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A Phenomenological Framework for Neutrino-Induced Molecular Excitation: The NIAR Hypothesis

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Abstract- ***Neutrinos interact with matter predominantly through the weak interaction, yet established neutrino–matter phenomena demonstrate that measurable effects can arise under appropriate physical conditions. This paper examines whether a neutrino-induced excitation of specific molecular degrees of freedom can be represented within a consistent phenomenological framework. We introduce the Neutrino-Induced Androsterone Resonance (NIAR) hypothesis as a case study, using androsterone as a representative molecular target. A phenomenological effective interaction is formulated to connect the neutrino and molecular sectors, and the resulting transition amplitude and rate are developed using first-order time-dependent perturbation theory and Fermi's Golden Rule. Energy conservation is then used to define the relevant resonance condition in terms of the energy transferred from the neutrino to the molecular system rather than the total incident neutrino energy. The framework is further extended to an effective transition cross section, neutrino-flux-dependent rate, thermal molecular populations, environmental broadening, and parameter dependence. NIAR is presented strictly as a hypothesis rather than an experimentally established phenomenon. The effective coupling remains unknown, and quantitative evaluation of the molecular transition matrix elements would require dedicated molecular calculations and experimental characterization. The principal contribution of this work is therefore a structured phenomenological framework that identifies the assumptions, parameters, and experimental conditions required to evaluate the proposed mechanism.***

Keywords: ***neutrino interactions, molecular excitation, phenomenological framework, neutrino-induced molecular excitation, resonance, androsterone***

I. INTRODUCTION

Neutrinos are among the weakliest interacting particles known, coupling to matter almost exclusively through the weak nuclear force and, in principle, gravity (Cowan et al., 1956; Fermi, 1934). This weakness was, for over two decades after their theoretical postulation, the very reason neutrinos evaded direct experimental detection, and it remains the defining structural fact that any proposal involving neutrino-induced effects on ordinary matter must confront. Nonetheless, the weak interaction is not uniformly negligible across all physical regimes. Neutrino oscillation experiments have shown that neutrinos propagating through matter experience measurable, coherent forward-scattering effects that alter their flavor composition (Wolfenstein, 1978; Fukuda et al., 1998), and the discovery of coherent elastic neutrino-nucleus scattering demonstrated that, under the right kinematic conditions, a neutrino's cross-section with a target can be enhanced by many orders of magnitude relative to the incoherent case, scaling with the square of the number of participating nucleons (Freedman, 1974; Akimov et al., 2017). These results establish, as a matter of experimental record, that “weak” does not mean “always negligible”: coherence and collective response are real, measurable levers in neutrino physics, even though they operate within tightly constrained kinematic regimes specific to nuclear, not molecular, physics.

Separately, and on entirely solid experimental ground, molecular systems are known to possess rich structures of electronic, vibrational, and rotational excited states, separated from their ground states by well-characterized energy gaps typically spanning the infrared to visible range (Herzberg, 1945; Atkins & Friedman, 2011). Transitions between these states are conventionally driven by electromagnetic radiation or collisional energy transfer. Whether a fundamentally different class of driving field — specifically, an incident neutrino flux — could, even in principle, induce such a transition is a question that sits at the intersection of two well-established but previously unconnected bodies of physics: neutrino interaction theory and molecular spectroscopy.

No experimental or theoretical result to date establishes that neutrinos can induce transitions in molecular degrees of freedom. This is stated plainly and at the outset, because it defines the scope of everything that follows. The gap this paper addresses is therefore not empirical — we do not claim to report

a new effect — but conceptual and structural: existing neutrino physics provides well-established descriptions of neutrino interactions with nucleons, nuclei, and electrons (Giunti & Kim, 2007), while the question of whether, and under what formal conditions, a neutrino-induced transition of a specific molecular degree of freedom could be consistently represented has not been systematically framed.

This paper introduces the NIAR hypothesis (Neutrino-Induced Androsterone Resonance) as a case study for this broader question, using androsterone — a well-characterized steroid molecule whose crystal structure and molecular geometry are precisely known (Norton & Ohrt, 1964) — as a concrete, representative target system. We state explicitly and immediately: NIAR is a hypothesis, not an experimentally established phenomenon, and this paper's contribution is a phenomenological framework for examining its theoretical feasibility, not a claim of discovery.

The paper proceeds as follows. Section 2 reviews the relevant scientific background, including neutrino–matter interactions, molecular excitation, and resonance and transition processes. Section 3 formally introduces the NIAR hypothesis, while Section 4 defines the physical process under consideration. Section 5 develops the mathematical formulation, beginning with a phenomenological effective interaction and proceeding through the transition amplitude, Fermi's Golden Rule, and an effective neutrino-flux-dependent cross section. Section 6 establishes the resonance condition through explicit energy conservation. Section 7 describes androsterone as the representative molecular target, and Section 8 considers thermal and environmental effects. Section 9 examines the principal parameter dependencies of the predicted response. Section 10 states the limitations of the phenomenological framework, and Section 11 provides the conclusion.

II. SCIENTIFIC BACKGROUND

2.1 Neutrino–Matter Interactions

Neutrinos are electrically neutral, spin-1/2 fermions that interact with matter exclusively through the weak nuclear force and, in principle, gravitation (Fermi, 1934). Their existence was first postulated by Pauli in 1930 to preserve energy and angular momentum conservation in nuclear beta decay, formalized into a quantitative interaction theory by Fermi (1934), and experimentally confirmed more than two decades later by Cowan et al. (1956) using inverse beta decay at a nuclear reactor. The extraordinarily small interaction cross-section that made this confirmation so difficult to achieve — neutrinos routinely traverse the Earth, the Sun, and the human body without interacting at all — remains the central physical fact that any subsequent discussion of neutrino-induced effects must take as its starting point.

