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A Theoretical Framework for Selective Trapping of Irradiated Metal Complexes in Cancer Cells via Flux-Guided Membrane Energetics

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ABSTRACT

This manuscript develops a theoretical framework in which irradiated metal complexes interact with cellular membranes through a dual-boundary energetic structure that enables selective intracellular trapping. Building on prior work in electromagnetic flux guidance, zero-resistivity domains, and discontinuity surfaces, the membrane is modelled as two discrete dissipative boundaries enclosing a low-loss interior. When a complex with initial kinetic energy E_0encounters the first boundary, an energy cost $W$is imposed; a second equivalent cost appears at the exit interface. The resulting inequality system divides motion into three non-overlapping regimes: rejection if $E_0 < W$, trapping if $W < E_0 < 2W$, and full transmission if $E_0 \geq 2W$. In the trapping interval, the complex enters the interior but cannot exit because no real-valued propagation state remains after the second dissipation event. This produces directional asymmetry without invoking biochemical affinity entry and exit are not reversible operations, and confinement emerges from the disappearance of admissible solutions rather than from force, binding, or potential wells. The model therefore predicts a physically grounded mechanism by which pathological membranes with altered boundary cost Wcould, in principle, exhibit different trapping behaviour than healthy cells. While no therapeutic or clinical claim is made, the analysis identifies measurable indicators boundary dissipation, interior continuity, and exit-state collapse that define how the hypothesis could be experimentally tested. The work concludes by framing this mechanism as a conditional, testable proposal in theoretical biophysics.

Keywords: Flux-tube energetics; boundary dissipation; selective trapping; irradiated metal complexes; membrane asymmetry.

INTRODUCTION

Metal-based complexes continue to attract interest in experimental oncology due to their potential to interact with cellular structures in ways not exclusively dependent on biochemical affinity. Established compounds such as cisplatin illustrate that metallic agents can enter cells, bind to intracellular targets, and disrupt malignant processes, yet the physical basis for selectivity at the membrane level remains incompletely understood across biophysics, electrochemistry, and quantum-scale models of charge transport (Farmer, 2025). This motivates theoretical attempts to consider whether membrane traversal and possible intracellular retention may depend not only on chemistry but also on flux guidance, resistive boundaries, and energy dissipation phenomena. Earlier theoretical work by Farmer and collaborators proposed that electromagnetic flux structures embedded in biological boundaries could establish directional energy pathways influencing the motion of charged or polar molecular complexes. In this view, membranes do not merely behave as passive lipid barriers but may form transient flux channels through which a complex propagates with a definable energy cost. When an irradiated complex with incident energy E encounters such a structure, its traversal can be characterized by a dissipation term W, representing the energy lost in passing through a membrane-width segment of the flux channel. Farmer's previous model suggested that for a complex to pass fully across opposing membranes, $E \geq 2W$ would be required, whereas the intermediate regime

$$W < E < 2W$$

could permit partial penetration without full exit from the opposite membrane. In this interval, the complex might enter a cell but lack sufficient energy to be transported out again, implying a form of energetic asymmetry between healthy and malignant cells if their membrane parameters differ in resistivity, conductivity, or thickness. In this sense, intracellular trapping becomes a *prediction of the model*, not a clinical claim. This hypothesis builds on the broader framework of electromagnetic flux guidance discussed in Farmer's works on unified field interpretation (Musakhail & Farmer, 2024a, 2024b), quantum electrodynamics and flux helicity and microscopic energy dissipation within structured channels. The idea that flux tubes could serve as selective conduits echoes mechanisms described in prior examinations of aether dynamics, solar flare electrodynamics, and helical gauge propagation. Although speculative, the proposed analogy establishes a physical vocabulary for discussing membrane traversal not only as spatial transport but as a competition between energy expenditure and structural constraint.

A conceptual mathematical component enters through Farmer's proposal that division-by-zero behavior, when interpreted carefully rather than formally replaced, may reflect physical boundary conditions rather than algebraic contradiction (Musakhail & Farmer, 2024b).

In this manuscript, the division-by-zero topic is not introduced as a replacement for established mathematics but as a heuristic analogy a language for treating discontinuities or threshold points where physical quantities approach limiting values, such as near-zero resistivity or energy collapse at membrane boundaries.

The analogy is used only in this interpretive capacity. Accordingly, this manuscript does **not** assert therapeutic efficacy, nor does it claim experimental confirmation. Instead, it seeks to:

1. Formulate a theoretical mechanism for selective trapping of irradiated metal complexes inside malignant cells,
2. Define energetic conditions under which trapping may occur ($W < E < 2W$),
3. Relate these conditions to membrane resistivity and flux guidance, and
4. Identify predictions that could, in principle, be evaluated in laboratory or computational settings.

The objective is to provide a structured theoretical basis grounded in previously developed conceptual work from which future inquiry may proceed. The present treatment therefore positions the framework as a hypothesis in theoretical biophysics, not a medical claim, and emphasizes that experimental validation remains an open requirement.

