Part B3 - **Interaction in the Photoelectric Effect**

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Abstract

The photoelectric effect provides a direct test of how electromagnetic radiation transfers energy to matter. This paper develops a local dynamical model in which a bound atomic electron interacts with a coherent electromagnetic wave structure formed by the coupled electric field E, magnetic field B, and displacement current J_D. The electron current locally perturbs this pre-existing structure and initiates a coupled electromagnetic response.

For analytical purposes, the transferred energy is separated into a direct electric-field contribution and a dynamically generated response,

$$W_{\mathrm{tr}} = W_E + W_{\mathrm{resp}}$$

The direct electric field acts immediately on the electron, while the frequency-dependent contribution develops through the local reorganization of the $E - B - J_D$ structure. For an approximately harmonic magnetic field,

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

so that the rate of electromagnetic response increases with frequency even when the characteristic field amplitudes remain approximately unchanged. To first approximation,

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

where A_{eff} is the effective local interaction area.

The model distinguishes the geometry of the electromagnetic wave from the geometry of a single photoelectric interaction. The quantities L, R, and A_{eff} describe only the region that becomes dynamically involved before electron ejection terminates the interaction. For the hydrogen ground-state reference case, the present working model gives approximately $L_1 = 13$ nm and $R_1 = 6.5$ nm, with representative characteristic field amplitudes near $E_0 = 1.5 \times 10^9 V/m$ and $B_0 = 5$ T.

For the ground-state reference interaction, the model gives the approximate consistency relation

$$h \approx 2\pi e B_0 A_{\mathrm{eff}}$$

or equivalently

$$\Phi_{\mathrm{eff}} \approx \frac{h}{2\pi e}$$

linking Planck's constant to the effective magnetic flux participating in the local interaction. This relation is presently a consistency condition rather than a first-principles derivation of h.

Application to the first four hydrogen levels shows that approximately common characteristic field amplitudes can be retained while the effective interaction region decreases for more weakly bound electrons. Electron ejection terminates the interaction when

$$W_E + W_{\mathrm{resp}} = W_b$$

is reached. The calculated interaction length decreases from approximately 13.0 nm for n=1 to 9.4 nm for n=4.

Within this framework, the photoelectric threshold is interpreted as a local dynamical energy-transfer condition. The relation W=hf describes the characteristic energy transferred through the frequency-dependent local interaction rather than necessarily the total energy of the complete electromagnetic wave. The principal remaining task is to derive the interaction geometry, response field, and ejection time directly from the self-consistent coupled dynamics of the electron and the $E - B - J_D$ structure.

1. Introduction

The photoelectric effect provides a particularly useful test of any physical model of electromagnetic radiation. A successful description must explain not only how electromagnetic energy is transferred to a bound electron, but also why electron ejection depends primarily on the frequency of the incident radiation and why a well-defined threshold frequency exists.

In the model developed in Parts B1 and B2, electromagnetic radiation is represented by coherent toroidal field structures formed by the coupled electric field E, magnetic field B, and displacement current J_D. These quantities are not treated as independent components. They form a dynamically organized electromagnetic structure in which energy is continuously redistributed between electric, magnetic, and displacement-current contributions.

The internal structure is also subject to radial stability. The electric contribution tends to expand the transverse field configuration, whereas the magnetic contribution provides an opposing compressive effect. A stable electromagnetic structure therefore tends toward a dynamically preferred transverse organization. At sufficiently developed field strength, the local amplitudes E_0 and B_0 are expected to remain within a comparatively narrow stability range, while additional electromagnetic energy can instead increase the transverse extent or coherent organization of the structure.

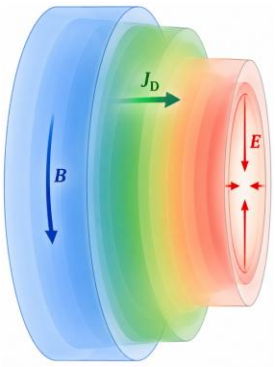

***Figure 1**. Schematic cross-section of the electromagnetic wave structure. The electric field E, magnetic field B, and*

displacement current J_D occupy strongly overlapping regions and do not form sharply separated layers. The indicated boundaries represent regions of predominant contribution rather than physical interfaces. The underlying toroidal organization and coherent propagation of the electromagnetic wave are discussed in Parts IV and V.

The characteristic transverse scale associated with such a stable structure will be denoted by R_0. Its numerical value is not assumed in the present paper. Part B2 treats R_0 as a structural property connected with radial saturation, coherent merging, and electromagnetic stability, and its determination remains an experimental question.

This distinction is important for the photoelectric interaction considered here. The electron does not interact simultaneously with the complete transverse electromagnetic structure. The photoelectric process is local. Only a limited region surrounding the atomic electron can participate effectively during the finite time before electron ejection terminates the interaction.

The present paper therefore introduces separate local interaction scales. The quantity L denotes the characteristic longitudinal extent over which the electromagnetic response can develop, while R denotes the corresponding effective transverse response scale. These quantities must not be confused with the structural radius R_0. In general,

$$R \ll R_0$$

is expected whenever the electromagnetic structure extends far beyond the atomic interaction region, but the quantitative analysis developed below does not require a predetermined numerical value of R_0.

The local interaction begins when the pre-existing electromagnetic structure encounters a bound atomic electron. The electric field acts directly on the electron, while the electron current simultaneously disturbs the local organization of E, B, and J_D. The resulting electromagnetic response redistributes the surrounding field and can generate an additional electric-field contribution capable of performing further work on the electron.

The process is therefore described as a coupled local disturbance of an already organized electromagnetic system rather than as the creation of a new field by the electron. Schematically, the interaction may be represented as

$$J_e \rightarrow \delta(E, B, J_D) \rightarrow E_{\mathrm{resp}}$$

where J_e denotes the electron current and E_{resp} the electric component of the local electromagnetic response acting back on the electron.

The magnetic field itself performs no direct work on the electron. Its importance lies in the coupled evolution of the electromagnetic structure. In particular, the time variation of the magnetic field is linked through Faraday's law to an electric response. For an approximately harmonic local field,

$$B(t) = B_0 \sin(2\pi f t)$$

and therefore

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

If the characteristic field amplitude B_0 is approximately fixed by the stable electromagnetic structure, the maximum rate of magnetic-field variation increases linearly with frequency. This provides the central mechanism by which frequency can enter the local energy-transfer process without requiring the field amplitudes themselves to increase with frequency.

The total energy transferred to the electron is consequently separated, for analytical purposes, into two coupled contributions. The first is the direct work of the pre-existing electric field. The second arises from the dynamically generated electromagnetic response produced by the local disturbance of

the $(E - B - J_D)$ structure. These contributions are not regarded as independent sources of energy; they are two stages of the same local electromagnetic interaction.

Electron ejection occurs when the accumulated transferred energy reaches the binding requirement. Once the electron leaves the bound state, the original interaction terminates. The effective interaction dimensions L and R are therefore not fixed geometrical dimensions of the incident electromagnetic structure. They describe how far the local response has developed before ejection occurs.

This termination mechanism becomes especially important for electrons with different binding energies. A strongly bound electron can remain coupled to the local electromagnetic response for a longer interval, whereas a more weakly bound electron can reach the ejection condition earlier. The characteristic electromagnetic structure may therefore retain approximately the same field amplitudes while the effective interaction dimensions change from one atomic state to another.

The purpose of the present paper is to examine whether this local field-interaction mechanism can reproduce the principal quantitative features of the photoelectric effect. Particular attention is given to the hydrogen atom, where the first four bound states provide a simple test of whether one common set of characteristic electromagnetic field amplitudes can remain consistent with substantially different binding energies.

The analysis develops approximate relations between the characteristic field amplitudes, the rate of electromagnetic response, the effective interaction geometry, and the threshold condition for electron ejection. It also examines the connection between the local magnetic flux participating in the interaction and the experimentally observed proportionality between transferred energy and frequency.

The model does not require the total energy of the complete electromagnetic structure to be equal to the energy transferred to a single electron. The photoelectric threshold is instead interpreted as a local dynamical condition: sufficient energy must be transferred from the surrounding electromagnetic structure to the electron during the finite interaction interval.

In this way, the photoelectric effect becomes a test not only of electromagnetic energy transfer, but also of the internal dynamics, radial stability, and local response of the toroidal electromagnetic structures developed in Parts B1 and B2. [1], [2]

2. Local Interaction Between the EM Structure and an Atomic Electron

In the present model, the photoelectric interaction is treated as a local event between a bound atomic electron and a limited region of a larger coherent electromagnetic structure. The complete dimensions of the toroidal structure do not determine the immediate interaction. What matters is the local electric field, the local magnetic-field dynamics, the displacement-current structure, and the electromagnetic response that develops in the region surrounding the electron.

The characteristic dimensions of this local interaction must therefore be distinguished from the characteristic dimensions of the complete electromagnetic structure. The transverse structural scale R_0 describes the organization of the electromagnetic wave (torus) itself, whereas the quantities introduced later in this paper describe only the region that participates effectively in a particular electron-ejection event. No numerical value of R_0 is required for the local analysis developed here.

Before the interaction begins, the electromagnetic structure already contains the

coupled electric field E, magnetic field B, and displacement current J_D. These quantities form one organized dynamical system. They occupy strongly overlapping regions and should not be interpreted as three sharply separated layers.

The displacement current is therefore not created by the atomic electron. It is already an intrinsic part of the propagating electromagnetic structure. In Maxwell's equations,

$$J_D = \varepsilon_0 \frac{\partial E}{\partial t}$$

so that the local displacement-current distribution is directly connected with the time variation of the electric field.