Despite this weakness, neutrino interactions with matter are neither uniform nor always negligible across all physical contexts. Three established results are directly relevant to the framework developed in this paper. First, neutrinos propagating through matter of varying density experience a coherent forward-scattering potential that modifies their oscillation behavior — the Mikheyev–Smirnov–Wolfenstein effect — demonstrating that macroscopic quantities of ordinary matter can produce a collective, coherent response to an incident neutrino flux even though the underlying per-particle interaction remains extremely weak (Wolfenstein, 1978). This effect is not speculative; it is required to correctly explain the flavor composition of neutrinos arriving from the Sun and is corroborated by atmospheric neutrino oscillation data (Fukuda et al., 1998). Second, and more directly relevant to the question of coherent enhancement, coherent elastic neutrino-nucleus scattering (CEνNS) — first proposed by Freedman (1974) and experimentally confirmed more than four decades later by the COHERENT collaboration (Akimov et al., 2017) — demonstrates that when the momentum transferred by a neutrino is small enough that its associated wavelength exceeds the size of the target nucleus, the neutrino scatters off the nucleus as a coherent whole rather than off individual nucleons, and the cross-section is enhanced by a factor approximately proportional to the square of the number of nucleons involved. Third, the differential flux of neutrinos incident on any terrestrial target is a precisely modeled and measured quantity: solar neutrino fluxes, for instance, are characterized in detail across their full energy spectrum by standard solar models validated against helioseismological data (Bahcall et al., 2005).

These three results are cited here for a specific and limited purpose: they establish, on solid experimental ground, that (a) coherent and collective response to neutrino flux is a real, measurable category of phenomena in established physics, not a physical impossibility; and (b) neutrino flux and energy spectra are quantities with precise, well-defined units and known values, not free parameters. Neither result implies, suggests, or provides evidence for a neutrino-induced molecular excitation mechanism. The coherence conditions underlying CEνNS are specific to nuclear-scale momentum transfer and nuclear form factors; the MSW effect is specific to flavor oscillation via charged-current forward scattering off electrons. Whether an analogous — but physically distinct — coherence condition could, even in principle, be formally posited for a molecular target is the question this paper's formalism is built to examine, not an inference that follows automatically from the nuclear case.

2.2 Molecular Excitation

Independent of neutrino physics, molecules possess well-characterized manifolds of excited quantum states, conventionally classified as electronic, vibrational, and rotational, in order of decreasing characteristic energy spacing (Herzberg, 1945). Electronic excitations, involving the promotion of an electron to a higher-energy molecular orbital, typically require energies in the near-infrared to ultraviolet range (roughly 1–10 eV). Vibrational excitations, corresponding to changes in the quantized oscillation of nuclei about their equilibrium bond positions, typically require energies in the mid-infrared range (roughly 0.01–0.5 eV). Rotational excitations, corresponding to changes in the molecule's quantized angular momentum about its center of mass, require still smaller energies, typically in the microwave to far-infrared range (below 0.01 eV) (Atkins & Friedman, 2011).

These energy scales are not approximate order-of-magnitude estimates specific to any one molecule; they follow from the underlying physics of electronic binding energies, bond force constants, and moments of inertia, and are directly measurable via absorption and emission spectroscopy (Herzberg, 1945). For a specific molecule such as androsterone — a C_{19} steroid whose crystal structure, bond geometry, and ring conformation have been precisely determined by X-ray diffraction (Norton & Ohrt, 1964) — the relevant vibrational and electronic transition energies are, in principle, calculable from its known molecular geometry and are empirically accessible via standard infrared and ultraviolet-visible spectroscopy, even though, to our knowledge, a dedicated spectroscopic catalogue specific to androsterone's neutrino-response properties does not exist, for the simple reason that no such response has been proposed or measured prior to this paper.

Transitions between these molecular energy levels are conventionally driven by absorption or emission of electromagnetic radiation, or by inelastic collisional energy transfer with the surrounding solvent or gas-phase environment. The theoretical machinery used to describe these transitions — time-dependent perturbation theory applied to a system driven by an external field — is well established and forms the second pillar of the formalism developed in this paper (Cohen-Tannoudji et al., 2020; Sakurai & Napolitano, 2020).

2.3 Resonance and Transition Processes

The general problem of computing the probability that a quantum system transitions from an initial state to a final state under the influence of a weak external perturbation is addressed by time-dependent perturbation theory, most compactly summarized in Fermi's golden rule, which gives the transition rate as proportional to the squared magnitude of the relevant interaction matrix element, weighted by the density of accessible final states (Sakurai & Napolitano, 2020). When the perturbation is oscillatory or resonant in character — that is, when it couples most strongly to transitions near a particular characteristic frequency — the transition probability as a function of detuning from that frequency takes the Breit–Wigner form, originally derived to explain anomalously large neutron-capture cross-sections near nuclear resonances (Breit & Wigner, 1936). The Breit–Wigner lineshape has since become a standard tool across many areas of physics, describing any process in which a driven system responds resonantly near a well-defined transition frequency, with a resonance width set by the total decay and dephasing rate of the excited state (Cohen-Tannoudji et al., 2020).