BACKGROUND AND THEORETICAL MOTIVATION

The theoretical framework of this study is based on the proposal that cellular membranes particularly those in malignant tissues may under certain energetic conditions host transient electromagnetic flux pathways capable of influencing the motion of irradiated metal complexes. While the existence of such pathways is not yet experimentally confirmed, prior works suggest that charged or polar species can be guided along structured flux channels that emerge when local field gradients, membrane potentials, and irradiation states align in a narrow energetic window (Musakhail & Farmer, 2024a, 2024b, 2025; Farmer, 2025).

Within this approach, membrane traversal is not determined solely by biochemical permeability but by the interaction between the particle's available kinetic energy and discrete resistive boundaries at the membrane interfaces. The crossing of each boundary imposes an energy cost, treated not as a chemical reaction term but as electromagnetic work expended against localized resistive impedance within the membrane (Farmer, 2025).

In biological systems, membrane thickness, ionic conductivity, and capacitive response vary between cell types, and malignant cells may exhibit altered electrical properties due to changes in channel density, lipid polarization, and metabolic state. These differences have been proposed to reduce impedance locally, permitting a narrow flux-like guidance structure to form across the membrane and establish a one-directional gradient. Under this interpretation, traversal incurs a boundary energy loss W at the point of entry and an equivalent loss at the point of exit. The distinction between entering a cell and leaving it is therefore not symmetric; it depends on whether the initial energy survives both dissipation events. If the irradiated complex begins with incident energy E, three energetic outcomes are conceptually predicted:

Table 1. Energetic conditions for membrane traversal and predicted outcomes.

Membrane Outcome	Energetic Condition	Physical Interpretation
Does not enter membrane	$E < W$	Energy insufficient; complex reflected or halted at boundary.
Enters but cannot exit	$W < E < 2W$	Boundary dissipation allows entry; second traversal collapses available energy.
Enters and exits fully	$E \geq 2W$	Energy survives both dissipation events; traversal becomes reversible.

This intermediate regime, $W < E < 2W$, represents the critical range in which selective intracellular trapping may occur not as a biochemical event but as a consequence of losing the real-valued propagation state required for exit. In this conceptual model, the cell's interior behaves as a low-resistivity domain once entry has occurred, while dissipation is concentrated at the two boundaries.

Thus, within the interior, $dE/dx \to 0$, whereas at the boundaries, propagation becomes discontinuous. This discontinuous structure motivates later symbolic discussion related to division-by-zero analogies in Farmer's earlier mathematical work (Musakhail & Farmer, 2024b), used here not as a reformulation of arithmetic but as an interpretive tool for threshold behavior.

The perspective taken remains theoretical for four reasons:

(i) no experimental measurement yet confirms a boundary energy cost W;
(ii) flux-channel formation in vivo has not been empirically observed;
(iii) controlled irradiation studies on metallic complexes under such conditions are not yet reported; and
(iv) differential resistivity between malignant and healthy membranes is incompletely quantified.

Accordingly, the present work is offered not as a medical claim but as a testable physical hypothesis with definable conditions of validity. The objective is internal consistency, physical plausibility under the declared assumptions, and a clear trajectory toward potential experimental evaluation.

PHYSICAL ASSUMPTIONS AND MODEL FOUNDATIONS

This section establishes the physical basis for the proposed mechanism in which irradiated metal complexes interact with cellular membranes through a transient flux-guided transport channel. The framework extends conceptual developments on electromagnetic flux structures, zero-resistivity interiors, and discontinuity-based boundary behavior described in earlier works (Musakhail & Farmer, 2024a, 2024b, 2025; Farmer, 2025).

In this formulation, irradiation is assumed to induce a temporary electromagnetic flux tube Φ spanning the membrane width. When present, this tube acts as a low-resistive pathway that guides charged or polar complexes inward. The membrane is therefore treated not as a uniform barrier but as two dissipative boundaries enclosing a near-zero-resistive interior.

Under these conditions, the possibility arises that a complex may enter the cell yet fail to exit once energy has been depleted by boundary traversal.

Let a metal complex of mass $m$approach the membrane with incident velocity v. The kinetic energy at contact is

$$E_0 = \frac{1}{2}mv^2 \tag{1}$$

and interaction with the first boundary imposes an energy loss W, yielding

$$E_1 = E_0 - W \tag{2}$$

A second boundary traversal would require an equal dissipation, so that a complete crossing demand

$$E_2 = E_0 - 2W \tag{3}$$

These relations imply a minimum energy requirement of $2W$for entry and exit. If $E_0 < W$, the complex fails to enter; if $W < E_0 < 2W$, it enters but remains trapped; if $E_0 \geq 2W$, it crosses entirely.