When the electromagnetic structure reaches the atom, the local electric field begins to act on the bound electron. The corresponding electric force is

$$F_E = qE$$

where q=-e for the electron.

This direct electric action modifies the bound motion of the electron and provides the first contribution to its energy change. At the same time, however, the motion of the electron introduces a local electric current. Schematically,

$$J_e = \rho_e v_e$$

where ρ_e represents the local charge density associated with the electron and v_e its velocity.

The electron current enters a region in which E, B, and J_D are already dynamically coupled. The interaction therefore does not disturb only the displacement current or only the magnetic field. It perturbs the local organization of the complete electromagnetic system.

Schematically, the local disturbance may be represented as

$$J_e \rightarrow \delta(E, B, J_D)$$

The three perturbations are coupled. Through the Ampère-Maxwell equation,

$$\nabla \times B = \mu_0 (J_e + J_D)$$

a change in the local current configuration is connected with a change in the magnetic field. At the same time, Faraday's law,

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

connects the changing magnetic field with the electric-field response.

The resulting interaction should therefore be viewed as a local electromagnetic reorganization rather than as a simple one-way sequence of independent processes. The electron perturbs the pre-existing $(E - B - J_D)$ structure, and the reorganized field acts back on the electron.

For analytical purposes, the electric field acting on the electron can be written as

$$E_{\text{tot}} = E + E_{\text{resp}}$$

where E is the pre-existing local electric field of the incident electromagnetic structure and E_{resp} denotes the additional electric component associated with the local electromagnetic response.

The corresponding energy transfer is

$$\Delta W = \int q E_{\text{tot}} \cdot v_e \, dt$$

or

$$\Delta W = \int q E \cdot v_e \, dt + \int q E_{\text{resp}} \cdot v_e \, dt$$

The first term represents the direct electric-field contribution. The second represents the additional work associated with the dynamically reorganized electromagnetic structure.

These two terms should not be interpreted as two independent sources of energy. Both belong to the same local interaction. The distinction is introduced only to separate the immediate action of the pre-existing electric field from the additional response generated

after the bound electron perturbs the local field organization.

The magnetic field participates critically in this response, but it does not perform direct work on the electron. The magnetic part of the Lorentz force is

$$F_B = qv_e \times B$$

and therefore

$$F_B \cdot v_e = 0$$

The magnetic field can change the direction of electron motion and contribute to the electromagnetic reorganization, but any net increase of electron energy must ultimately be associated with an electric-field component.

The interaction is also spatially limited. A disturbance created in the vicinity of the electron cannot instantaneously reorganize the complete electromagnetic structure. During the finite time available before electron ejection, only a limited surrounding region can contribute effectively.

This motivates the introduction of a characteristic longitudinal interaction scale L and a transverse response scale R. These quantities describe the spatial extent reached by the local electromagnetic response during the electron-ejection process. They are not structural dimensions of the complete (toroidal) electromagnetic wave.

The duration and extent of the response can also depend on the atomic binding energy. A strongly bound electron can remain coupled to the local electromagnetic response for a longer interval, while a more weakly bound electron can reach the ejection condition earlier. Electron ejection therefore naturally terminates the development of the local response.

The interaction may thus be summarized by the sequence

$$E, B, J_D + J_e \rightarrow \delta(E, B, J_D) \rightarrow E_{\text{resp}} \rightarrow \Delta W$$

with electron ejection occurring when the accumulated transferred energy reaches the binding requirement.

This local description provides the basis for the following sections, in which the direct electric-field contribution and the dynamically generated electromagnetic response are considered separately for quantitative analysis. [3], [4]

3. Direct Electric-Field Contribution

The first interaction between the electromagnetic wave structure and a bound atomic electron is produced by the local electric field. Unlike the dynamically generated response considered in the following section, this contribution acts immediately when the electromagnetic wave reaches the electron.

The electric force acting on the electron is

$$F_E = qE$$

and the corresponding instantaneous rate of energy transfer is

$$P_E = qE \cdot v_e$$

The energy transferred directly by the electric field during the effective interaction interval is therefore

$$W_E = \int qE \cdot v_e \, dt$$

The magnitude of this contribution depends not only on the characteristic field amplitude but also on the electron trajectory, the orientation of the electron motion relative to the local electric field, and the duration of the interaction. The electric field can deform the initially bound motion and progressively modify the electron trajectory before ejection occurs.

For the present model, the characteristic electric-field amplitude is denoted by E_0. In the electromagnetic-wave structure developed in

Parts IV and V, E_0 is associated with the locally stable and saturated field configuration. It is therefore not assumed to increase systematically with frequency.

This distinction is essential. The frequency dependence of the photoelectric effect is not attributed primarily to a larger electric-field amplitude at higher frequency. Instead, E_0 is treated as an approximately stable characteristic amplitude of the electromagnetic wave, while the frequency dependence arises mainly from the rate at which the coupled $E - B - J_D$ structure changes and responds during the interaction.

If the direct electric field alone were responsible for electron ejection, the threshold condition would depend mainly on field amplitude and interaction geometry rather than displaying the observed dominant dependence on frequency. The direct contribution must therefore remain below the complete ejection requirement while still being strong enough to perturb the bound electron and initiate the subsequent electromagnetic response.

The direct electric contribution consequently plays two related roles. First, it transfers energy immediately to the bound electron. Second, it changes the electron motion and thereby modifies the local interaction between the electron current and the surrounding electromagnetic-wave structure.

The electron-ejection condition is reached only when the total transferred energy satisfies

$$W_E + W_{\mathrm{resp}} \geq W_b$$

where W_b is the binding energy and W_{resp} denotes the additional energy transferred through the dynamically generated electromagnetic response.

The direct contribution should therefore not be interpreted as a separate energy-transfer mechanism competing with the dynamic response. Both contributions belong to the same local interaction. The distinction is introduced only to identify the immediate work performed by the pre-existing electric field before the full local electromagnetic reorganization has developed.

The characteristic value of E_0 is not derived independently in the present paper. Instead, the photoelectric interaction provides a quantitative constraint on the range of values compatible with electron ejection and with the requirement that the direct electric interaction alone should not dominate the frequency-dependent threshold behavior.

Approximate trajectory calculations developed later in this paper constrain the characteristic field amplitude to the order of

$$E_0 \sim 10^9\ \mathrm{V/m}$$

More specifically, the working interval used in the quantitative calculations is approximately

$$1.1 \times 10^9\ \mathrm{V/m} \lesssim E_0 \lesssim 1.6 \times 10^9\ \mathrm{V/m}$$

This interval should not be interpreted as a physical variation of E_0 between different electromagnetic waves or frequencies. It represents the present uncertainty in determining the preferred saturated field amplitude of the model.

For the numerical calculations developed below, the representative value

$$E_0 = 1.5 \times 10^9\ \mathrm{V/m}$$

is used.

At this field amplitude, the approximate direct electric contributions obtained for the first four hydrogen levels are:

Hydrogen level	Binding energy (eV)	Approximate (W_E) (eV)
n=1	13.606	0.088
n=2	3.401	0.186
n=3	1.512	0.291
n=4	0.850	0.412

Table 1. *Estimated direct electric-field energy contribution for the first four hydrogen levels.*

Its relative importance increases as the electron binding energy decreases.

For the ground state, the direct electric contribution represents only a small fraction of the binding energy. The dominant contribution required for ejection must therefore arise from the dynamic electromagnetic response. For higher levels, the binding energy decreases rapidly, while the direct electric contribution becomes a progressively larger fraction of the total energy required for ejection.

This increasing relative importance of the direct contribution becomes important for the termination of the interaction. A weakly bound electron can reach the ejection condition earlier, so that the dynamically responding region does not have time to develop to the same extent as for a more strongly bound electron.

Thus, the direct electric field has two principal functions in the present model: it provides the immediate initial energy transfer and it perturbs the bound electron motion, thereby initiating the coupled local electromagnetic response developed in the following section. [3], [4], [6]

4. Dynamic Electromagnetic Response

The direct electric-field contribution described in the preceding section does not by itself explain the dominant frequency dependence of the photoelectric effect. In the present model, this dependence arises from the dynamic response of the pre-existing electromagnetic-wave structure during its interaction with the bound electron.

Before the interaction begins, the electromagnetic wave already contains the coupled quantities E, B, and J_D. These quantities form one dynamical field structure and occupy strongly overlapping regions. The atomic electron therefore does not create the displacement current or the magnetic field. Instead, its local current perturbs an already organized electromagnetic system.

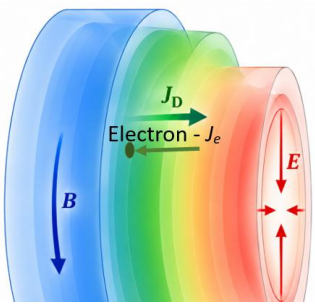

Figure 2. Local electromagnetic response during interaction with a bound electron. *The electron current J_e locally perturbs the pre-existing coupled $E - B - J_D$ structure as a whole. The resulting electromagnetic reorganization produces a response electric field E_{resp}, which can perform additional work on the electron. Only a limited local region of the larger electromagnetic wave participates effectively during a single electron-ejection event.*

The local electron current may be written schematically as

$$J_e = \rho_e v_e$$

and its interaction with the pre-existing field structure produces a local perturbation

$$J_e \rightarrow \delta(E, B, J_D)$$

This notation is intended to emphasize that the electric field, magnetic field, and displacement current respond as a coupled system. The response should not be interpreted as a sequence of completely separated processes.