In realistic physical systems, an excited state's linewidth is not determined solely by its intrinsic radiative decay rate; it is also broadened by interactions with the surrounding environment, a phenomenon generally described within the framework of open quantum systems and environmentally induced decoherence (Breuer & Petruccione, 2002). For a molecule embedded in a solvent or cellular environment — as would be the case for androsterone under physiological conditions — this environmental broadening is typically the dominant contribution to the effective linewidth of any given transition, and must be incorporated into any resonance-based model applied to such a system.

Finally, when a proposed interaction has no established microscopic origin within the Standard Model, the standard theoretical procedure is not to abandon formal analysis but to construct an effective field theory: positing the most general interaction consistent with the symmetries of the problem, treating its coefficients as free parameters to be constrained by dimensional analysis and, ultimately, by experiment (Weinberg, 1979; Georgi, 1993). This effective-field-theory approach — widely used throughout particle physics to parametrize physics associated with an unknown, typically much higher energy scale (Peskin & Schroeder, 1995) — provides the methodological template this paper follows in Section 5 to construct a posited, symmetry-motivated effective interaction Hamiltonian for the NIAR process, from which the transition probability and rate are then formally derived.

III. THE NIAR HYPOTHESIS

We now formally state the hypothesis this paper investigates. NIAR (Neutrino-Induced Androsterone Resonance) is proposed as a phenomenological hypothesis in which an incident neutrino interacts with a molecular system and induces a transition between molecular states, potentially producing an enhanced response under appropriate resonance conditions. Androsterone is adopted as the representative molecular target throughout this paper because its molecular geometry, ring conformation, and crystal structure are precisely characterized (Norton & Ohrt, 1964), making it a well-defined system against which any proposed transition operator's symmetry properties can, in principle, be checked.

It must be stated with complete clarity, and repeated wherever necessary to avoid ambiguity: NIAR is a hypothesis, not an experimentally established phenomenon. No measurement has detected a neutrino-induced molecular transition of any kind, in androsterone or any other molecule. Nothing in Section 2's review of established neutrino physics or molecular spectroscopy implies that such a process occurs. The purpose of formalizing NIAR is to construct a self-consistent theoretical framework — with explicit, checkable assumptions — within which the question of its feasibility can be posed precisely, its parameter dependencies identified, and its consequences, if any, rendered falsifiable. A framework that cannot be subjected to consistency checks or distinguished in principle from the null hypothesis of no interaction would be scientifically limited regardless of its mathematical elaborateness. The present framework therefore focuses on explicit physical assumptions, energy conservation, parameter dependencies, and clearly stated limitations.

The NIAR hypothesis, precisely stated, is as follows: if neutrinos couple to a molecular degree of freedom of androsterone through some effective interaction — whose existence is not established but is treated here as a working hypothesis to be formally examined — then under conditions of sufficient energy matching between the neutrino's energy loss and a molecular transition energy, an incident neutrino flux could in principle induce a population transfer from the androsterone ground state to an excited vibrational or electronic state, at a rate that depends on the neutrino flux, the (unknown) coupling strength, the degree of energy matching, and the local thermal environment.

This statement is deliberately conditional and hedged at every clause, because each clause identifies a specific, distinct assumption whose validity is not known and which the remainder of this paper examines in turn: the existence of an effective coupling (addressed in Section 5), the degree of energy matching required (Section 6), the specific molecular target and its transition structure (Section 7), and the role of the thermal environment (Section 8).

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It is useful to be explicit about what NIAR, as formalized here, does not claim. It does not claim that androsterone possesses any special or privileged sensitivity to neutrinos relative to other molecules; androsterone is adopted as a concrete, structurally well-characterized case study, not because there is any specific reason to expect it to respond to neutrino flux more strongly than any other steroid or organic molecule of comparable size. It does not claim biological, physiological, or hormonal relevance; the hypothesis concerns a purely physical transition between quantum-mechanical energy levels of an isolated or solvated molecule, and any inference from this framework to biological function would require an entirely separate chain of argument not attempted here. And it does not claim to identify the microscopic origin of the proposed coupling; as with any effective-field-theory treatment of an unconfirmed interaction (Weinberg, 1979), the coupling is treated as a phenomenological parameter pending either a derivation from a more fundamental theory or, more likely given the constraints derived in Section 5, an experimental upper bound demonstrating its absence or negligibility.

IV. PHYSICAL MODEL

Having stated the NIAR hypothesis in words, we now define the specific physical process under consideration with precision sufficient to support the derivation carried out in Section 5. We model the hypothetical interaction as a scattering process in which an incident neutrino interacts with an androsterone molecule initially in its quantum-mechanical ground state, transferring energy to the molecule and exiting with correspondingly reduced energy, while the molecule is left in an excited vibrational or electronic state.

This process is written as

$$\nu + Ai \rightarrow \nu' + Af \qquad (1)$$

Here, $\nu \; and \; \nu'$ denote the incident and outgoing neutrino states, respectively, while $A_i \; and \; A_f$ denote the initial and final molecular states of androsterone. The process is therefore formulated as inelastic neutrino scattering accompanied by molecular excitation rather than complete neutrino absorption.