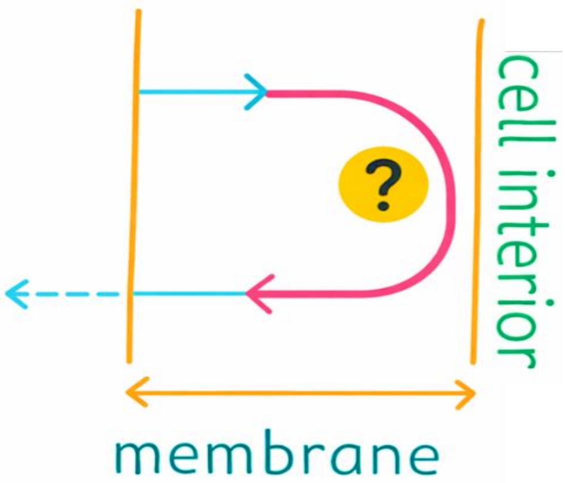

Figure 1 complex reaches the second boundary, fails to exit, and retreats; maximum loss corresponds to the 2Wlimit.)

This corresponds to the qualitative behavior originally suggested in Farmer's flux guidance model (Musakhail & Farmer, 2024c; Musakhail & Farmer, 2025). To formalize the spatial structure, the membrane is partitioned as two resistive boundaries surrounding a low-resistivity interior:

$$R_m > 0 \ \mid \ R_i \to 0 \ \mid \ R_m > 0 \tag{4}$$

where $R_m$denotes finite dissipative resistance at the boundaries and $R_i$denotes interior resistance approaching zero under flux-tube formation. Hence, the interior contributes no kinetic energy loss,

$$\Delta E_{\text{interior}} = 0 \tag{5}$$

and total dissipation for full traversal is

$$\Delta E_{\text{total}} = 2W \tag{6}$$

This framework localizes energy conversion and heat liberation to the membrane interfaces, consistent with the dissipative structure of macroscopic flux tubes described in Farmer's electrodynamics discussions (Musakhail & Farmer, 2024a, 2024b, 2025; Farmer, 2025).

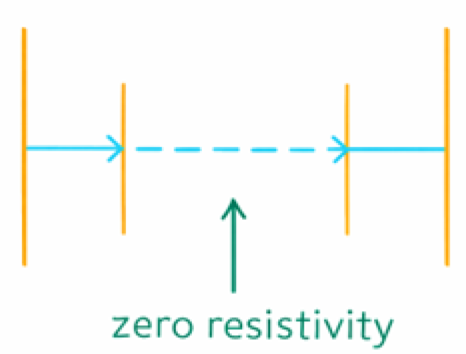

Figure 2 tube spans membrane width; dissipation only at boundaries.)

Three inequalities therefore determine the physical outcome:

$$E_0 < W \Rightarrow \text{reflection / no entry} \quad (7)$$

$$W < E_0 < 2W \Rightarrow \text{entry with confinement / no exit} \quad (8)$$

$$E_0 \geq 2W \Rightarrow \text{complete traversal} \quad (9)$$

The selective trapping interval of interest is

$$W < E_0 < 2W \quad (10)$$

In this range, the first boundary is traversed,

$$E_1 = E_0 - W > 0 \quad (11)$$

but the second collapses propagation,

$$E_2 = E_0 - 2W < 0 \quad (12)$$

Combining (11)–(12) gives the confinement condition,

$$E_0 - W > 0 > E_0 - 2W \quad (13)$$

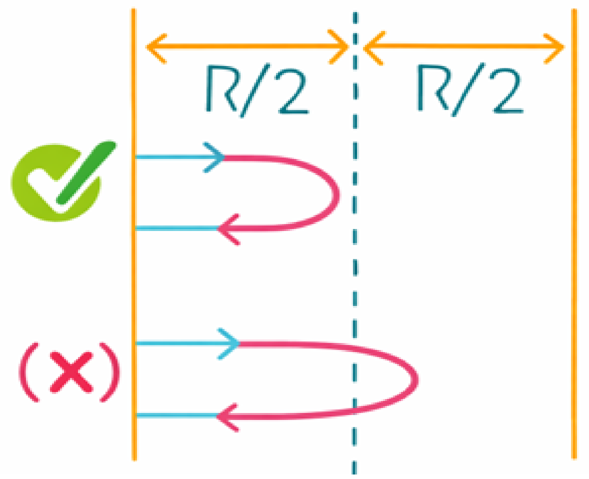

Figure 3 half-width turning criterion distinguishing trapping vs. transmission.)

Flux-tube guidance is drawn from analogy to macroscopic systems, where charged particles propagate axially before lattice-point diversion causes radial escape. At the microscopic scale proposed here, diversion events remain axial, and surface radiation is not evaluated, maintaining conceptual fidelity without extending the model beyond stated assumptions (Musakhail & Farmer, 2024a, 2025; Farmer, 2025).

