If the fine-structure constant α\alpha quantifies the universal strength of electromagnetic coupling, then its biological counterpart, α_{bio}, can describe the degree to which living matter preserves this resonance under cellular conditions.

We define the effective biological fine-structure constant as:

$$\alpha_{bio} = e_{eff}^2/(4\pi\varepsilon_{cell}\hbar c_{eff}) \qquad (4)$$

where e_{eff} represents the effective charge transfer during biochemical reactions, ε_{cell} is the dielectric constant of the intracellular medium, and c_{eff} is the velocity of electromagnetic wave propagation within biological tissue. The values of ε_{cell} and c_{eff} depend on water structuring, membrane potentials, and protein conformations—all of which change with age and metabolic stress. As these parameters drift, α_{bio} deviates from α, indicating a loss of electromagnetic coherence that parallels physiological decline.

3.4. Life as an Electromagnetic Phenomenon

Life fundamentally depends on the organization of electron flow. In respiration and photosynthesis, electrons travel through structured protein complexes in quantized steps, exchanging photons and maintaining redox balance. These flows are not purely chemical—they form resonant electromagnetic networks [9] extending through water and membrane structures. Biological coherence arises when the phase relations among electrons and dipoles remain synchronized. This coherence may be viewed as a living analogue of electromagnetic resonance tuned to α, while α_{bio} quantifies its realization within cellular environments.

With aging, coherence fades: mitochondrial chains become noisy, reactive oxygen species accumulate, water loses ordering, and proteins unfold. These processes slow electron transfer, disrupt resonant fields, and effectively lower c_{eff} and increase dielectric noise, shifting α_{bio} away from its ideal resonance. The result is biological decoherence—the gradual detuning of life from the universal electromagnetic order [10].

4. Discussion

4.1. Electronic Biology and the Role of α and α_{bio}

The recognition of α_{bio} as a measurable or inferable quantity opens a path toward a quantitative foundation for Electronic Biology—the study of living systems as organized electromagnetic structures. By uniting EIIP with α_{bio}, the electromagnetic properties of molecules can be analyzed across scales, from atoms to tissues, using a single universal parameter.

This unified view suggests that biological specificity, communication, and even consciousness may rely on the precise tuning of α_{bio} near the universal α. At the cellular level, maintaining α_{bio} involves stabilizing redox potentials, preserving hydration shells, and ensuring phase coherence

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across molecular assemblies. These conditions are not merely biochemical—they are electromagnetic in nature, governed by dielectric structuring and photon-mediated interactions.

Recent experimental investigations have provided substantial support for the pro-posed theoretical framework. Long-range, resonance-dependent electrodynamic interactions have been detected between biological macromolecules at distances significantly exceeding the Debye screening length, thereby enabling selective molecular recognition without direct physical contact [11]. These observations substantiate the long-standing hypothesis that intermolecular communication in biological systems involves a resonant electromagnetic component, particularly under conditions of high macromolecular crowding where diffusion-driven encounters are insufficient to account for molecular specificity.

This evidence is consistent with the central tenets of Electronic Biology, which postulate that coherence, frequency tuning, and resonant coupling represent fundamental physical mechanisms underlying biological organization. Within this conceptual context, αbio may serve as a quantitative descriptor of biological order, reflecting the degree of electromagnetic coherence in living systems.

From this standpoint, therapeutic and longevity-oriented strategies can be reinterpreted as efforts to reestablish resonance rather than solely to repair molecular damage. Aging, accordingly, may be viewed not only as biochemical deterioration but as progressive electromagnetic detuning, in which biological systems deviate from their optimal resonant states within the α-space.

The coupling between EIIP periodicity and α_{bio} resonance provides a unifying framework linking quantum physics, biochemistry, and medicine. Within this framework:

- EIIP-based bioinformatics descriptors can be regarded as electromagnetic finger-prints of molecular coherence.

- Redox-sensitive diagnostic approaches may be refined through monitoring fluctuations in αbio, offering a novel quantitative measure of physiological vitality.

- Quantum biological models can incorporate α_{bio} as a governing parameter connecting atomic-scale constants to emergent biological functions.

Additional experimental and theoretical studies further corroborate this interpretation. Photon-induced electronic excitations in biomolecules have been shown to transfer energy into coherent vibrational modes, thereby establishing electromechanical coupling within macromolecular assemblies [12]. Moreover, theoretical modeling has demonstrated selective co-resonance between a DNA fragment and the restriction enzyme *EcoRI*, which is abolished upon sequence randomization [13].

The present study extends these findings by employing the Electron–Ion Interaction Potential (EIIP) as a universal electromagnetic descriptor capable of predicting resonance-based molecular compatibility prior to physical contact. This approach provides a quantitative theoretical foundation that directly links atomic composition with experimentally observed long-range electrodynamic selectivity, suggesting that biological organization may be understood as a state of matter tuned to universal electromagnetic resonance conditions rather than solely as a product of chemical encoding.

5. Conclusion

EIIP encapsulates the periodic and electromagnetic nature of matter, while α defines the universal scale of interaction. Extending these concepts to biology through α_{bio} reveals that life represents a coherent electromagnetic state tuned to α, and aging reflects its progressive detuning.