The local coupling is governed by Maxwell's equations. The Ampère-Maxwell equation gives

$$\nabla \times B = \mu_0 (J_e + J_D)$$

with

$$J_D = \varepsilon_0 \frac{\partial E}{\partial t}$$

while Faraday's law gives

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

A local disturbance of the electron motion therefore modifies the current configuration, the magnetic field, the electric field, and the displacement-current distribution simultaneously.

For analytical purposes, the resulting electric field acting on the electron is written as

$$E_{\text{tot}} = E + E_{\text{resp}}$$

where E denotes the pre-existing electric field of the electromagnetic wave and E_{resp} the additional electric component produced by the local electromagnetic reorganization.

The response field performs additional work on the electron,

$$W_{\text{resp}} = \int q E_{\text{resp}} \cdot v_e \, dt$$

so that the total transferred energy is

$$W_{\text{tot}} = W_E + W_{\text{resp}}$$

The two terms do not represent independent energy sources. Both are contributions from the same electromagnetic wave. The distinction merely separates the immediate action of the pre-existing electric field from the additional energy transfer that develops through the local response.

The magnetic field itself does not perform direct work on the electron because

$$F_B = q v_e \times B$$

and therefore

$$F_B \cdot v_e = 0$$

Its importance lies in the coupled electromagnetic dynamics. A changing magnetic field is associated with a curl of the electric field, and this provides a natural route by which the internal dynamics of the electromagnetic wave can generate an additional electric response.

For an approximately harmonic local magnetic field,

$$B(t) = B_0 \sin(2\pi f t)$$

the time derivative is

$$\frac{dB}{dt} = 2\pi f B_0 \cos(2\pi f t)$$

and therefore

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

This relation introduces frequency directly into the local electromagnetic response. If the characteristic magnetic amplitude B_0 remains approximately within its saturated stability range, increasing frequency increases the maximum rate at which the magnetic structure changes.

The important quantity is therefore not merely the field amplitude, but the rate of reorganization of the coupled $(E - B - J_D)$ structure.

The dynamic response may be represented schematically as

$$\delta(E, B, J_D) \rightarrow E_{\text{resp}}$$

with the characteristic magnitude of the response field controlled by the local rate of electromagnetic change.

A first-order estimate based on Faraday's law gives

$$E_{\text{resp}} \sim L \left|\frac{dB}{dt}\right|$$

where L represents the characteristic spatial scale over which the local response develops.

The magnitude of the induced electric response depends on the geometry of the local magnetic-field variation.

For an approximately circular response region of radius R, Faraday's law gives

$$\oint_C E_{resp} \cdot dl = -\frac{d\Phi_B}{dt}$$

Assuming an approximately uniform magnetic-field component through this region, the characteristic tangential response field is

$$E_{resp} \approx -\frac{R}{2}\frac{dB}{dt}$$

Using the working geometrical relation $R \approx L/2$, this becomes

$$\left|E_{resp}\right| \approx \frac{L}{4}\left|\frac{dB}{dt}\right|$$

For a harmonic magnetic field with characteristic amplitude B_0,

$$\left|E_{resp}\right|_{max} \approx \frac{L}{4}\omega B_0$$

The energy transferred to the electron depends on the component of this response field along the electron trajectory:

$$W_{dyn} = q\int \mathrm{b}E_{resp}\cdot v, dt$$

For a favorable interaction phase and an effective electron displacement s_{eff}, a first-order estimate gives

$$W_{dyn} \sim eE_{resp}s_{eff}$$

Consequently,

$$W_{dyn} \sim \frac{\pi}{2}eLB_0 s_{eff} f$$

This expression demonstrates how a frequency-dependent energy transfer can arise from the local electromagnetic response. The proportionality to frequency is obtained when the effective interaction geometry and electron displacement remain approximately unchanged.

The circular geometry is an illustrative approximation. The actual response field, its orientation relative to electron motion, and the effective interaction displacement must ultimately be determined from the coupled electromagnetic and electron dynamics.

Using the harmonic-field relation,

$$E_{\mathrm{resp}} \sim 2\pi f B_0 L$$

This relation expresses the central frequency dependence of the proposed mechanism. For approximately constant B_0 and a given effective local interaction geometry,

$$E_{\mathrm{resp}} \propto f$$

and consequently the dynamic contribution to the electron energy also increases with frequency.

The electromagnetic response does not develop instantaneously throughout the complete wave structure. The disturbance initiated near the electron can propagate only over a finite region during the available interaction time.

If the interaction lasts for a time τ the characteristic longitudinal extent of the responding region is of the order

$$L \sim c\tau$$

while the effective transverse response scale is denoted by R.

The quantities L and R therefore describe the local response region, not the complete geometry of the electromagnetic wave.

The associated effective interaction area is written approximately as

$$A_{\mathrm{eff}} \sim \pi R^2$$

This area should not be interpreted as a sharply bounded physical disk. The actual fields overlap continuously, and different parts of the responding region may contribute with different magnitudes and orientations. The quantity A_{eff} is therefore an effective measure of the part of the local electromagnetic structure that contributes constructively to electron acceleration.

A useful first-order scaling of the dynamic contribution is then

$$W_{\mathrm{resp}} \propto A_{\mathrm{eff}}\left|\frac{dB}{dt}\right|$$

and therefore

$$W_{\text{resp}} \propto f B_0 A_{\text{eff}}$$

For approximately fixed B_0,

$$W_{\text{resp}} \propto f A_{\text{eff}}$$

This is the principal frequency-dependent result of the present section.

The frequency dependence of the photoelectric interaction therefore does not require the characteristic field amplitudes E_0 and B_0 to increase with frequency. The increase arises from the rate at which the coupled electromagnetic-wave structure can change and reorganize.

The effective interaction geometry, however, need not remain the same for every electron. Electron ejection terminates the bound-state interaction. A more weakly bound electron may reach the ejection condition earlier, before the local response has developed over the same spatial extent as for a more strongly bound electron.

Consequently, the values of L, R, and A_{eff} can depend on the termination of the interaction, even while the characteristic field amplitudes of the incident electromagnetic wave remain approximately unchanged.

The dynamic response may therefore be summarized by the sequence

$$J_e \rightarrow \delta(E, B, J_D) \rightarrow E_{\text{resp}} \rightarrow W_{\text{resp}}$$

with the frequency dependence entering primarily through

$$\left|\frac{dB}{dt}\right| \propto f$$

and the magnitude of the total dynamic contribution being controlled additionally by the effective interaction geometry.

This provides the basis for the next section, where the characteristic interaction length L, transverse scale R, and effective interaction area are considered in more detail. [3], [4]

5. Effective Interaction Length and Area

The electromagnetic response described in the preceding section is local and develops over a finite time. The complete electromagnetic-wave structure does not participate simultaneously in a single electron-ejection event. Only the region reached by the local electromagnetic reorganization before electron ejection can contribute effectively to the interaction.

To characterize this local region, the model introduces a longitudinal interaction scale L. If the effective interaction lasts for a time τ electromagnetic changes can propagate over a characteristic distance of the order

$$L \sim c\tau$$

This relation should be interpreted as a characteristic causal scale of the electromagnetic response. It does not describe the distance travelled by the electron itself, and it does not imply that the complete surrounding electromagnetic structure participates uniformly in the interaction.

The local response also develops transversely. Its effective transverse scale is denoted by R. The quantity R should not be confused with the characteristic transverse scale R_0 of the complete electromagnetic wave structure. The two quantities describe different physical properties.

The structural quantity R_0 characterizes the transverse organization and radial stability of the electromagnetic wave. In contrast, R describes how far the local photoelectric response has developed transversely before the interaction terminates.

The relation between the longitudinal and transverse response scales is not yet derived from the complete electromagnetic geometry. It is therefore written in the general form

$$R = \kappa L$$

where κ is a geometrical response factor.

For the approximate numerical model developed in the following sections, the working estimate

$$\kappa \approx \frac{1}{2}$$

is used, giving

$$R \approx \frac{L}{2}$$

The factor $1/2$ should not be interpreted as a fundamental geometrical constant. It is a first-order approximation representing the present estimate of the relation between longitudinal development of the response and the transverse region capable of contributing during the available interaction time.

The corresponding geometrical area would be

$$A = \pi R^2$$

However, the actual electromagnetic response is not expected to be uniformly distributed over this entire area. The electric field E, magnetic field B, and displacement current J_D occupy strongly overlapping regions and vary continuously across the local field structure. Different parts of the transverse region can therefore contribute with different magnitudes and orientations.

Some contributions may act constructively in the electron-ejection direction, while others may partly cancel because of field geometry and symmetry. The effective interaction area is consequently introduced as

$$A_{\text{eff}} = \eta_A \pi R^2$$

where η_A is an effective geometrical or coherence factor satisfying approximately

$$0 < \eta_A \leq 1$$

The factor η_A represents the fraction of the geometrically accessible region that contributes effectively to the energy transfer in the relevant direction.

At the present level of approximation, the simplest working assumption is

$$\eta_A \approx 1$$

so that

$$A_{\text{eff}} \approx \pi R^2$$

Combining this with

$$R = \kappa L$$

gives

$$A_{\text{eff}} = \eta_A \pi \kappa^2 L^2$$

and, for the working values

$$\kappa = \frac{1}{2}$$

and

$$\eta_A = 1$$

the relation becomes

$$A_{\text{eff}} \approx \frac{\pi L^2}{4}$$

This is the geometrical approximation used in the numerical analysis below.

The sequence of effective scales can therefore be summarized as

$$\tau \rightarrow L \rightarrow R \rightarrow A_{\text{eff}}$$

with

$$L \sim c\tau$$

$$R = \kappa L$$

and

$$A_{\text{eff}} = \eta_A \pi R^2$$

The quantities L, R, and A_{eff} are not fixed dimensions of the incident electromagnetic wave. They describe how far the local electromagnetic response has developed during a particular interaction.