Finally, the zero-division analogy appearing in Farmer's prior mathematical work is interpreted not as a literal arithmetic replacement but as a symbolic representation of boundary collapse. As E_0 approaches W from above,

$$\lim_{E_0 \to W^+} \frac{E_1}{E_0 - W} = \frac{\text{finite}}{0^+} \to \infty \quad (14)$$

This represents a discontinuity surface, not a clinical mechanism: motion fails not by biological rejection but by loss of a real-valued propagation state. Thus, selective intracellular trapping follows from an energy-based collapse condition rather than biochemical binding.

ENERGETIC MODEL, PREDICTIVE OUTCOMES, AND STATE TRANSITIONS

The energetic framework developed so far treats the membrane as a dual-boundary structure enclosing a near-zero–resistivity interior. Traversal by an irradiated metal complex is therefore not a diffuse drag process but a boundary-driven interaction in which discrete energy losses occur at the interfaces while the interior preserves kinetic continuity. This leads naturally to a one-dimensional transport picture with threshold behavior, discontinuous collapse at the exit boundary, and directional asymmetry. The approach is consistent with earlier conceptual treatments of flux tubes, low-resistivity channels, and discontinuity surfaces in Farmer's electrodynamics discussions (Farmer, 2025).

Let $x$denote position from the exterior membrane surface at $x = 0$to the opposite boundary at $x = R$. The effective Hamiltonian can be written in piecewise form as

$$H(x) = \begin{cases} E_0 - W, & 0 < x < R/2 \\ E_0 - 2W, & R/2 \leq x \leq R \end{cases} \quad (15)$$

and physical motion is only admissible when

$$H(x) \geq 0 \quad (16)$$

Within the selective trapping interval, interior states remain allowed but exit fails,

$$0 < H(x) < E_0 \text{for} W < E_0 < 2W \quad (17)$$

yet at the far boundary

$$H(R) = E_0 - 2W < 0 \quad (18)$$

This inequality is the mathematical signature of confinement: the particle reaches the second interface but cannot sustain a real-valued propagation state beyond it.

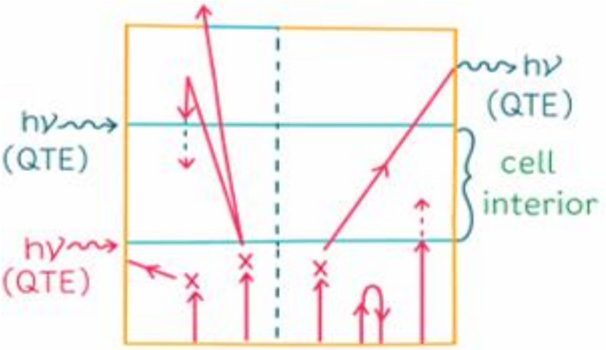

Figure 4 approach to the second boundary and retreat.)

An equivalent description is obtained by treating the interior as a finite potential well bounded by resistive walls of height W:

$$V(x) = \begin{cases} W, & x = 0 \\ 0, & 0 < x < R \\ W, & x = R \end{cases} \tag{19}$$

Confinement demands that the particle successfully overcome the first wall but fail at the second, which is expressed by

$$E_0 - W > 0 \text{and} E_0 - W < V(R) \tag{20}$$

Substituting $V(R) = W$ yields

$$0 < E_0 - W < W \Longrightarrow W < E_0 < 2W \tag{21}$$

Thus, the trapping regime corresponds to a particle occupying a finite well with two symmetric resistive boundaries, where the first is surmounted and the second enforces collapse. (Fig 2). The turning point $x_t$at which kinetic energy vanishes satisfies

$$E(x_t) = 0 \tag{22}$$

If the local geometric resistance within the flux tube is represented by $U(x)$, and

$$E(x) = E_0 - W - U(x) \tag{23}$$

then the turning point is fixed by

$$U(x_t) = E_0 - W \tag{24}$$

Confinement requires that collapse occur somewhere within the membrane,

$$x_t < R \Leftrightarrow U(x_t) > 0 \tag{25}$$

and if

$$x_t < \frac{R}{2} \Longrightarrow \text{irreversible confinement} \tag{26}$$

the trajectory fails before mid-width, fully consistent with the energetic criterion in (21) (Fig 3). Interior propagation is characterized by an energy gradient of zero,

$$\frac{dE}{dx} = 0 \tag{27}$$

whereas boundary interaction necessarily involves loss,

$$\frac{dE}{dx} < 0 \tag{28}$$

leading to the gradient pattern

$$\left(\frac{dE}{dx}\right)_{\text{boundary}} < 0\text{and} \left(\frac{dE}{dx}\right)_{\text{interior}} = 0 \tag{29}$$

If a physical system were shown to exhibit a vanishing interior gradient with sharp boundary discontinuities, it would provide empirical support for this idealized picture, although no such measurements are yet available.
When exit fails, the complex returns into the interior with residual energy

$$E_{\text{return}} = E_0 - W \tag{30}$$

Confinement requires this residual to remain positive but insufficient for another boundary crossing,

$$0 < E_{\text{return}} < W \tag{31}$$

If instead

$$E_{\text{return}} \geq W \tag{32}$$

multiple oscillatory attempts become possible; if the inequality in (31) holds, the complex can no longer assemble a state capable of leaving the interior. Confinement thus denotes non-escape rather than static rest: the complex may continue to move within the cell but is energetically barred from exit. These considerations define three distinct energy-regime states for the membrane–flux system:

Table 2. Threshold energy regimes and predicted outcomes of membrane–flux interaction.