By expressing EIIP and defining αbio analogously to equations (3) and (4), we establish a unified framework that connects atomic identity with biological vitality through a common electromagnetic language. This formulation bridges the quantum foundations of matter with the dynamic processes of life, opening new avenues for interdisciplinary applications—from solid-state physics to molecular biology—anchored in the universal principles of quantum structure.

Future research should aim to:

- Quantify α_{bio} experimentally across tissues and conditions.
- Correlate α_{bio} with redox, dielectric, and hydration parameters.

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- Explore its modulation as a biophysical marker of coherence, aging, and therapeutic potential.

In doing so, we move toward a unified electromagnetic theory of life, where the fine-structure constant and its biological counterpart illuminate the deep symmetry between matter and living systems.

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Appendix A

Alpha-bio as a Universal Descriptor of Electron–Phonon Coupling in Biology
A bridging principle linking solid-state THz physics and molecular bioelectrodynamics

Appendix A.1. A Recent Breakthrough in THz Electron–Phonon Coupling

A new study [14] has shown that electron–phonon coupling strength in hydrogen-bonded network crystals exhibits a discrete, quantized behavior when probed in the THz frequency range. The author reports that the fundamental increment of coupling g_0, is approximately:

$$g_0 \approx 5 \times 10^{-3}\ \mathrm{cm^{-1}\ K^{-1}} \approx \alpha \cdot k_B$$

where α is the fine-structure constant. He concludes that a "coupling-constant (α) scheme" applies to electron–phonon interactions in hydrogen-bonded crystals.

This is a direct experimental indication that α governs energy exchange between electrons and THz vibrational modes in molecular hydrogen-bond networks.

Appendix A.2. THz Collective Dynamics in Proteins

A Scientific Reports study [15] demonstrates optical pumping of a protein (BSA) leading to energy transfer into its lowest vibrational phonon mode. The process resembles Fröhlich-type phonon condensation, resulting in a large oscillating dipole.

This effect enables long-range resonant electrodynamic forces between biological macromolecules—again, in the THz domain.

The physical mechanism—electronically driven activation of low-frequency phonons—is the same class of interaction that was experimentally quantized by α in the recent study.

Appendix A.3. Sequence-Dependent THz Dynamics in DNA Using EIIP

It was applied Davydov/Holstein–Fröhlich physics to examine electron currents along DNA strands [16]. Periodic DNA sequences exhibit sharp frequency peaks, while randomized sequences yield broad noise spectra.

Importantly, the authors directly use Electron–Ion Interaction Potential (EIIP) values of nucleotides [17] as numerical electronic descriptors of DNA sequences.

Thus, EIIP already connects electronic properties of biomolecules to the selective generation of THz spectral features.

Appendix A.4. Long-Range DNA–Protein Recognition in the THz Domain

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A recent modeling study shows that EcoRI identifies its target DNA sequence via electrodynamic forces operating at large distances [18]. DNA and enzyme exhibit co-resonant peaks in their Fourier spectra only when the correct sequence is present.

When the sequence is random, the resonance disappears and the spectrum becomes broad and noisy, eliminating long-range selectivity.

This supports the concept that selective THz electrodynamic forces provide pre-contact biological recognition.

Appendix A.5. Enter α-Bio: A Biological Generalization of α

This preprint proposes α-bio, an effective biophysical analogue of the fine-structure constant:

$$\alpha_{bio} = e_{eff}^2/(4\pi\varepsilon_{cell}\hbar c_{eff})$$

where ε_{cell} and c_{eff} describe biological dielectric properties and electromagnetic propagation. EIIP is reformulated as:

$$EIIP = f(Z)\alpha$$

explicitly linking molecular electronic structure to α-scaled interactions.

The preprint interprets deviation of α-bio from α as a measure of loss of resonance and coherence in biological systems.

Appendix A.6. Convergence: Three Independent Domains, One Constant

Domain	Key phenomenon	Governing constant
Hydrogen-bond crystals	Quantized e–phonon coupling in THz	α
Proteins in solution	THz phonon condensation + long-range forces	α-dependent EM dynamics
DNA–protein recognition	Sequence-encoded THz co-resonance	EIIP $\propto \alpha$

This alignment suggests:

Electron–phonon coupling in the THz domain is universally α-scaled, not only in crystalline matter but also in biological macromolecules.

α-bio then emerges as the context-dependent realization of this universal constant in living media**.**

Appendix A.7. Implication for Biological Order and Aging

If healthy biological systems maintain THz resonant coherence based on α-scaled coupling, then detuning of α-bio (via dielectric changes, molecular damage, hydration shifts) would reduce:

- THz phonon condensation
- molecular co-resonance
- long-range recognition efficiency

Such a framework suggests a physically grounded interpretation of aging as loss of α-constrained coherence**.**

Appendix A.8. Conclusion

Three independent research lines now form a consistent physical narrative:

1. α quantizes e–phonon coupling in hydrogen-bond networks (solid-state THz physics)
2. Biomolecules support THz collective dynamics that drive long-range recognition
3. EIIP and α-bio provide molecular scaling of these interactions in living matter

Together, they position α-bio as a realistic and physically justified descriptor of electromagnetic coherence in biology, grounded in:

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- experimental THz spectroscopy,
- established macromolecular biophysics,
- and universal quantum electrodynamics.

This coordinated evidence strongly supports the central thesis:

Life's specificity and coherence may be fundamentally regulated by α—manifested biologically as α-bio.

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