This is deliberately written as an inelastic scattering process rather than an absorption process (in which the neutrino would vanish entirely): unlike a photon, which can be fully absorbed because it carries no conserved lepton number that must appear in the final state, a neutrino is expected, by analogy with all other confirmed weak-interaction processes (Fermi, 1934; Cowan et al., 1956), to persist in the final state of any neutral-current-type process that does not involve charged-lepton production. We restrict our treatment to this neutral-current-like channel throughout, since it is the only channel structurally analogous to the coherent and matter-oscillation processes reviewed in Section 2.1 (Freedman, 1974; Wolfenstein, 1978).

During the proposed inelastic scattering process, the molecular system undergoes a transition from an initial state $A_i \; to \; a \; final \; state \; A_f$. The corresponding energy required to promote the molecule between these states is determined by the difference between their molecular energy eigenvalues. We therefore define the molecular excitation energy as:

$$\Delta E_A = E_{A,F} - E_{A,i} \qquad (2)$$

where $E_{A,i}$ and $E_{A,f}$ denote the energies of the initial and final molecular states, respectively, and $\Delta E_A > 0$ represents the energy gained by the molecular system during the transition. This quantity provides the characteristic energy scale of the molecular excitation and will subsequently be compared with the energy transferred from the incident neutrino to the molecular system.

The initial and final molecular states are treated as eigenstates of the unperturbed molecular Hamiltonian, $\hat{H}_{mol}$. This establishes the molecular energy eigenstates independently of the proposed neutrino interaction and provides the basis for describing the transition between the states involved in the NIAR process. Thus, for the initial and final states considered here,

$$\hat{H}_{mol}|\psi_n\rangle = E_{A,n}|\psi_n\rangle, \qquad n = i, f \qquad (3)$$

where $|\psi_i\rangle \; and \; |\psi_f\rangle$ denote the initial and final molecular eigenstates, respectively, with corresponding energies $E_{A,1} \; and \; E_{A,f}$. The molecular

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states are assumed to be well described within the conventional Born–Oppenheimer framework, in which electronic, vibrational, and rotational degrees of freedom provide the relevant molecular excitations.

In this framework, the present study does not attempt to calculate the molecular wavefunctions $|\psi_i\rangle \; and \; |\psi_f\rangle$ explicitly from first-principles electronic-structure calculations. Instead, they are treated as physically defined molecular eigenstates whose energy differences and transition properties can, in principle, be constrained by spectroscopic measurements. The proposed NIAR mechanism enters only through the interaction Hamiltonian introduced in Section 5.

V. MATHEMATICAL FORMULATION

5.1 Phenomenological Effective Interaction Hamiltonian

No established interaction within the Standard Model directly couples a neutrino current to the internal electronic, vibrational, or rotational degrees of freedom of a specific molecule such as androsterone. The NIAR mechanism considered here is therefore formulated as a phenomenological hypothesis rather than as a derived consequence of established particle physics. To provide a mathematical representation of this hypothesis, we introduce an effective interaction Hamiltonian that factorizes the neutrino-sector and molecular-sector contributions:

$$\hat{\mathrm{H}}_{int}(t) = \; g_{eff} \; \hat{J}_v(t) \; \widehat{O}_A(t) \qquad (4)$$

Here, g_{eff} is an effective coupling coefficient representing the strength of the hypothesized neutrino–molecular interaction. Its magnitude and dimensions are not fixed a priori because the microscopic origin of the proposed interaction is unspecified. The operator $\hat{J}_v$ represents the relevant neutrino-sector current, while $\widehat{O}_A$ is a Hermitian molecular operator acting on the androsterone degrees of freedom involved in the transition.

$$\hat{J}_v = \; \bar{v}\Gamma_v v \qquad (5)$$

In Equation (5), v denotes the neutrino field, $\bar{v}$ its Dirac adjoint, and Γ_v denotes a model-dependent matrix specifying the Lorentz structure of the neutrino current. Because the microscopic interaction responsible for NIAR is not established, no specific choice of Γ_v is imposed at this stage. This formulation therefore represents a general phenomenological neutrino-current coupling rather than a claim that a particular new interaction has been experimentally established.

The molecular operator $\widehat{O}_A$ represents the molecular degree of freedom through which the hypothesized interaction acts. Depending on the microscopic mechanism ultimately identified, this operator could correspond to an electronic, vibrational, rotational, or other molecular coordinate. The transition matrix element of this operator between the states defined in Equation (3) is therefore the quantity that determines the molecular sensitivity of the proposed process.

Equations (4) and (5) should be understood as a phenomenological starting point for the mathematical development that follows. They do not constitute a derivation of a new fundamental neutrino interaction. Rather, they provide a parameterized interaction structure from which the transition amplitude and associated rate can be derived under the assumptions of the NIAR hypothesis.

5.2 Transition Amplitude

Having specified the phenomenological interaction Hamiltonian in Equations (4) and (5), we next derive the transition amplitude connecting the initial and final states of the neutrino–molecular system. Within first-order time-dependent perturbation theory, the transition amplitude is obtained by integrating the interaction matrix element over the duration of the perturbation.

For the transition defined in Equation (1), the first-order amplitude is therefore:

$$A_{fi}^{(1)}(t) = -\frac{i}{\hbar}\int_0^t dt' \, \langle \mathrm{f} \, |\hat{\mathrm{H}}_{int}(t')|i\rangle \qquad (6)$$

where $|i\rangle \; and \; |f\rangle$ denote the complete initial and final states of the combined neutrino–molecular system, respectively. For the process considered here, these states are written as

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$$|i\rangle = |v_i\rangle \otimes |\varphi_i\rangle, \quad |f\rangle = |v_f\rangle \otimes |\varphi_f\rangle \tag{7}$$

Here, $|v_i\rangle$ and $|v_f\rangle$ denote the initial and final neutrino states, while $|\varphi_i\rangle$ *and* $|\varphi_f\rangle$ are the corresponding initial and final molecular states introduced in Equation (3). The transition amplitude therefore describes the joint evolution of the neutrino and molecular subsystems under the hypothesized interaction.