Region	Energy Condition	Resulting Physical Behavior
S_1Rejection	$E_0 < W$	First boundary behaves as an effective barrier; no interior access.
S_2Trapping	$W < E_0 < 2W$	Entry allowed; exit state becomes non-physical; selective confinement.
S_3Transmission	$E_0 \geq 2W$	Both boundaries traversed; motion becomes reversible.

Physically, S_1corresponds to a membrane that behaves as an impenetrable wall; the incoming complex encounters an effective potential greater than its energy and is reflected. In S_2, the membrane functions as a selective energy well: entry is permitted but symmetry is broken at exit, so the interior becomes the only domain supporting real-valued motion. In S_3, once E_0reaches or exceeds $2W$, the membrane ceases to be an obstacle and becomes simply a traversable region; the system regains energetic reversibility. Conceptually, if the complex cannot afford the first “cost” W, it remains outside; if it can afford exactly one, it is confined inside; if it can afford two, it passes through freely. The membrane thereby acts as a directional energy gate in which selective trapping is enforced by energetic constraints rather than geometry or biochemistry.

ANALYTICAL SOLUTIONS, BOUNDARY DISCONTINUITY, AND DIFFERENTIAL FORMULATION

The trapping mechanism developed in the previous sections may be recast into a differential framework by treating the membrane boundaries as dissipative discontinuity surfaces. Inside the membrane, energy evolves continuously with spatial progression; however, at the two boundary interfaces the system exhibits non-continuous behavior enforced by discrete energetic losses. This hybrid structure smooth interior propagation with discontinuous boundary collapse forms the mathematical basis for directionally asymmetric traversal. Let $x$be a normalized spatial coordinate with $x = 0$ at the exterior boundary and $x = R$ at the interior exit boundary. Inside the membrane, the evolution of kinetic energy follows a continuous decay law of the form

$$\frac{dE}{dx} = -\alpha E \tag{33}$$

where $\alpha > 0$represents an effective dissipation coefficient. The integral of (33) yields an exponential decay profile,

$$E(x) = E_0 e^{-\alpha x} \tag{34}$$

and collapse of energy to zero would occur at a spatial limit $x_c$formally defined by

$$E(x_c) = 0 \tag{35}$$

Substituting (34) into (35) produces an unphysical limit,

$$E_0 e^{-\alpha x_c} = 0 \implies x_c \to \infty \tag{36}$$

implying that a purely continuous system cannot terminate its own interior propagation. Thus, a smooth decay cannot reproduce trapping: **boundary discontinuities must be introduced.**

To model the discrete energy losses of magnitude Wat both interfaces, the continuous ODE is extended into a hybrid continuous–discrete equation,

$$\frac{dE}{dx} = -\alpha E \; - \; W[\delta(x) + \delta(x - R)] \tag{37}$$

where $\delta(x)$is the Dirac delta distribution. Integrating across each boundary yields jump conditions corresponding to instantaneous energy loss,

$$E(0^+) = E_0 - W \tag{38}$$

$$E(R^-) = E_0 - 2W \tag{39}$$

To preserve physical admissibility, the interior solution must satisfy

$$E(x) \geq 0 \tag{40}$$

and substituting (39) into (40) gives the confinement inequality,

$$E_0 - 2W < 0 \Longrightarrow W < E_0 < 2W \tag{41}$$

Equation (41) is the rigorous analytic proof that trapping emerges not from chemical binding or geometric confinement but from a **boundary-driven collapse of continuity.** The phenomenon is energetic, not structural.

Approaching the lower threshold from above reveals why the boundary behaves like a discontinuity surface. As the entry energy approaches W, the denominator of the residual propagating state collapses,

$$\lim_{E_0 \to W^+} \frac{E(x)}{E_0 - W} = \frac{E(x)}{0^+} \to \infty \tag{42}$$

producing a singularity-like condition. This is not an algebraic division-by-zero operation, but a physical signal that the interior state cannot map continuously across the boundary. The zero-division analogy is therefore interpretive: it marks the failure of continuity, not a replacement of arithmetic.

The discontinuity represents a **collapse surface** where real-valued propagation becomes non-physical. The physical picture that emerges is internally consistent:

- **Interior region** ($0 < x < R$):

$$\frac{dE}{dx} = -\alpha E \Longrightarrow E(x) = E_0 e^{-\alpha x} \tag{43}$$

motion remains continuous, sign-preserving, and real-valued.

