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The Mechanism of Molecular Collisions and Interactions Illustrates the Philosophical Implications of the Universal Interconnectedness of All Things

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Abstract: In order to resolve the long-standing dilemma of abstract interpretations of the principle of universal interconnection in dialectical materialism, this paper takes the microscopic physical mechanism of molecular collisions as a concrete vehicle. After analyzing the three fundamental modes of interaction—elastic collisions, inelastic collisions, and reactive collisions—and integrating deeper operational logics such as mediating coupling, non-linear emergence, and boundary interpenetration, it provides a comprehensive and systematic exposition of the intrinsic characteristics of the universal interconnection of things from three dimensions: ontology, methodology, and praxis. The research reveals that collision interactions at the molecular level are not isolated microphysical phenomena, but rather the microscopic emergent forms of universal interconnection in the material world: the inevitability of collisions confirms the objectivity of interconnection; the diverse modes of collisions correspond to the richness of interconnection; the chain-reaction-like emergence of collisions generates the wholeness of interconnection; and the transformation of mass and energy in collisions embodies the developmental nature of interconnection.

Keywords: Molecular collisions; Interaction mechanisms; Universal connections; Philosophical implications

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1. Micro-ontological verification of universal interconnection

The universal interconnection of the material world is not an abstract principle detached from experience, but is rooted in the inherent properties of motion possessed by microscopic matter. As the fundamental building blocks of macroscopic matter, molecules—through their ceaseless thermal motion and continuous collisions and interactions—constitute the most fundamental and universal microscopic manifestation of the universal interconnection of things.

The absolute nature of molecular thermal motion determines the inevitability of collisions, which forms the physical basis for the objectivity of connections. According to the kinetic theory of gases, as long as the temperature is above absolute zero, the molecules constituting matter are constantly engaged in random thermal motion; this motion is an intrinsic property of matter and is independent of any external influence. Under standard conditions, the average velocity of air molecules can reach several hundred meters per second, whilst the average mean free path between molecules is only approximately 6.8×10^{-8} meters; a single molecule experiences as many as 6.5×10^{9} collisions per second. Such a high frequency of collisions means that no molecule can exist in isolation, free from the interplay of collisions; the state of motion and energy level of every molecule are constantly influenced and reshaped by other molecules. This inevitable interconnection at the microscopic level is precisely the ontological root of the universal interconnectedness in the macroscopic world: connection is not a contingent, external relationship superimposed upon things, but rather the inherent mode of existence of matter; the very existence of a thing inherently entails a connection with other things [1].

The universal nature of collisions highlights the pervasive dimension of interactions, ranging from the rarity of interstellar gas to the density of solid crystal lattices, from inorganic chemical systems to organic living systems—wherever molecules exist, collisions and interactions occur. In gaseous systems, molecules achieve the global transfer of energy and momentum through frequent collisions; in liquid systems, molecules facilitate the diffusion and mixing of matter through close-range collisions; and in solid systems, the vibrations of molecules around their equilibrium positions are, fundamentally, the result of continuous collisions and interactions between neighboring molecules. Even the gas molecules remaining in a high-vacuum environment continue to collide, although their mean free path becomes longer and the collision frequency decreases slightly; This universality of collisions transcends both states of matter and physical systems; it corresponds to the universality associated with philosophy. From microscopic particles to macroscopic celestial bodies, and from the inorganic world to human society, everything is interconnected with its surroundings; absolutely isolated entities do not exist in the real world.

Different types of collisions give rise to different patterns of interaction, as there are not one but three forms of molecular collision. Based on their outcomes, these can be categorized into elastic collisions, inelastic collisions, and reactive collisions; these three categories correspond to different depths and natures of the connections between things. In an elastic collision, molecules merely transfer momentum and translational kinetic energy, whilst their internal structure and chemical properties remain unchanged. This corresponds to superficial, quantitative connections between things—such as the transfer of mechanical forces between objects or the superficial transmission of information—which alter only the external state of things without affecting their essential characteristics. In an inelastic collision, part of the translational kinetic energy is converted into the molecules' rotational and vibrational internal energy, causing changes in their internal energy levels; however, the chemical composition remains unchanged. This corresponds to intermediate-level connections between things involving partial qualitative changes, such as changes in the physiological state of a living organism following external stimulation, or shifts in the views of a social group influenced by public opinion. Such interactions penetrate deep into the internal structure of things and alter their intrinsic state, although they do not yet breach the fundamental boundaries of the things themselves. Reaction collisions, on the other hand, involve effective collisions between activated molecules, accompanied by the breaking of old chemical bonds and the formation of new ones, whereby the original molecules are transformed into entirely new ones. This corresponds to deep-seated connections between things involving qualitative changes—such as interactions that breach the essential boundaries of things, leading to the extinction of the old and the emergence of the new, thereby achieving a fundamental transformation of material form. The hierarchical differences among these three types of collision patterns reveal that universal connections are not merely single, linear links, but rather a unified whole comprising diverse forms of varying depths and distinct natures [2].