The phase accumulated during the transition is determined by the difference between the total final and initial energies. We therefore define the corresponding angular-frequency difference as:

$$\omega f_i = \frac{(E_{v,f} + E_{A,f}) - (E_{v,i} + E_{A,i})}{\hbar} \tag{8}$$

where $E_{v,i}$ *and* $E_{v,f}$ denote the initial and final neutrino energies, respectively, and $E_{A,i}$ *and* $E_{A,f}$ denote the corresponding molecular energies. For an energetically allowed transition, conservation of total energy requires $w_{fi} = o$, or equivalently,

$$E_{v,i} + E_{A,i} = E_{v,f} + E_{A,f} \tag{9}$$

This relation shows that the energy lost by the incident neutrino is transferred to the molecular system. Accordingly, the neutrino energy transfer is

$$\Delta E_v = E_{v,i} - E_{v,f} = E_{A,f} - E_{A,i} = \Delta E_A \tag{10}$$

Thus, the proposed molecular excitation does not require the total incident neutrino energy to equal the molecular excitation energy. Rather, the relevant condition is that the energy transferred from the neutrino during the scattering process matches the energy required to promote the molecule from its initial state to its final state. This distinction is central to the NIAR framework and provides the basis for defining the resonance condition developed below.

5.3 Transition Probability and Fermi's Golden Rule

The transition amplitude derived in Section 5.2 provides the starting point for determining the probability and rate of the proposed neutrino-induced molecular transition. In the long-time limit and under the assumptions of first-order time-dependent perturbation theory, the transition rate can be expressed using Fermi's Golden Rule. This formulation separates the interaction matrix element from the density of accessible final states and provides the appropriate connection between the microscopic transition amplitude and the interaction rate.

$$\Gamma_{i\to f} = \frac{2\pi}{\hbar} |M_{fi}|^2 \rho f \tag{11}$$

Here, $\Gamma_{i\to f}$ denotes the transition rate from the initial state to the final state $f_i M_{fi}$, is the corresponding interaction matrix element, and ρf is the density of accessible final states. The transition rate has dimensions of inverse time and should therefore be distinguished from a dimensionless transition probability.

For the phenomenological interaction defined in Equation (4), the transition matrix element can be factorized into contributions from the neutrino and molecular sectors:

$$M_{fi} = g_{eff} M_v M_A \tag{12}$$

where the neutrino-sector matrix element is defined as

$$M_v = \langle \mathrm{vf} \,|\, \hat{J}_v | v_i \rangle \tag{13}$$

and the molecular transition matrix element is

$$M_A = \langle \psi_f \mid \hat{O}_A \mid \psi_i \rangle \tag{14}$$

Here, M_v describes the neutrino-sector contribution to the transition, whereas M_A describes the molecular transition induced by the operator $\hat{O}_A$. The effective coupling g_{eff} controls the overall strength of the hypothesized interaction. Because the microscopic origin of this coupling has not been established, its numerical value is not specified in the present phenomenological formulation.

Substituting Equation (12) into Equation (11) gives the transition rate in terms of the separate neutrino and molecular contributions:

$$\Gamma_{i\to f} = \frac{2\pi}{\hbar} |g_{eff}|^2 |M_v|^2 |M_A|^2 \rho f \tag{15}$$

Equation (15) shows that the transition rate depends on the squared effective coupling, the neutrino-sector transition strength, the molecular transition matrix element, and the density of accessible final states. The

molecular response therefore depends not only on the existence of a hypothesized neutrino–molecular coupling, but also on the structure of the molecular states connected by $\hat{O}_A$.

At this stage, $\Gamma_{i\to f}$ represents the microscopic transition rate for a specified initial and final state. The incident neutrino flux has not yet been included. The next step is therefore to connect the microscopic transition description to an observable interaction rate by introducing the neutrino flux and an effective NIAR cross section.

5.4 Effective Cross Section and Neutrino-Flux–Driven Rate

The microscopic transition rate derived in Section 5.3 describes a specified transition between an initial and final neutrino–molecular state. To connect this microscopic description with an experimentally measurable response, it is useful to express the interaction in terms of an effective transition cross section. The cross section provides the appropriate quantity for folding the proposed molecular interaction with an incident neutrino flux and obtaining a transition rate per target molecule.

For a given molecular transition $i \to f$, we therefore introduce the phenomenological NIAR cross section in the form

$$\sigma_{i\to f}(E_v) = S_{i\to f}(E_v)\, L_{i\to f}(\Delta E_v - \Delta E_A; \Gamma) \quad (16)$$

where $S_{i\to f}(E_v)$ is an effective resonance-strength factor and $L_{i\to f}$ is a normalized energy-domain line-shape function. The resonance-strength factor contains the interaction normalization and the relevant neutrino and molecular transition matrix elements, while the line-shape function describes the dependence of the transition on the energy mismatch between the neutrino energy transfer and the molecular excitation energy.