This distinction becomes important when electrons with different binding energies are considered. A strongly bound electron can remain coupled to the local electromagnetic

response for a longer time. A more weakly bound electron can reach the ejection condition earlier and terminate the interaction before the response has developed over the same spatial extent.

Consequently,

$$\tau = \tau(W_b)$$

implies corresponding changes in

$$L, \quad R, \quad A_{\text{eff}}$$

even though the characteristic field amplitudes E_0 and B_0 of the incident electromagnetic wave remain approximately unchanged.

For the hydrogen ground state, the present quantitative model gives a characteristic interaction length of approximately

$$L_1 \approx 13 \text{ nm}$$

Using the working approximation

$$R = \frac{L}{2}$$

gives

$$R_1 \approx 6.5 \text{ nm}$$

and therefore

$$A_{\text{eff},1} \approx \pi R_1^2$$

or

$$A_{\text{eff},1} \approx 1.33 \times 10^{-16} \text{ m}^2$$

These values should be interpreted as effective local interaction scales rather than sharply bounded physical dimensions.

The central point is that the photoelectric interaction does not require knowledge of the complete transverse size of the electromagnetic wave structure. The relevant quantity is the region that can become dynamically involved before the electron leaves the bound state.

This local interaction region will be used in the following section to connect the dynamic electromagnetic response with Planck's constant and the observed linear dependence of photoelectric energy on frequency. [3], [7], [8]

6. Connection with Planck's Constant

The preceding sections describe a local interaction in which the dynamically generated contribution to electron ejection depends on two principal quantities: the rate of electromagnetic field variation and the effective area over which the local response develops.

For an approximately harmonic magnetic field,

$$B(t) = B_0 \sin(2\pi f t)$$

the maximum rate of change is

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

If the characteristic magnetic amplitude B_0 remains approximately within its stable range, the rate of electromagnetic change is directly proportional to frequency.

The local electric response associated with this changing magnetic field can be related to Faraday's law,

$$\oint E \cdot dl = -\frac{d\Phi_B}{dt}$$

where Φ_B is the magnetic flux through the effective interaction region.

For the present local model, the characteristic magnetic flux is written as

$$\Phi_{\text{eff}} = B_0 A_{\text{eff}}$$

where A_{eff} is the effective interaction area introduced in the preceding section.

Using the general geometrical expression

$$A_{\text{eff}} = \eta_A \pi \kappa^2 L^2$$

gives

$$\Phi_{\text{eff}} = B_0 \eta_A \pi \kappa^2 L^2$$

The electromotive effect associated with a harmonic variation of this flux has a characteristic magnitude

$$\mathcal{E} \sim 2\pi f \Phi_{\text{eff}}$$

The estimated energy transfer assumes that the effective electron motion couples constructively to the induced electromotive response. The corresponding geometrical and phase-dependent coupling factor remains to be determined from the complete electron trajectory.

The corresponding characteristic energy transferred to an electron is

$$W_{\text{resp}} \sim e\mathcal{E}$$

Therefore,

$$W_{\text{resp}} \sim 2\pi e f \Phi_{\text{eff}}$$

or

$$W_{\text{resp}} \sim 2\pi e f B_0 A_{\text{eff}}$$

This expression has the same linear dependence on frequency as the experimentally established photoelectric relation

W=hf

For the ground-state reference interaction, where the direct electric-field contribution is small compared with the total binding energy, comparison of the two expressions gives the approximate consistency condition

$$h \approx 2\pi e B_0 A_{\text{eff}}$$

or equivalently

$$h \approx 2\pi e \Phi_{\text{eff}}$$

The corresponding effective magnetic flux is therefore

$$\Phi_{\text{eff}} \approx \frac{h}{2\pi e}$$

Numerically,

$$\Phi_{\text{eff}} \approx 6.58 \times 10^{-16}\ \text{Wb}$$

This result provides a direct connection between the observed coefficient h and the local electromagnetic parameters of the interaction.

It should not, however, be interpreted as a derivation of Planck's constant from Maxwell's equations. The present model starts from the experimentally established proportionality between transferred energy and frequency and identifies the combination of local field amplitude and effective interaction geometry that reproduces the same coefficient.

The relation

$$h \approx 2\pi e B_0 A_{\text{eff}}$$

is therefore a **consistency condition** of the present electromagnetic-wave model.

Using

$$A_{\text{eff}} = \eta_A \pi \kappa^2 L^2$$

gives

$$h \approx 2\pi^2 e B_0 \eta_A \kappa^2 L^2$$

and therefore

$$B_0 \approx \frac{h}{2\pi^2 e \eta_A \kappa^2 L^2}$$

For the working approximation adopted in Section 5,

$$\kappa = \frac{1}{2}$$

and

$$\eta_A = 1$$

so that

$$A_{\text{eff}} \approx \frac{\pi L^2}{4}$$

and consequently

$$B_0 \approx \frac{2h}{\pi^2 e L^2}$$

For the ground-state reference value

$$L_1 \approx 13\ \mathrm{nm}$$

this gives approximately

$$B_0 \approx 5.0\ \mathrm{T}$$

Using the characteristic electromagnetic-wave relation

$$E_0 \approx cB_0$$

gives

$$E_0 \approx 1.5 \times 10^9\ \mathrm{V/m}$$

These values are consistent with the working field range used in the preceding sections.

The relation also shows that the photoelectric threshold does not independently determine the characteristic field amplitude and the effective interaction size. Instead, it constrains their combination.

From

$$h \approx 2\pi e B_0 A_{\mathrm{eff}}$$

it follows that

$$B_0 A_{\mathrm{eff}} \approx \mathrm{const.}$$

for the ground-state reference interaction.

Thus, a larger characteristic magnetic amplitude corresponds to a smaller effective interaction area, while a smaller magnetic amplitude requires a larger participating area in order to reproduce the same frequency coefficient.

Using

$$A_{\mathrm{eff}} \propto L^2$$

gives approximately

$$B_0 L^2 \approx \mathrm{const.}$$

for fixed values of κ and η_A.

This explains why the characteristic field amplitudes and the local interaction dimensions cannot yet be determined independently from the photoelectric threshold alone. The present calculation defines a family of mutually compatible values.

The significance of the result lies primarily in the appearance of a characteristic local magnetic flux,

$$\Phi_{\mathrm{eff}} \approx \frac{h}{2\pi e}$$

which connects the internal electromagnetic response with the observed linear dependence of transferred energy on frequency.

Within the present model, the role of frequency is therefore separated from the role of field amplitude. Frequency determines how rapidly the local $E - B - J_D$ structure changes, while B_0 and A_{eff} determine the magnitude of the local response that can participate before electron ejection terminates the interaction.

For electrons in more weakly bound states, the effective interaction area need not reach the same value as in the ground-state reference case. Earlier ejection can terminate the response at smaller L, R, and A_{eff}. The relation between this termination and the binding energy is developed in the following section. [1], [2], [5]

7. Electron Ejection and Termination of the Interaction

The local interaction between the electromagnetic wave and a bound electron does not continue indefinitely. Its effective duration is determined by the evolution of the electron itself.

During the interaction, energy is transferred through two coupled contributions,

$$W_{\mathrm{tot}} = W_E + W_{\mathrm{resp}}$$

where W_E is the direct electric-field contribution and W_{resp} is the dynamically generated electromagnetic contribution.

Electron ejection becomes possible when the accumulated transferred energy reaches the binding requirement,

$$W_E + W_{\mathrm{resp}} \geq W_b$$

At the threshold,

$$W_E + W_{\mathrm{resp}} \approx W_b$$

Once this condition is reached, the electron leaves the bound state and the original bound-state interaction terminates.

This termination condition gives the effective interaction dimensions introduced in Section 5 their physical meaning. The quantities L, R, and A_{eff} do not describe fixed dimensions of the incident electromagnetic wave. They describe how far the local electromagnetic response has developed before electron ejection interrupts the interaction.

For a particular bound state n, the effective interaction time may therefore be written as

$$\tau_n = \tau(W_{b,n})$$

with the corresponding interaction scales

$$L_n \sim c\tau_n$$

$$R_n = \kappa_n L_n$$

and

$$A_{\mathrm{eff},n} = \eta_{A,n}\pi\kappa_n^2 L_n^2$$

A strongly bound electron generally requires a larger accumulated energy before ejection and can therefore remain coupled to the local electromagnetic response for a longer interval. A more weakly bound electron can reach the ejection condition earlier.

Consequently,

$$W_{b,n} < W_{b,1}$$

can lead to

$$\tau_n < \tau_1$$

and therefore to smaller effective interaction dimensions.

This reduction does not imply that the electromagnetic wave itself becomes smaller or changes its characteristic structure when it encounters a different atomic state. What changes is only the portion of the local field structure that becomes dynamically involved before the electron leaves the bound state.

The termination mechanism becomes particularly important because the relative direct electric-field contribution increases for the higher hydrogen levels.

At threshold, the dynamic response needs to provide only the energy not already supplied directly by the electric field,

$$W_{\mathrm{resp},n} = W_{b,n} - W_{E,n}$$

This quantity will be referred to as the required dynamic contribution.