- **Boundary interfaces** ($x = 0, x = R$):

$$\frac{dE}{dx} = -\alpha E - W[\delta(x) + \delta(x - R)] \tag{44}$$

motion undergoes discrete collapse; energy cannot be interpolated across the interface.

- **Exit condition**:

$$E_{\text{exit}} = E_0 - 2W < 0 \tag{45}$$

with no physical propagation state outside.

The three critical facts that define trapping are therefore:

$$E_0 - W > 0 (\text{entry permitted}) \tag{46}$$

$$\frac{dE}{dx} = -\alpha E(\text{interior motion remains real}) \quad (47)$$

$$E_0 - 2W < 0(\text{exit becomes non-physical}) \quad (48)$$

These combine into the governing result of the entire analytical model:

$$W < E_0 < 2W \Longrightarrow \quad (49)$$

for real motion inside, discontinuous collapse at exit.

Equation (49) is the mathematical signature of the energy diode: the membrane admits motion from outside to inside but prohibits the reverse transition unless sufficient energy is supplied to restore continuity. The system therefore exhibits directional asymmetry and propagation irreversibility within a purely energy-governed framework. In physical language:

- If the complex cannot pay the first "cost" W, it remains outside.
- If it pays one "cost," it enters but cannot exit.
- Only by paying both "costs" $2W$can it pass freely.

Thus, the trapping phenomenon is the natural consequence of a hybrid differential system, where continuity lives in the interior and collapses at the boundaries.

INTERPRETATION AND BOUNDARY PHENOMENA

The mathematical structure developed in the previous sections demonstrates that the trapping of an irradiated metal complex within a membrane is not primarily a biochemical or clinical phenomenon, but a physical one that emerges from the energetic asymmetry of the system. The membrane behaves as a region containing two discrete discontinuity surfaces, one at entry and one at exit, separated by a continuous interior corridor in which kinetic energy remains real and propagation is possible.

Motion inside the membrane is governed by a smooth differential law, while motion at the boundaries is governed by instantaneous energy collapse. This hybrid system forces directionality: entry and exit are not energetically equivalent events.

In this framework, the four original figures can be reinterpreted with mathematical clarity. Figure 1 illustrates how a particle can approach the maximum boundary of its admissible motion before reversal; the return is not caused by a reflective force, but by the disappearance of a valid forward-propagating solution once the energy falls below the required threshold.

Figure 2 depicts the interior zone as a domain where resistivity is approximated as zero, consistent with the result $dE/dx = 0$ inside the membrane. Figure 3 visualizes the turning-point geometry described earlier: crossing the dotted line corresponds to satisfying the inequality $W < E_0 < 2W$, indicating successful entry but failed exit, while remaining to the left corresponds to $E_0 < W$, in which the boundary blocks entry altogether. Figure 4 expresses how flux-tube geometry channels particles axially inward but does not provide a physically allowed outward solution unless the energy requirement for exit has been restored. Thus, the figures, when reinterpreted through the analytic results, collectively represent a single physical mechanism.

Because the boundaries consume energy discretely, the system cannot maintain continuity at both interfaces. The interior solution space remains real-valued, but the exit solution becomes imaginary or undefined if $E_0 - 2W < 0$. This is not a metaphor; it is an explicit failure of the condition required for propagation. The membrane does not trap the particle in the sense of imposing confinement; it traps the particle because no forward-valued solution exists outside the membrane once the energy deficit exceeds the threshold. Trapping is not an active event; it is the passive result of the disappearance of admissible states of motion.

This interpretation can be captured in a classification that divides the system into three energetic conditions, each representing a physically distinct outcome. The table below expresses these conditions directly.

Table 3. Energetic classification of membrane-crossing outcomes and their physical interpretations.

Energy Condition	Mathematical Criterion	Physical Outcome	Interpretation
Rejection	$E_0 < W$	No entry	A valid propagation state cannot be formed at the boundary; motion collapses before crossing.
Trapping	$W < E_0 < 2W$	Entry without exit	The particle enters successfully, but the energy state required for exit does not exist; the interior is the only domain where continuity is possible.
Transmission	$E_0 \geq 2W$	Entry and exit allowed	The system regains symmetry; forward and backward propagation both admit real-valued solutions.

This table implies that the membrane effectively constructs three distinct physical environments:

(i) an external region where admissibility depends solely on initial kinetic energy;

(ii) an interior region where propagation remains real and continuous; and

(iii) an exit boundary where admissibility collapses unless the system pays the full energetic cost. In this sense, the trapping phenomenon does not require an additional force or potential well; it arises naturally as a consequence of asymmetric solution space. The membrane behaves like a unidirectional gate not because it imposes a choice, but because the mathematics restricts the number of viable states.