The energy transferred by the neutrino is defined as

$$\Delta E_v = E_{v,i} - E_{v,f} \quad (17)$$

and the molecular excitation energy was defined previously as

$$\Delta E_A = E_{A,i} - E_{A,f}$$

The detuning between the neutrino energy transfer and the molecular transition is therefore

$$\delta E = \Delta E_v - \Delta E_A \quad (18)$$

so that exact energy matching corresponds to $\delta E = 0$
For a finite-width molecular transition, the normalized resonance profile is represented phenomenologically by the Lorentzian function

$$L(\delta; E\Gamma) = \frac{1}{\pi}\frac{\Gamma/2}{(\delta E)^2 + (\Gamma/2)^2} \quad (19)$$

where Γ denotes the full width at half maximum of the transition in energy units. The line shape is normalized according to

$$\int_{-\infty}^{+\infty} L(\delta; E\Gamma)\, d(\delta E) = 1 \quad (20)$$

which ensures that the resonance function describes the distribution of transition strength over energy without introducing an additional dimensional normalization.

For an incident differential neutrino flux $\Phi^{\nu}(E^{\nu})$, the transition rate per target molecule is obtained by folding the effective cross section over the neutrino energy spectrum:

$$r^{i\to f} = \int d\, E^{\nu} \Phi^{\nu}(E^{\nu}) \sigma^{i\to f}(E^{\nu}) \quad (21)$$

where $r^{i\to f}$ has units of inverse time per target molecule.

For an ensemble containing N^{mol} target molecules, the corresponding total transition rate is

$$R^{i\to f} = N^{mol} r^{i\to f} \quad (22)$$

provided that the target molecules can be treated as independent and that collective many-body effects are not included in the present phenomenological description.

The dimensions of Equation (21) follow directly from the standard flux–cross-section relation. If $\Phi^{\nu}(E^{\nu})$ has units of inverse area, inverse time, and inverse energy,

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while has units of area, then integration over neutrino energy gives

$$[\Phi^{\nu}(E^{\nu})\sigma^{i\to f}(E^{\nu})dE^{\nu}] = time^{-1}$$

Thus,

$$[r^{i\to f}] = s^{-1} \qquad (23)$$

as required for a transition rate per target molecule.
At this stage, $S^{i\to f}(E^{\nu})$ remains an unconstrained phenomenological quantity because the microscopic interaction responsible for NIAR has not been established. The formulation therefore does not assign a numerical value to the NIAR cross section. Instead, it provides a dimensionally well-defined structure in which the unknown interaction strength, molecular transition matrix element, neutrino-sector contribution, and resonance behavior can be incorporated once an underlying microscopic model is specified.

VI. RESONANCE CONDITION

The proposed NIAR mechanism requires the energy transferred from the incident neutrino to be compatible with an allowed molecular transition. From the energy-conservation relation established in Equation (9),

$$E^{\nu,i} + E^{A,i} = E^{\nu,f} + E^{A,f},$$

the energy transferred from the neutrino is

$$\Delta E^{\nu} = E^{\nu,i} - E^{\nu,f} = \Delta E^{A} \qquad (24)$$

where ΔE^{A} is the molecular excitation energy defined in Equation (2). The resonance condition therefore corresponds to

$$\delta E = \Delta E^{\nu} - \Delta E^{A} = 0 \qquad (25)$$

rather than requiring the total incident neutrino energy to equal the molecular excitation energy.

For a transition with finite linewidth, the response is distributed around this condition according to the resonance function introduced in Equation (19). Consequently, the predicted NIAR response is expected to be largest when the neutrino energy transfer approaches the molecular transition energy and to decrease as the energy mismatch increases.

The resonance condition is therefore a necessary condition within the phenomenological framework, but it does not by itself establish that the underlying neutrino–molecular interaction exists.

VII. MOLECULAR MODEL OF ANDROSTERONE

7.1 Structure and Relevant Degrees of Freedom

Androsterone ($C_{19}H_{30}O_2$) is a C_{19} steroid possessing the characteristic four-ring (three six-membered, one five-membered) steroid nucleus, with a hydroxyl group at the C-3 position and a ketone at C-17. Its precise molecular geometry — bond lengths, ring-junction conformation, and the axial orientation of the C-3 hydroxyl group — was determined by X-ray crystallography, establishing the space group, unit cell parameters, and atomic positional coordinates of the molecule to high precision (Norton & Ohrt, 1964). This is significant for the present framework in one specific respect: it means that, unlike a hypothetical or poorly characterized molecule, androsterone's normal vibrational modes and electronic transition symmetries are, in principle, fully computable from established molecular quantum mechanics (Atkins & Friedman, 2011), even though such a calculation is not undertaken in this paper.

Three categories of candidate transition are relevant to a molecule of this size and complexity, following the general classification established in Section 2.2: vibrational modes, of which androsterone (a 51-atom molecule) possesses 3(51) − 6 = 147 normal modes spanning stretching, bending, and torsional motions with characteristic energies in the mid-infrared range typical of C–H, O–H, and C=O vibrations (Herzberg, 1945); electronic transitions, principally the carbonyl (C=O) group at C-17, whose lowest-energy n→π* transition is expected, by analogy with other saturated ketones, in the near-ultraviolet range; and rotational structure, which in a condensed (solvated or crystalline) phase under physiological conditions is not resolvable as discrete transitions, and is instead subsumed into the broadened linewidth Γ introduced in Equation (19), consistent with the treatment of environmental decoherence discussed in Section 2.3 (Breuer & Petruccione, 2002).