From Section 6, the first-order dynamic response scales as

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

and with

$$A_{\mathrm{eff}} = \eta_A \pi\kappa^2 L^2$$

we obtain

$$W_{\mathrm{resp}} \propto f B_0 \eta_A \kappa^2 L^2$$

For two different bound states, this gives the general ratio

$$\frac{W_{\mathrm{resp},n}}{W_{\mathrm{resp},1}} = \frac{f_n}{f_1}\frac{B_{0,n}}{B_{0,1}}\frac{\eta_{A,n}}{\eta_{A,1}}\frac{\kappa_n^2}{\kappa_1^2}\frac{L_n^2}{L_1^2}$$

The present working model assumes that the incident electromagnetic wave retains approximately the same characteristic field amplitude for the different hydrogen levels,

$$B_{0,n} \approx B_{0,1}$$

and, as a first approximation, that the geometrical response factors do not change strongly,

$$\kappa_n \approx \kappa_1$$

$$\eta_{A,n} \approx \eta_{A,1}$$

Under these assumptions,

$$\frac{W_{\mathrm{resp},n}}{W_{\mathrm{resp},1}} \approx \frac{f_n}{f_1}\frac{L_n^2}{L_1^2}$$

and therefore

$$L_n = L \sqrt[1]{\frac{W_{\mathrm{resp},n} f_1}{W_{\mathrm{resp},1} f_n}}$$

Using

$$W_{\mathrm{resp},n} = W_{b,n} - W_{E,n}$$

gives

$$L_n = L \sqrt[1]{\frac{W_{b,n} - W_{E,n} f_1}{W_{b,1} - W_{E,1} f_n}}$$

For hydrogen at the photoelectric threshold,

$$hf_n = W_{b,n}$$

and therefore

$$\frac{f_1}{f_n} = \frac{W_{b,1}}{W_{b,n}}$$

so that the working termination relation becomes

$$L_n = L \sqrt[1]{\frac{W_{b,n} - W_{E,n} W_{b,1}}{W_{b,1} - W_{E,1} W_{b,n}}}$$

This relation expresses the central idea of the termination model: as the direct electric contribution becomes a larger fraction of the binding requirement, less dynamic energy transfer is required and the electron can be ejected before the electromagnetic response has developed over the full ground-state reference region.

The corresponding transverse response scale is

$$R_n = \kappa L_n$$

and, using the present working approximation,

$$R_n \approx \frac{L_n}{2}$$

The effective interaction area is correspondingly

$$A_{\mathrm{eff},n} = \eta_A \pi \kappa^2 L_n^2$$

or, for the present working values,

$$A_{\mathrm{eff},n} \approx \frac{\pi L_n^2}{4}$$

For the representative value

$$E_0 = 1.5 \times 10^9 \ \mathrm{V/m}$$

the approximate direct electric contributions obtained in Section 3 are

n	W_b (eV)	W_E (eV)
1	13.606	0.088
2	3.401	0.186
3	1.512	0.291
4	0.850	0.412

Table 2. *Comparison of hydrogen binding energies and direct electric-field contributions used to determine the remaining energy required from the dynamic response.*

Using the ground-state reference value

$$L_1 = 13.0 \ \mathrm{nm}$$

the phenomenological termination relation gives approximately

n	L_n (nm)	R_n (nm)
1	13.00	6.50
2	12.69	6.35
3	11.72	5.86
4	9.36	4.68

Table 3. *Calculated effective interaction dimensions for hydrogen levels n = 1–4. Earlier electron ejection limits the spatial development of the electromagnetic response.*

The reduction is modest for the first two excited states but becomes much stronger for n=4, where the direct electric contribution already represents a substantial fraction of the binding energy.

The resulting mechanism is therefore self-terminating. The incident electromagnetic wave can retain approximately the same characteristic field amplitudes, while the

atomic binding energy determines how long the local interaction is allowed to develop.

The causal sequence can be summarized as

$$W_E + W_{\mathrm{resp}}(t) \rightarrow W_b \rightarrow \text{electron ejection} \rightarrow \text{termination of the local response}$$

This provides a physical distinction between the structure of the electromagnetic wave and the extent of an individual photoelectric interaction.

It is important, however, to distinguish the termination mechanism itself from the quantitative relation used above. The physical statement that electron ejection terminates the bound-state interaction is a central assumption of the model. The equation for L_n, by contrast, is presently a phenomenological consequence of the threshold energy balance combined with the assumed scaling

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

and the working geometrical relations for A_{eff}.

The calculated values of L_n should therefore not yet be interpreted as independent predictions. A stronger version of the model must calculate the time-dependent electron trajectory and the coupled $E - B - J_D$ response directly and determine the instant of ejection without imposing the final threshold energy balance in advance.

The present termination relation nevertheless provides a consistent working description of how one electromagnetic-wave structure with approximately common characteristic field amplitudes can interact with electrons having substantially different binding energies. [5], [6]

8. Quantitative Results for Hydrogen n=1–4

The relations developed in the preceding sections can now be applied to the first four hydrogen energy levels. The purpose of this calculation is to examine whether one common set of characteristic electromagnetic-wave field amplitudes can remain consistent with electrons having substantially different binding energies.

For hydrogen, the binding energy is

$$W_{b,n} = \frac{13.606\ \mathrm{eV}}{n^2}$$

At the photoelectric threshold,

$$hf_n = W_{b,n}$$

and therefore

$$f_n = \frac{W_{b,n}}{h}$$

The corresponding threshold wavelength is

$$\lambda_n = \frac{c}{f_n}$$

The first four levels are therefore approximately:

n	W_b (eV)	f_{th} (Hz)	λ_{th} (nm)
1	13.606	3.29×10^{15}	91.1
2	3.401	8.22×10^{14}	364.6
3	1.512	3.66×10^{14}	820
4	0.850	2.06×10^{14}	1458

Table 4. *Hydrogen binding energies and corresponding threshold frequencies and wavelengths. These values provide the reference conditions for the photoelectric interaction model.*

For the quantitative comparison, the representative characteristic field values

$$E_0 = 1.5 \times 10^9\ \mathrm{V/m}$$

and

$$B_0 \approx 5.0\ \mathrm{T}$$

are used, together with the ground-state reference interaction length

$$L_1 = 13.0\ \mathrm{nm}$$

For the working geometry,

$$\kappa = \frac{1}{2}$$

and

$$\eta_A = 1$$

so that

$$R_n = \frac{L_n}{2}$$

and

$$A_{\mathrm{eff},n} \approx \frac{\pi L_n^2}{4}$$

The approximate direct electric-field contributions obtained in Section 3 are

$$W_{E,1} = 0.088\ \mathrm{eV}$$

$$W_{E,2} = 0.186\ \mathrm{eV}$$

$$W_{E,3} = 0.291\ \mathrm{eV}$$

$$W_{E,4} = 0.412\ \mathrm{eV}$$

The dynamic electromagnetic response must therefore provide

$$W_{\mathrm{resp},n} = W_{b,n} - W_{E,n}$$

giving approximately

$$W_{\mathrm{resp},1} = 13.518\ \mathrm{eV}$$

$$W_{\mathrm{resp},2} = 3.215\ \mathrm{eV}$$

$$W_{\mathrm{resp},3} = 1.221\ \mathrm{eV}$$

and

$$W_{\mathrm{resp},4} = 0.438\ \mathrm{eV}$$

The corresponding interaction lengths follow from the phenomenological termination relation derived in Section 7,

$$L_n = L_1 \sqrt{\frac{W_{b,n} - W_{E,n} W_{b,1}}{W_{b,1} - W_{E,1} W_{b,n}}}$$

Using

$$L_1 = 13.0\ \mathrm{nm}$$

gives approximately

n	W_b (eV)	W_E (eV)	W_{resp} (eV)	L_n (nm)	R_n (nm)
1	13.606	0.088	13.518	13.00	6.50
2	3.401	0.186	3.215	12.69	6.35
3	1.512	0.291	1.221	11.72	5.86
4	0.850	0.412	0.438	9.36	4.68

Table 5. *Summary of the calculated energy contributions and interaction dimensions. The model retains common characteristic field amplitudes while the effective interaction region decreases for higher hydrogen levels.*

The direct and dynamic fractions of the threshold energy are therefore approximately

n	Direct W_E/W_b	Dynamic W_{resp}/W_b
1	0.6%	99.4%
2	5.5%	94.5%
3	19.2%	80.8%
4	48.5%	51.5%

Table 6. *Relative contributions of direct electric-field work and dynamic electromagnetic response. The dynamic contribution dominates at n = 1, while the two become nearly equal at n = 4.*

The calculation reveals two complementary trends.

First, the absolute direct electric contribution increases moderately with increasing n, while the binding energy decreases rapidly. The relative importance of the direct contribution therefore grows strongly for the higher levels.

For the ground state, almost the entire binding requirement must be supplied through the dynamic electromagnetic response. For n=4, in contrast, the direct electric field already supplies nearly one half of the required energy.

Second, the effective interaction dimensions decrease as the binding energy becomes smaller. Since the electron reaches the ejection condition earlier, the local electromagnetic response has less time to develop.

The reduction in L is modest for the first two excited states but becomes significant for n=4,

$$L_1 = 13.0\ \text{nm}$$

compared with

$$L_4 = 9.36\ \text{nm}$$

Since the effective area scales as

$$A_{\text{eff}} \propto L^2$$

the reduction in participating area is larger than the reduction in interaction length.

For n=4,

$$\frac{A_{\text{eff},4}}{A_{\text{eff},1}} \approx \left(\frac{9.36}{13.0}\right)^2$$

which gives approximately

$$\frac{A_{\text{eff},4}}{A_{\text{eff},1}} \approx 0.52$$

Thus, only about one half of the ground-state effective interaction area is required before the n=4 electron reaches the ejection condition.

This behavior is consistent with the proposed termination mechanism. The electromagnetic wave does not need different characteristic field amplitudes for the four hydrogen levels. Instead, the atomic binding energy determines how long the local interaction continues and therefore how much of the available response region becomes dynamically involved.