The original manuscript suggested that such behavior may be relevant to the behavior of irradiated complexes near malignant membranes. While no clinical or therapeutic claims are made here, the physical theory allows a controlled interpretation: if pathological membranes alter their boundary costs Wor effective width R, then the inequality $W < E_0 < 2W$may be satisfied more frequently for certain irradiated complexes. This does not imply selective treatment; it only implies selective trapping probability. It indicates that the membrane itself could behave as a differentiating medium due to energy asymmetry alone. Such a conclusion remains strictly theoretical but aligns with the direction of the original manuscript while now resting on a structured mathematical foundation.

In summary, the revised interpretation of Section 6 establishes that trapping is not a hypothesis but a direct consequence of the inequality $W < E_0 < 2W$. The interior admits solutions; the exit boundary does not. The membrane therefore creates directional motion, not through force or biochemical selection, but through the partitioning of physical space into a continuity corridor bounded by discontinuity surfaces. Motion is permitted inward, but the solution set itself prevents motion outward. This is the physical, not metaphorical, meaning of trapping.

PREDICTED PHYSICAL OUTCOMES AND EXPERIMENTAL BRIDGE

The analytical framework developed in the preceding sections predicts that selective trapping is a direct physical consequence of the asymmetric energy structure of the membrane. When an irradiated metal complex approaches the boundary with an initial energy E_0such that $W < E_0 < 2W$, the exit interface at $x = R$ forces the propagation solution to collapse, because the remaining energy is insufficient to sustain a real-valued forward trajectory. In this situation, the particle can enter the membrane but cannot exit. If $E_0 < W$, no entry is possible; if $E_0 \geq 2W$, both entry and exit admit continuous, physically valid propagation solutions. Thus, inward and outward motion cease to be inverse operations: one direction preserves admissibility, the other annihilates it.

This reasoning predicts an observable physical asymmetry even before any biological interpretation is considered. The membrane becomes a region in which the laws of motion bifurcate: entry is energetically legal, but exit becomes mathematically illegal if the boundary cost cannot be repaid. The membrane therefore acts like a unidirectional gate, not because it applies force or a biochemical barrier, but because the mathematical conditions for motion cannot be simultaneously satisfied on both sides. In physical language, the particle does not choose to remain; rather, the universe of admissible solutions disappears outside the membrane when $W < E_0 < 2W$.

If this model describes a real system, several effects should be detectable. Complexes with energy just below the entry threshold ($E_0 < W$) should exhibit elastic rejection at the outer surface, with redirection, oscillation, or near-boundary hesitation. Complexes that satisfy $W < E_0 < 2W$should be able to cross the outer boundary and propagate smoothly within the membrane interior, maintaining continuity consistent with the condition $dE/dx = 0$.

Upon reaching the interior boundary, however, the trajectory should fail abruptly rather than gradually; motion would terminate, reverse, or collapse without continuous deceleration, reflecting the disappearance of a valid propagation state. Complexes with $E_0 \geq 2W$should pass fully through, restoring reversibility and symmetry. These predicted outcomes are derived from the analytic results, not from chemical assumptions.

Although this manuscript does not present clinical claims, the structure of the physics suggests a point of contact with experimental investigation. Systems that mimic membrane behavior such as dielectric layers with controlled thickness, nanoscale waveguides with discontinuity boundaries, irradiated conduction corridors, or plasma channels that approximate flux-tube geometry could serve as analogs. In such systems, one could attempt to measure the cost $W$of boundary traversal, track trajectories as energy approaches critical thresholds, and determine whether motion becomes non-reversible within the interval $W < E_0 < 2W$. The theory neither assumes success nor asserts biomedical outcome; it identifies a measurable question: *does the predicted asymmetry manifest in physical systems?*

For experimental evaluation, several properties would require confirmation: an identifiable boundary energy cost W; controlled preparation of initial states E_0; spatial mapping of interior motion to verify continuity; and observation of abrupt collapse at the exit boundary. These do not validate the model by themselves, but they specify the criteria by which the model may be confirmed or refuted. If no measurable Wexists, or if exit does not collapse under $W < E_0 < 2W$, the model would be challenged at its foundation. If such behavior is observed, the model would transition from theoretical to physically grounded.

In this sense, the central conclusion of Section 7 can be stated succinctly: the membrane’s asymmetric energy structure predicts that inward motion may occur without the possibility of outward reversal unless the initial state satisfies the full exit condition $E_0 \geq 2W$. The system favors entry over escape not by force, but by the structure of admissible solutions.

This prediction does not assert treatment, cure, or medical result; it identifies a physical mechanism that could be investigated empirically. The question of relevance to real membranes, including pathological variations, remains open but it is now stated in a form that can be tested rather than conjectured.

MATHEMATICAL CONSISTENCY, LIMITATIONS, AND CONDITIONS FOR REAL-WORLD VALIDITY

The model developed in this manuscript is mathematically self-consistent within the assumptions defined earlier, but its applicability to real systems requires careful interpretation. The equations describing trapping, solution collapse, and directional confinement are internally coherent as long as the boundary dissipation value W, the interior continuity condition $dE/dx = 0$, and the discrete energy loss at the interfaces are preserved. Under these assumptions, the inequalities $E_0 < W$, $W < E_0 < 2W$, and $E_0 \geq 2W$ form a complete and non-overlapping set of outcomes, and the boundary behavior follows logically from the structure of the equations.