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7.2 Candidate Transitions and Characteristic Energy Scales

For the purposes of this framework, we do not compute a specific numerical value of ΔE_A for any single vibrational or electronic mode of androsterone; doing so would require a dedicated quantum chemical calculation beyond this paper's scope. Instead, we characterize ΔE_A by the ranges established generically for molecules of this class in Section 2.2: ΔE_A ~ 0.05–0.4 eV for vibrational transitions, and ΔE_A ~ 3–6 eV for the lowest-lying electronic transitions. These ranges are what enter the resonance and rate expressions of Sections 5–6 and the parameter analysis of Section 9; refining them for specific vibrational or electronic modes of androsterone is identified explicitly in Section 10 as a necessary future step rather than treated as already accomplished here.

7.3 Environmental Effects on the Target

Under physiological conditions, androsterone would not exist as an isolated gas-phase molecule but as a solvated species, embedded in an aqueous or lipid environment. This has two consequences for the framework developed here. First, as already incorporated via Γ in Equation (19), solvent collisions and interactions substantially broaden the molecule's transition linewidths relative to the gas phase, an effect well documented in condensed-phase spectroscopy generally (Breuer & Petruccione, 2002). Second, solvent interactions can shift transition energies (solvatochromism) relative to their gas-phase values, meaning that any eventual numerical estimate of ΔE_A appropriate to this framework would need to account for the specific solvent environment under consideration, rather than relying on gas-phase spectroscopic values alone.

VIII. THERMAL AND ENVIRONMENTAL EFFECTS

The microscopic transition rate developed in Section 5 describes a specified molecular transition beginning from a defined initial state. In a macroscopic sample at finite temperature, however, molecules may occupy a distribution of accessible molecular states. The contribution of each initial state to the observable NIAR response must therefore be weighted according to its thermal population. In addition, the condensed-phase environment can modify molecular transition energies and broaden the associated resonance linewidth. These effects are considered separately below.

8.1 Boltzmann Population of Molecular States

Androsterone molecules in a macroscopic sample are treated as distinguishable molecules whose accessible molecular states are populated according to conventional Boltzmann statistics at thermal equilibrium. The population fraction of an initial molecular state i
is therefore:

$$p^i(T) = Z g^i e^{-E^{A,i}/k^B T} \tag{26}$$

where g^i is the degeneracy of state $i, E^{A,i}$ is its molecular energy, T is the absolute temperature, k^B is the Boltzmann constant, and Z is the molecular partition function,

$$Z = n \sum g^n e^{-E^{A,n}/k^B T} \tag{27}$$

For the simplified case in which the relevant NIAR transition originates predominantly from the molecular ground state, the ground-state population fraction may be written as:

$$p^{ground}(T) = \sum^{n} g^n \, e^{-(E^{A,n} - E^{A,0})/k^B T} g^0 \tag{28}$$

where $E^{A,0}$ denotes the ground-state energy. If the ground state is non-degenerate, $g^0 = 1$.

The thermally averaged NIAR rate is then obtained by weighting the transition rate associated with each initial state by its corresponding population:

$$r^{NIAR}(T) = i \sum p^i(T) r^i \tag{29}$$

where r^i denotes the NIAR transition rate per molecule originating from initial state i.

When the ground state overwhelmingly dominates the molecular population, Equation (29) reduces approximately to the ground-state transition rate multiplied by p^{ground}.

8.2 Physiological-Temperature Limit

At approximately physiological temperature, $T \approx 300K$, the thermal energy scale is

$$k^B T \approx 0.026eV.$$

For molecular transitions whose excitation energies are substantially larger than $k^B T$

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, the corresponding excited-state populations are exponentially suppressed. Thus, when

$$\Delta E^A \gg k^B T \quad (30)$$

the ground-state approximation

$$p^{ground} \approx 1 \quad (31)$$

is justified.

For lower-energy molecular modes whose excitation energies are comparable to $k^B T$, thermal occupation of excited states may become non-negligible and Equation (29) should be used rather than assuming that all molecules initially occupy the ground state.

8.3 Solvent and Environmental Broadening

The molecular transition does not occur in isolation when the target is present in a condensed-phase or biological environment. Interactions with surrounding solvent molecules and other environmental degrees of freedom can broaden and shift molecular transitions. These effects can therefore modify both the effective transition energy ΔE^A and the linewidth Γ appearing in the resonance function introduced in Equation (19). For any future quantitative application of the NIAR framework, the relevant linewidth and transition energy should therefore be treated as properties of the specific molecular environment under consideration rather than assumed to be identical to their isolated gas-phase values.

The environmental contribution is particularly important because the proposed resonance condition depends on the difference between the neutrino energy transfer and the molecular transition energy. Environmental shifts in ΔE^A can therefore alter the location of the predicted resonance, while environmental broadening modifies the width of the response.

8.4 Molecular Concentration

The rate $r^{NIAR}(T)$ defined in Equation (29) represents the transition rate per target molecule. For a sample containing N^{mol} independently responding androsterone molecules, the corresponding total event rate is

$$R^{total} = N^{mol} r^{NIAR}(T) \quad (32)$$

where $N^{mol}$is the total number of target molecules in the sample.

Thus, within the independent-target approximation, increasing the number of androsterone molecules increases the total predicted NIAR event rate linearly, while the rate per molecule remains determined by the neutrino flux, effective interaction strength, molecular transition properties, resonance condition, and thermal population.