The present calculation should not, however, be interpreted as four independent predictions of the hydrogen threshold energies. The termination relation used to obtain L_n was constructed from the threshold energy balance together with the assumed dynamic-response scaling

$$W_{\text{resp}} \propto f B_0 A_{\text{eff}}$$

The exact recovery of

$$W_E + W_{\text{resp}} = W_b$$

is therefore built into the present phenomenological construction.

The quantitative significance of the result is different: it shows that one common electromagnetic-wave field scale can be made internally consistent with substantially different hydrogen binding energies by allowing the effective interaction region to terminate at different stages of its development.

The required geometrical adjustment is moderate. The characteristic field amplitudes remain approximately unchanged, while the effective interaction length decreases from about $13\ \text{nm}$ to about $9.4\ \text{nm}$ over the first four hydrogen levels.

The resulting working picture is therefore

$$E_0, B_0 \approx \text{const.}$$

$$f_n \rightarrow \text{rate of electromagnetic response}$$

$$W_{b,n} \rightarrow \text{termination time}$$

$$\tau_n \rightarrow L_n, R_n, A_{\text{eff},n}$$

This provides the quantitative basis for the interpretation of the photoelectric threshold developed in the following section. [5], [6]

9. Interpretation of the Photoelectric Threshold

The photoelectric threshold is conventionally expressed as the minimum frequency at which an incident electromagnetic wave can eject an electron from a bound state.

In the present model, this threshold is interpreted as a local dynamical energy-transfer condition.

Electron ejection becomes possible when the accumulated energy transferred during the local interaction reaches the binding requirement,

$$W_E + W_{\text{resp}} \geq W_b$$

At threshold,

$$W_E + W_{\text{resp}} \approx W_b$$

where W_E is the direct electric-field contribution and W_{resp} is the dynamically generated electromagnetic contribution.

For a given atomic state, the binding energy W_b is fixed. The direct contribution depends primarily on the characteristic electric-field amplitude E_0, the electron trajectory, and the duration of the interaction.

The principal frequency dependence enters through the dynamic electromagnetic response.

For an approximately harmonic magnetic field,

$$B(t) = B_0 \sin(2\pi f t)$$

the maximum rate of change is

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

For approximately constant B_0,

$$\left|\frac{dB}{dt}\right|_{max} \propto f$$

Increasing frequency therefore increases the rate at which the coupled $(E - B - J_D)$ structure can reorganize during its interaction with the electron.

To first approximation,

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

The threshold frequency is consequently the lowest frequency for which the combined direct and dynamic contributions can reach the binding energy before the bound-state interaction terminates.

This provides a local physical interpretation of the photoelectric threshold. The decisive question is not whether the complete electromagnetic wave contains enough total energy to eject the electron. The decisive question is whether sufficient energy can be transferred through the local interaction during the available time.

It is therefore useful to distinguish between the total energy of the electromagnetic wave,

$$W_{\mathrm{wave}}$$

and the energy transferred locally to one electron,

$$W_{\mathrm{tr}} = W_E + W_{\mathrm{resp}}$$

The condition for photoemission is not, in the present model,

$$W_{\mathrm{wave}} \geq W_b$$

but rather

$$W_{\mathrm{tr}} \geq W_b$$

The total electromagnetic-wave energy and the energy transferred in a single photoelectric event are therefore different physical quantities.

At frequencies below threshold,

$$f < f_{\mathrm{th}}$$

the direct electric field can still perturb the electron and a dynamic electromagnetic response can still develop. However, during the available interaction,

$$W_E + W_{\mathrm{resp}} < W_b$$

and the electron remains bound.

The local $(E - B - J_D)$ structure and the electron can therefore interact without producing photoemission.

At the threshold frequency,

$$f = f_{\mathrm{th}}$$

the accumulated transferred energy reaches the binding requirement,

$$W_E + W_{\mathrm{resp}} = W_b$$

and electron ejection becomes possible.

Below the photoelectric threshold, the local electromagnetic interaction may remain oscillatory, with positive and negative energy-transfer contributions partly compensating over successive phases. The interaction therefore need not produce a continuously increasing electron energy. A quantitative

description of this behavior requires the time-dependent coupled electron-field dynamics.

The threshold therefore marks the transition between an interaction that remains below the binding requirement and one capable of reaching it.

The interpretation above also clarifies why the characteristic amplitudes E_0 and B_0 need not increase systematically with frequency.

Two electromagnetic waves can have approximately the same characteristic field amplitudes while differing in frequency. Their local dynamic response can nevertheless differ because

$$\left|\frac{dB}{dt}\right| \propto f$$

and therefore the electromagnetic reorganization proceeds at a different rate.

Frequency thus controls primarily the **rate of the local response**, whereas the characteristic amplitudes and effective interaction geometry control its magnitude.

The connection with the conventional photoelectric relation follows from the approximately linear frequency dependence derived in Section 6,

$$W_{\mathrm{resp}} \sim 2\pi e f B_0 A_{\mathrm{eff}}$$

For the ground-state reference interaction, where the direct contribution is small,

$$W_E \ll W_b$$

the threshold condition becomes approximately

$$W_b \approx 2\pi e f B_0 A_{\mathrm{eff}}$$

Comparison with

$$W_b = hf$$

gives the consistency relation

$$h \approx 2\pi e B_0 A_{\mathrm{eff}}$$

or

$$\Phi_{\mathrm{eff}} \approx \frac{h}{2\pi e}$$

with

$$\Phi_{\mathrm{eff}} = B_0 A_{\mathrm{eff}}$$

Within the present model, the coefficient h therefore constrains the characteristic local magnetic flux involved in the ground-state reference interaction.

This relation should not be interpreted as a derivation of Planck's constant. It expresses the local electromagnetic combination required for the proposed interaction model to reproduce the experimentally established proportionality between transferred energy and frequency.

For higher hydrogen levels, the situation is modified because the direct electric contribution becomes a larger fraction of the binding energy and electron ejection occurs earlier.

The effective area is then reduced,

$$A_{\mathrm{eff},n} < A_{\mathrm{eff},1}$$

and the ground-state flux condition should not be imposed unchanged on every atomic level.

Instead, each interaction terminates when

$$W_{E,n} + W_{\mathrm{resp},n} = W_{b,n}$$

is first reached.

This makes the threshold simultaneously an energy condition and a termination condition.

Once the binding requirement is reached,

$$W_{\mathrm{tr}} = W_b$$

the electron leaves the bound state and the original interaction no longer develops in the same manner. Consequently, the quantities

$$\tau, \quad L, \quad R, \quad A_{\mathrm{eff}}$$

are determined by how long the interaction continues before ejection.

The causal structure of the model can therefore be summarized as

$$f \rightarrow \frac{dB}{dt} \rightarrow \delta(E, B, J_D) \rightarrow E_{\text{resp}} \rightarrow W_{\text{resp}}$$

together with the simultaneous direct contribution

$$E \rightarrow W_E$$

and the termination condition

$$W_E + W_{\text{resp}} = W_b$$

This interpretation separates three roles clearly.

Frequency determines how rapidly the electromagnetic structure can respond.

The binding energy determines how much energy must be transferred.

Electron ejection determines when the interaction terminates.

The photoelectric threshold therefore emerges, within the present model, as the lowest frequency for which the local electromagnetic interaction can reach the binding requirement before termination.

The relation

W=hf

is consequently interpreted here as a relation governing the energy that can be transferred through the local frequency-dependent interaction. It is not assumed to specify the total energy stored in the complete electromagnetic wave structure.

The present analysis is concerned primarily with the threshold condition. The detailed division of energy above threshold, including the kinetic energy of the emitted electron, remains outside the present approximation. [1], [2], [5]

10. Model Accuracy and Open Problems

The model developed in the preceding sections should be regarded as a first quantitative description of a local photoelectric interaction within the electromagnetic-wave structure introduced in Parts IV and V.

Its present purpose is not to provide a complete solution of the coupled electron-field dynamics, but to determine whether the proposed mechanism can connect frequency, local electromagnetic response, interaction geometry, and electron ejection within one internally consistent framework.

The calculations identify a representative characteristic electric-field amplitude of the order

$$E_0 \sim 10^9 \text{ V/m}$$

with the working interval

$$1.1 \times 10^9 \text{ V/m} \lesssim E_0 \lesssim 1.6 \times 10^9 \text{ V/m}$$

and a corresponding magnetic amplitude of the order

$$B_0 \sim 5 \text{ T}$$

For the hydrogen ground-state reference interaction, the present approximation gives

$$L_1 \approx 13 \text{ nm}$$

and, using the working geometrical relation,

$$R_1 \approx 6.5 \text{ nm}$$

These values should not be interpreted as independently measured or uniquely derived constants. They form a mutually constrained working parameter set.

In particular, the photoelectric relation constrains approximately the combination

$$B_0 A_{\text{eff}} \approx \frac{h}{2\pi e}$$

rather than determining B_0 and A_{eff} independently.

The first major open problem is therefore the **independent determination of the local interaction geometry**.

The present analysis uses

$$R = \kappa L$$

and

$$A_{\text{eff}} = \eta_A \pi \kappa^2 L^2$$

with the working values

$$\kappa \approx \frac{1}{2}$$

and

$$\eta_A \approx 1$$

These relations provide a useful first approximation, but neither \(\kappa\) nor η_A has yet been derived from the actual three-dimensional electromagnetic response.

A complete calculation should determine how the perturbation initiated by the electron propagates longitudinally and transversely through the overlapping $E - B - J_D$ structure.