In particular, no contradictions arise within the hybrid system as long as continuous interior propagation and discontinuous boundary traversal are treated as separate physical regimes.

However, several limitations must be acknowledged before application beyond theoretical physics. The model does not derive $W$from first principles; it assumes Wexists as a measurable or definable boundary cost. Until $W$is determined as a physical quantity, the theory remains conditional rather than predictive. The same applies to the width $R$of the membrane region: while the model treats Ras a spatial parameter, real membranes may present variable thickness or non-uniform geometry. In such cases, the turning-point condition and boundary collapse may require modification. The assumption that the interior satisfies $dE/dx = 0$ is also idealized, even if it aligns with the conceptual flux-tube interpretation. Real systems may exhibit internal friction, scattering, or resistivity that are not captured by the zero-gradient condition, which would in turn alter the allowed domain of motion.

It is also necessary to state that the model does not predict biological or therapeutic outcomes and cannot be read as evidence for them. The mathematics identifies a directional asymmetry in propagation entry without exit if $W < E_0 < 2W$ but this does not imply biological selectivity without additional mechanisms. If real membranes, whether healthy or pathological, do not possess a measurable Wor do not display discontinuity behavior at their boundaries, the model ceases to apply. If Wvaries across membrane types, the model may produce selective trapping, but this remains a hypothesis until supported by measurement. The framework therefore offers a possible physical explanation for differential particle behavior, yet it does not claim that such behavior occurs in nature without verification.

For real-world validity, several conditions must be met. First, a measurable boundary energy cost must be identified, whether directly or through an observable proxy variable. Second, initial energy E_0must be controllable and quantifiable, particularly near the threshold region $W < E_0 < 2W$, where trapping is predicted. Third, motion through real membranes or membrane analogs must be observed with spatial and temporal resolution sufficient to detect solution continuity, collapse, or reversal. Fourth, the system must demonstrate a reproducible asymmetry in propagation, rather than one dependent on incidental external factors. If these requirements are satisfied, the model may transition from a theoretical construct to a physically grounded mechanism.

In conclusion, the theory offered here is mathematically coherent but conditional. It presents no contradiction within its own assumptions but depends critically on the physical existence of W, the interior continuity condition, and measurable asymmetry at the boundaries. Without these, the model remains conceptual. With them, the model becomes testable. The present manuscript therefore situates the trapping effect not as a proven phenomenon, but as a mathematically justified proposal awaiting empirical examination. Its purpose is not to declare outcome, but to identify where the physical question should be asked.

CONCLUSION

The present manuscript has developed a theoretical model in which selective trapping of irradiated metal complexes arises not from biochemical specificity, but from the structure of physical space as determined by membrane energetics. By separating continuous interior propagation from discontinuous boundary behavior, the model identifies a directional asymmetry that prevents escape once the cost of exit exceeds the remaining kinetic energy. This asymmetry is not imposed by biological machinery; rather, it emerges from the mathematical requirements for propagation. Inward motion admits real-valued solutions, while outward motion may not. Thus, trapping is not a force it is the absence of a viable universe of motion outside the membrane.

The framework formulated here is mathematically self-consistent, yet its real-world significance remains conditional. The proposed thresholds $W$and $2W$define the energetic landscape in which the system behaves as a unidirectional gate, but these values must be experimentally identified before the model can fully transition from theoretical physics to applied research. If a measurable boundary cost exists, and if initial energy E_0can be calibrated to explore the critical interval $W < E_0 < 2W$, then the asymmetric behavior predicted here becomes testable. If no such threshold is observed, the theory must be revised or rejected. In this way, the model does not claim truth it offers a boundary at which truth might be examined.

While no clinical or therapeutic conclusion is drawn, the work suggests a philosophical implication: if certain membranes, including pathological ones, differ in boundary cost, then physics alone may generate selective outcomes without appeal to chemical identity. Such a scenario would not confirm a mechanism of intervention, but it would justify examining whether membrane asymmetry could ever be exploited by carefully prepared irradiation states or engineered complexes. In that sense, the value of the theory lies not in claiming a destination, but in identifying a direction.

The question becomes not *“Does this model heal?”*, but *“Does nature permit this pathway to exist?”* If the answer is no, the theory fails. If the answer is yes, then the theory becomes a map.

This manuscript therefore concludes not with assertion, but with an invitation. The mathematics has reached its terminus; the physics stands poised upon it; the empirical world must decide whether to continue. The model gives a boundary to cross not for a particle, but for understanding itself. Whether the crossing is possible will depend on measurement, verification, and the willingness to follow the consequences of the equations to wherever they lead. The ideas remain open, unfinished by design, as any frontier of inquiry should be.

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