IX. PREDICTED NIAR RESPONSE

The phenomenological framework developed above identifies several physical quantities that determine the predicted NIAR response. These include the incident neutrino flux, the effective interaction strength, the molecular transition energy, the resonance linewidth, the thermal population of the initial molecular states, and the number of target molecules. Because the microscopic NIAR interaction has not been established, these dependencies are considered qualitatively and parametrically rather than assigned specific numerical values.

9.1 Dependence on Neutrino Flux

From Equation (21), the transition rate per target molecule is obtained by folding the effective NIAR cross section with the incident differential neutrino flux. Consequently, for otherwise identical neutrino energy spectra and target conditions,

$$r^{NIAR} \propto \Phi^{\nu} \quad (33)$$

Thus, increasing the incident neutrino flux is expected to increase the predicted NIAR rate, provided that the effective interaction and molecular target remain unchanged. For neutrino sources with different energy spectra, the response depends on the spectral overlap between the incident flux and the molecular resonance rather than on the total integrated flux alone.

9.2 Dependence on Effective Interaction Strength

The microscopic transition rate derived in Section 5 contains the squared effective coupling. Accordingly, when the effective cross section is generated by an interaction amplitude proportional to g^{eff}, the predicted response scales as

$$r^{NIAR} \propto | g^{eff} |^2 \quad (34)$$

The numerical value of g^{eff} remains unconstrained because the microscopic origin of the proposed neutrino–molecular interaction has not been

established. Equation (34) should therefore be interpreted as a parametric dependence rather than as a quantitative prediction.

9.3 Dependence on Molecular Transition Energy

The molecular transition energy determines the location of the resonance through the detuning defined in Equation (18):

$$\delta E = \Delta E^{\nu} - \Delta E^{A} \quad (35)$$

The predicted response is therefore enhanced when the neutrino energy transfer approaches the molecular excitation energy,

$$\Delta E^{\nu} \approx \Delta E^{A} \quad (36)$$

and decreases as the energy mismatch becomes larger. Consequently, molecular transitions with different excitation energies can respond differently to the same neutrino source.

9.4 Dependence on Temperature

The temperature dependence enters through the thermal populations defined in Equations (26)– (29). The ensemble rate can therefore be written as:

$$r^{NIAR}(T) = i\sum p^{i}(T) r^{i} \quad (37)$$

When one initial molecular state dominates the population, the temperature dependence of the overall response is expected to be weak. If several molecular states become appreciably populated, however, their different transition energies and matrix elements may produce a measurable temperature dependence.

9.5 Dependence on Molecular Concentration

For independently responding target molecules, Equation (22) gives a linear dependence of the total response on the number of molecules:

$$R^{total} \propto N^{mol} \quad (38)$$

Thus, increasing the amount of androsterone in the target sample increases the total predicted event rate proportionally, provided that the incident neutrino flux and molecular environment remain unchanged.

9.6 Dependence on Resonance Width

The resonance linewidth Γdetermines the energy range over which the molecular transition can contribute appreciably to the response. From Equation (19), a narrower resonance produces stronger energy selectivity, whereas a broader resonance distributes the response over a wider energy interval. The linewidth may therefore depend on molecular environment, temperature, and other broadening mechanisms.

Overall, the framework predicts that the NIAR response should be governed by the combined effects of neutrino flux, effective interaction strength, molecular transition properties, resonance broadening, thermal state populations, and target quantity. Because the underlying interaction remains hypothetical, these relationships define testable parameter dependencies rather than established quantitative predictions.

X. LIMITATIONS

The present framework is phenomenological and should not be interpreted as evidence that neutrinos interact with androsterone or with molecular degrees of freedom. The effective interaction introduced in Equation (4) is a hypothesis rather than a derivation from an established microscopic theory, and the corresponding effective coupling remains unknown. In addition, the molecular transition matrix element has not been evaluated through a dedicated quantum-chemical calculation, and no experimental measurement of the proposed NIAR effect is reported. Consequently, the equations developed here provide a structured framework for examining the hypothesis and identifying experimentally testable conditions, but they do not constitute a quantitative prediction of an established physical phenomenon.

XI. CONCLUSION

This paper presents Neutrino-Induced Androsterone Resonance (NIAR) as a phenomenological hypothesis for a possible neutrino-induced excitation of molecular degrees of freedom. Using androsterone as a representative molecular target, the study develops a mathematical framework connecting a hypothesized neutrino–molecular interaction to transition amplitudes, transition rates, energy transfer, resonance behavior, thermal population, and an effective interaction cross section.

A central feature of the framework is that the relevant resonance condition is determined by the energy transferred from the neutrino, rather than by requiring the total incident neutrino energy to equal the

molecular excitation energy. The formulation also shows how the predicted response would depend on the incident neutrino flux, effective interaction strength, molecular transition properties, resonance linewidth, temperature, and number of target molecules.

The present work does not establish NIAR experimentally, nor does it provide a microscopic derivation of the proposed neutrino–molecular interaction. The effective coupling remains unknown, and the relevant molecular transition matrix elements require dedicated molecular calculations and experimental characterization. Accordingly, the equations presented here should be interpreted as a phenomenological framework for evaluating and testing the hypothesis, rather than as a quantitative prediction of an established physical effect.

Future work should focus on identifying experimentally accessible molecular transitions, calculating the corresponding molecular matrix elements, constraining the effective interaction through established neutrino sources, and determining whether a measurable molecular response can be distinguished from conventional thermal, electromagnetic, and environmental effects. Such investigations would provide the necessary basis for determining whether the NIAR hypothesis has physical validity.

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