The effective area should ultimately emerge from the real field distribution rather than from an assumed circular geometry.

The second major open problem concerns the **time-dependent coupled response of E, B, and J_D**.

The present model represents the local disturbance schematically as

$$J_e \rightarrow \delta(E, B, J_D)$$

followed by the development of an electric response field,

$$\delta(E, B, J_D) \rightarrow E_{\text{resp}}$$

This notation summarizes the proposed physical mechanism but does not yet determine the magnitude, phase, spatial distribution, or propagation speed of the individual perturbations.

A more complete treatment should solve the coupled electromagnetic evolution around the electron and determine directly how the pre-existing wave structure reorganizes.

This is especially important for the displacement current J_D. In the present model, J_D is not merely a mathematical term in Maxwell's equations but an intrinsic part of the internal electromagnetic dynamics of the wave. Its spatial distribution and its response to the electron current therefore require explicit calculation.

The third open problem is the **independent determination of the interaction time and interaction length**.

At present,

$$L \sim c\tau$$

provides a causal scale, while the actual value of L is inferred indirectly from the threshold-energy balance.

For the higher hydrogen levels, the termination relation

$$L_n = L \sqrt[1]{\frac{W_{b,n} - W_{E,n} W_{b,1}}{W_{b,1} - W_{E,1} W_{b,n}}}$$

is constructed from the assumed scaling of the dynamic response together with the threshold condition.

Therefore, the numerical values obtained for L_n are not yet independent predictions.

A stronger calculation should determine the accumulated transferred energy continuously,

$$W_{\text{tr}}(t) = W_E(t) + W_{\text{resp}}(t)$$

and identify the first time $t = t_{\text{ej}}$ at which

$$W_{\text{tr}}(t_{\text{ej}}) = W_b$$

The termination time,

$$\tau = t_{\text{ej}}$$

would then determine L, R, and A_{eff} dynamically rather than through the final energy balance.

The fourth open problem concerns the **electron trajectory itself**.

The present estimates of the direct electric contribution use a simplified semiclassical description of the bound electron. In reality, the electron trajectory and the electromagnetic response evolve simultaneously.

The local field changes the electron motion,

$$m_e \frac{dv_e}{dt} = q(E + v_e \times B)$$

while the resulting electron current modifies the local electromagnetic structure.

The complete problem is therefore coupled in both directions:

$$(E, B, J_D) \rightarrow v_e$$

and

$$v_e \rightarrow J_e \rightarrow \delta(E, B, J_D)$$

A self-consistent calculation should follow these processes simultaneously.

The fifth open problem concerns the **origin of the characteristic field amplitudes E_0 and B_0**.

Parts IV and V suggest that stable electromagnetic waves possess preferred local field amplitudes associated with radial stability and saturation. The photoelectric calculation is consistent with characteristic values near

$$E_0 \approx 1.5 \times 10^9 \,\text{V/m}$$

and

$$B_0 \approx 5 \,\text{T}$$

but Part B3 does not derive these values independently.

Their origin should ultimately follow from the internal stability conditions of the electromagnetic wave rather than from fitting the photoelectric interaction.

This question is directly related to the still-undetermined structural transverse scale R_0.

The present photoelectric model does not require a numerical value of R_0. This is an advantage, because R_0 should be regarded as a property of the electromagnetic-wave structure itself, not as a parameter adjusted to the atomic interaction.

Nevertheless, a complete theory should determine R_0 independently from the radial structure, field saturation, energy content, and coherent organization of the wave.

The sixth open problem concerns the **connection with Planck's constant**.

The present model gives the consistency condition

$$h \approx 2\pi e B_0 A_{\text{eff}}$$

or

$$\Phi_{\text{eff}} \approx \frac{h}{2\pi e}$$

This is a notable quantitative relation, but it does not yet explain why the electromagnetic-wave structure should naturally produce this particular effective flux.

A stronger theory should derive the characteristic combination

$$B_0 A_{\text{eff}}$$

from the internal field dynamics and geometry rather than obtaining it by comparison with the empirical coefficient h.

Such a derivation would provide a much stronger test of the proposed mechanism.

The seventh open problem concerns the **relation between the local photoelectric interaction and the larger electromagnetic-wave structure**.

The present theory intentionally separates the local response scales

$$L, \quad R, \quad A_{\text{eff}}$$

from the structural transverse scale

$$R_0$$

This separation should be retained.

However, a complete theory should explain how a local nanometre-scale disturbance is embedded in the larger coherent electromagnetic wave, how energy is transported from the surrounding structure into the active response region, and how the wave reorganizes after the energy transfer.

The Poynting vector provides the general energy-flow relation,

$$S = \frac{1}{\mu_0} E \times B$$

but the actual local redistribution associated with a photoelectric event remains to be calculated.

The eighth open problem is the extension of the model beyond hydrogen.

Hydrogen provides a particularly transparent first test because its binding energies are well defined and its structure is comparatively simple. Other atoms introduce multiple electrons, screening, different orbital geometries, and more complex binding environments.

If E_0 and B_0 are properties of the incident electromagnetic wave rather than of the target atom, their characteristic values should remain transferable while the electron trajectories, binding energies, interaction geometry, and termination conditions change.

Such calculations would provide an important test of whether the present mechanism is genuinely general.

The model also remains semiclassical at its present stage. The hydrogen binding energies are used as physical input rather than derived from the electromagnetic-wave model. Part B3 therefore does not attempt to replace the quantum-mechanical derivation of the atomic spectrum.

Its more limited objective is to investigate the mechanism by which an electromagnetic wave transfers energy to an already bound electron.

The present results can therefore be separated into two categories.

The first consists of working quantitative constraints:

$$E_0 \sim 10^9\ \mathrm{V/m}$$

$$B_0 \sim 5\ \mathrm{T}$$

$$L_1 \sim 13\ \mathrm{nm}$$

together with the effective-flux condition

$$B_0 A_{\mathrm{eff},1} \approx \frac{h}{2\pi e}$$

The second consists of the proposed dynamical mechanism,

$$J_e \rightarrow \delta(E, B, J_D) \rightarrow E_{\mathrm{resp}} \rightarrow W_{\mathrm{resp}}$$

combined with the direct contribution

$$E \rightarrow W_E$$

and terminated by

$$W_E + W_{\mathrm{resp}} = W_b$$

The principal task for further development is therefore to connect these two levels: the coupled electromagnetic dynamics should reproduce the presently inferred interaction scales and field constraints without imposing them from the final photoelectric threshold.

If this can be achieved, the model would move from an internally consistent phenomenological description toward a genuinely predictive dynamical theory of the photoelectric interaction

11. Discussion

The analysis developed in this paper suggests that the photoelectric effect can be approached as a local dynamical interaction between a bound electron and a coherent electromagnetic wave structure.

The central question is not simply whether the complete incident electromagnetic wave contains sufficient energy to eject the electron. The relevant question is how much energy can be transferred locally to the bound electron during the finite interaction.

In the proposed model, the electromagnetic wave contains the coupled dynamical quantities E, B, and J_D. These quantities occupy overlapping regions and form one organized electromagnetic structure. When the wave encounters a bound electron, the electron current locally perturbs this pre-existing organization.

The interaction is represented schematically as

$$J_e \rightarrow \delta(E, B, J_D)$$

and the resulting electromagnetic reorganization produces an additional electric response,

$$\delta(E, B, J_D) \rightarrow E_{\text{resp}}$$

which can perform work on the electron.

For analytical purposes, the total transferred energy is separated into

$$W_{\text{tr}} = W_E + W_{\text{resp}}$$

where W_E is the direct contribution of the pre-existing electric field and W_{resp} is the additional contribution associated with the dynamic electromagnetic response.

These two terms do not represent separate energy sources. They are two parts of the same interaction.

The direct electric field acts immediately when the electromagnetic wave reaches the electron. However, this contribution alone does not reproduce the dominant frequency dependence of the photoelectric threshold.

In the present model, the principal frequency dependence enters through the changing electromagnetic structure. For an approximately harmonic magnetic field,

$$B(t) = B_0 \sin(2\pi f t)$$

and therefore

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

For approximately stable B_0,

$$\left|\frac{dB}{dt}\right| \propto f$$

Thus, increasing frequency does not require a proportional increase of the characteristic field amplitudes. Instead, it increases the rate at which the local $E - B - J_D$ structure changes and can respond to the perturbation produced by the electron.

This distinction is important. The model separates the characteristic amplitudes of the electromagnetic wave from the frequency-dependent rate of its internal dynamics.

The first-order response relation developed in this paper is

$$W_{\text{resp}} \propto f B_0 A_{\text{eff}}$$

where A_{eff} represents the effective local region participating in the interaction.

The quantities L, R, and A_{eff} describe this local interaction region. They are not geometrical dimensions of the complete electromagnetic wave.

The structural transverse scale R_0, discussed in Part B2, belongs to the organization of the electromagnetic wave itself. Its numerical value is not required in the present photoelectric model.

This separation between global wave structure and local interaction geometry is one of the important consequences of the present analysis.

For the ground-state reference interaction, the working model gives approximately

$$L_1 \approx 13\ \text{nm}$$

and

$$R_1 \approx 6.5\ \mathrm{nm}$$

using the working geometrical approximation

$$R = \kappa L$$

with

$$\kappa \approx \frac{1}{2}$$

and

$$A_{\mathrm{eff}} = \eta_A \pi R^2$$

with

$$\eta_A \approx 1$$

at the present level of approximation.

These quantities should not be regarded as independently established constants. They form part of a mutually constrained parameter set together with E_0 and B_0.

The present calculations indicate characteristic working values near

$$E_0 \approx 1.5 \times 10^9\ \mathrm{V/m}$$

and

$$B_0 \approx 5\ \mathrm{T}$$

but these values are not yet independently derived from the internal stability of the electromagnetic wave.

An important quantitative relation emerges when the dynamic response is compared with the experimentally established frequency coefficient.

For the ground-state reference interaction,

$$h \approx 2\pi e B_0 A_{\mathrm{eff}}$$

or equivalently,

$$B_0 A_{\mathrm{eff}} \approx \frac{h}{2\pi e}$$

This relation suggests that the coefficient h can be represented, within the present approximation, by a characteristic local electromagnetic combination involving charge, magnetic-field amplitude, and effective interaction area.

It is important to distinguish this result from a derivation of Planck's constant. The model currently identifies the combination required to reproduce the observed proportionality

$$W \propto f$$

but does not yet derive that combination independently from the internal electromagnetic-wave dynamics.

A deeper theory should therefore explain why the local interaction develops the characteristic effective magnetic flux

$$\Phi_{\mathrm{eff}} \approx \frac{h}{2\pi e}$$

without imposing the value of h externally.

The hydrogen calculations provide a second important result.

A common characteristic field scale can be retained for the first four hydrogen levels. What changes is not primarily the incident electromagnetic wave, but the duration and spatial extent of the local interaction.

For the ground state, the direct electric contribution is only a small fraction of the binding energy, so almost the entire required energy must be supplied through the dynamic electromagnetic response.

For higher levels, the binding energy decreases rapidly while the relative importance of the direct electric contribution increases.

Consequently, the ejection condition

$$W_E + W_{\mathrm{resp}} = W_b$$

is reached earlier.

The interaction therefore terminates at a smaller L, R, and A_{eff}.

For the present working model,

$$L_1 \approx 13.0\ \mathrm{nm}$$

while

$$L_4 \approx 9.4\ \mathrm{nm}$$

The corresponding effective area decreases more strongly because approximately

$$A_{\mathrm{eff}} \propto L^2$$

This provides a natural self-termination mechanism. A weakly bound electron does not require the same extent of dynamically developed interaction as a strongly bound electron.

At the same time, the numerical agreement for the first four hydrogen levels must be interpreted correctly. The relation used to calculate L_n was constructed from the threshold energy balance together with the assumed scaling

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

The recovery of the hydrogen threshold energies is therefore an internal consistency test of the proposed interaction mechanism, not yet an independent prediction of those energies.

A decisive next step is to calculate the interaction dynamically.

Instead of obtaining L from the final threshold condition, the coupled evolution of the electron and the electromagnetic field should determine continuously

$$W_{\mathrm{tr}}(t) = W_E(t) + W_{\mathrm{resp}}(t)$$

and electron ejection should occur at the first time for which

$$W_{\mathrm{tr}}(t) = W_b$$

The corresponding interaction time would then determine

$$\tau, \quad L, \quad R, \quad A_{\mathrm{eff}}$$

without imposing them through the final energy balance.

The present interpretation also introduces a distinction between the total energy of the electromagnetic wave and the energy transferred in a single photoelectric event.

The relevant ejection condition is

$$W_{\mathrm{tr}} \geq W_b$$

not necessarily

$$W_{\mathrm{wave}} \geq W_b$$

for the complete electromagnetic wave structure.

Only a local fraction of the available electromagnetic energy needs to participate in the interaction with a particular electron.

Within this interpretation, the familiar relation

W=hf

describes the characteristic energy associated with the local frequency-dependent transfer process. It is not assumed here to define the complete energy content of the electromagnetic wave.

The proposed model therefore connects several quantities that are usually considered separately:

$$f, \quad \frac{dB}{dt}, \quad \delta(E, B, J_D), \quad A_{\mathrm{eff}}, \quad W_b, \quad t_{\mathrm{ej}}$$

The central dynamical sequence can be summarized as

$$f \rightarrow \frac{dB}{dt} \rightarrow \delta(E, B, J_D) \rightarrow E_{\mathrm{resp}} \rightarrow W_{\mathrm{resp}}$$

together with the direct contribution

$$E \rightarrow W_E$$

and the termination condition

$$W_E + W_{\mathrm{resp}} = W_b$$

The present model is therefore more than a geometrical interpretation of the photoelectric effect. It proposes a specific dynamical mechanism by which frequency can control local energy transfer without requiring the characteristic amplitudes E_0 and B_0 themselves to increase with frequency.

Its strongest present result is the identification of a coherent physical chain linking frequency, local field dynamics, effective interaction geometry, and electron ejection.

Its principal unresolved task is equally clear: the presently inferred parameters and scaling relations must ultimately emerge from a self-consistent calculation of the coupled electron and $E - B - J_D$ dynamics.

12. Conclusions

This paper has developed a local dynamical model of the photoelectric interaction within the electromagnetic-wave framework introduced in Parts IV and V.

The interaction is treated as a local event in which a bound atomic electron perturbs a pre-existing electromagnetic structure formed by the coupled electric field E, magnetic field B, and displacement current J_D.

The total transferred energy is separated, for analytical purposes, into a direct electric-field contribution and a dynamically generated electromagnetic contribution,

$$W_{\mathrm{tr}} = W_E + W_{\mathrm{resp}}$$

The direct electric field acts immediately on the bound electron, while the dynamic contribution develops through the local reorganization of the coupled $E - B - J_D$ structure initiated by the electron current.

The essential response mechanism is represented by

$$J_e \rightarrow \delta(E, B, J_D) \rightarrow E_{\mathrm{resp}} \rightarrow W_{\mathrm{resp}}$$

The magnetic field does not perform direct work on the electron. Its importance lies in the dynamics of the coupled electromagnetic response.

For an approximately harmonic magnetic field,

$$\left|\frac{dB}{dt}\right|_{max} = 2\pi f B_0$$

so that, for approximately stable B_0, the rate of electromagnetic change increases linearly with frequency.

The model therefore does not require the characteristic field amplitudes E_0 and B_0 themselves to increase systematically with frequency. Frequency enters primarily through the rate at which the local electromagnetic structure changes and responds.

To first approximation, the dynamic contribution follows

$$W_{\mathrm{resp}} \propto f B_0 A_{\mathrm{eff}}$$

where A_{eff} describes the effective local region participating in the electron-ejection event.

The quantities L, R, and A_{eff} are therefore interpreted as local interaction scales rather than dimensions of the complete electromagnetic wave. The structural transverse scale R_0 belongs to the electromagnetic wave itself and is not required numerically in the present photoelectric calculation.

For the hydrogen ground-state reference interaction, the present working model gives approximately

$$L_1 \approx 13\ \mathrm{nm}$$

and, using the present geometrical approximation,

$$R_1 \approx 6.5\ \mathrm{nm}$$

with representative characteristic field amplitudes near

$$E_0 \approx 1.5 \times 10^9\ \mathrm{V/m}$$

and

$$B_0 \approx 5\ \mathrm{T}$$

These values form a mutually constrained working parameter set and should not be interpreted as independently derived constants.

For the ground-state reference interaction, where the direct electric contribution is small,

the model gives the approximate consistency relation

$$h \approx 2\pi e B_0 A_{\text{eff}}$$

or equivalently

$$\Phi_{\text{eff}} \approx \frac{h}{2\pi e}$$

This relation connects Planck's constant with the characteristic magnetic flux participating in the local interaction.

At the present stage, this is a consistency condition rather than a first-principles derivation of h. A deeper theory should explain why the coupled electromagnetic-wave structure naturally produces this characteristic combination of B_0 and A_{eff}.

Application to the first four hydrogen levels shows that approximately common characteristic field amplitudes can be retained while the effective interaction region changes.

Electron ejection terminates the interaction when

$$W_E + W_{\text{resp}} = W_b$$

is first reached.

For more weakly bound electrons, this condition is reached earlier. Consequently, the effective interaction time and spatial extent decrease.

In the present working calculation,

$$L_1 \approx 13.0\ \text{nm}$$

for the ground state, while

$$L_4 \approx 9.4\ \text{nm}$$

for n=4.

The reduction reflects earlier termination of the local response rather than a change in the basic structure of the incident electromagnetic wave.

The numerical agreement for the four hydrogen levels should be interpreted as an internal consistency result. The termination relation used to obtain L_n was constructed from the threshold energy balance together with the assumed scaling of the dynamic response. The hydrogen thresholds are therefore not independently predicted by the present calculation.

The central physical interpretation of the model is that the photoelectric threshold is a local dynamical energy-transfer condition.

The relevant condition is

$$W_{\text{tr}} \geq W_b$$

rather than a requirement that the total energy of the complete electromagnetic wave satisfy the binding condition.

Within this framework, the familiar relation

W=hf

is interpreted as governing the characteristic energy transferred through the local frequency-dependent interaction, rather than necessarily defining the total energy contained in the complete electromagnetic wave.

The model therefore establishes a coherent causal chain connecting frequency, electromagnetic field dynamics, local interaction geometry, and electron ejection:

$$f \rightarrow \frac{dB}{dt} \rightarrow \delta(E, B, J_D) \rightarrow E_{\text{resp}} \rightarrow W_{\text{resp}}$$

together with the direct contribution

$$E \rightarrow W_E$$

and the termination condition

$$W_E + W_{\text{resp}} = W_b$$

The principal next step is to derive the effective interaction time, interaction dimensions, and response field directly from the coupled evolution of the electron and the $E - B - J_D$ structure.

Such a calculation would determine whether the presently inferred field amplitudes, interaction geometry, frequency dependence,

and photoelectric threshold can emerge from one self-consistent dynamical model.

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