2. The logic of interaction in universal interconnection

The realization of universal interconnection does not involve a direct juxtaposition of things, but rather a mediating interactive process centered on collisions. The mechanism of molecular collisions clearly demonstrates the mediating, chain-like, and structural nature of these connections, providing a microscopic paradigm for understanding the intrinsic operational logic of universal interconnection.

The essence of a collision lies in mediated interactions, which reveal the universality of indirect connections. On the surface, a molecular collision appears to be a direct contact between two molecules; however, a deeper examination of the physical nature of the phenomenon reveals that molecules are not rigid entities. The essence of a collision lies in the electromagnetic interaction between the outer electron clouds of the molecules, with the electromagnetic field serving as the mediating carrier through which intermolecular interactions occur. There is no such thing as an absolutely direct connection without mediation; even a collision that appears direct requires the transmission of interactions via the field as a form of matter. Furthermore, the vast majority of energy and matter transfer within molecular systems is not achieved through direct collisions between two molecules, but rather through a relay transfer involving a series of intermediary molecules. For example, during heat conduction, molecules in a high-temperature region transfer energy to neighboring molecules through collisions; these neighboring molecules then pass it on to the next layer of molecules, gradually conducting heat to the low-temperature region. Each molecule acts both as a receiver and a transmitter of energy, forming a chain of intermediary links. This mediating role at the microscopic level corresponds to the universality of indirect connections in the macroscopic world: the vast majority of connections between things can only be realized through several intermediary links; mediation is an indispensable constituent element of universal connections. Catalysts in chemical reactions are a prime example of this mediating role: through surface adsorption, catalysts collide with reactant molecules, lowering the activation energy of the reaction and promoting effective collisions, whilst retaining their chemical properties unchanged before and after the reaction. As mediators of connection, catalysts profoundly alter the efficiency and pathways of connections between things; this shares an intrinsic isomorphism with the roles of intermediary organizations—such as platforms, media, and institutions—within social systems [3].

The transmission mechanism of chain collisions demonstrates the chain-like nature of interactions and their causal extension. Collisions in molecular systems are often not isolated, one-off events, but rather a sequence of processes characterized by chain-like transmission effects. When a molecule that has acquired high energy collides with another molecule, it transfers part of its energy to the other molecule, causing it to become a high-energy molecule as well, which in turn triggers further collisions, forming a chain reaction. In atmospheric photochemical reactions, hydroxyl radicals generated by ultraviolet irradiation collide with methane molecules to produce methyl radicals and water molecules; the methyl radicals then collide with oxygen molecules to form peroxymethyl radicals; the peroxymethyl radicals may in turn collide with nitric oxide to produce nitrogen dioxide and methoxyl radicals… This series of interlinked collisions forms a complex reaction chain. This chain-reaction mechanism is precisely the microscopic foundation of causal relationships: causes and effects are continuously transformed through the chain of collisions, and an initial minute interaction can be amplified through successive transmissions, ultimately triggering significant effects at the macroscopic level. The transmission of energy through food chains in natural ecosystems, fluctuations in supply chains within economic systems, and the spread of public opinion in social systems are, in essence, macroscopic manifestations of this chain-reaction linkage. It is worth noting that the transmission of chain collisions is not a linear, equal-quantity transfer, but is accompanied by energy dissipation and path branching during the process; this also explains the complexity and non-linear characteristics of causal relationships in reality.

The coupling effects of cooperative collisions endow these interactions with structure and order; the collisions of a large number of molecules are not haphazard, random events, but rather form ordered patterns of cooperative coupling under specific conditions. In crystalline materials, atoms or molecules undergo regular vibrations at lattice nodes, whilst collisions and interactions between neighboring molecules build a stable lattice structure, resulting in the regular geometric shape and fixed physical properties characteristic of crystals at the macroscopic level. This system, which is essentially a coupled system formed by the synergistic collisions of a large number of molecules through their interactions, means that the motion of individual molecules is no longer entirely independent and random; rather, it is constrained by the overall lattice vibrations, forming collective phonon modes. The coupling effects of molecular collisions demonstrate that the connections between things are not scattered and disordered, but rather construct relatively stable structures during the process of interaction; structure is the ordered manifestation of these connections. Different material structures arise from different modes of collision coupling; these correspond to distinct macroscopic properties, which precisely illustrates the microscopic roots of the concept that structure determines function. From microscopic crystal lattices to macroscopic celestial systems, and from the structure of biological cells to the organizational structure of human society, these are essentially interconnected structures formed through the interaction and coupling of matter at different levels [4].

3. The dialectical and developmental nature of universal interconnection

Universal interconnection is not a static relationship, but rather a dynamic process involving the movement of contradictions and transformations in quality and state. The relativity of boundaries, the tension between attraction and repulsion, and the bidirectional dynamic equilibrium observed in molecular collisions profoundly illustrate the dialectical and developmental nature of universal interconnection.

The relativity of the effective collision diameter reveals the conditional nature of interactions and the permeability of boundaries. What is commonly referred to as the molecular collision diameter is not an absolute rigid boundary of the molecule, but rather the effective range of intermolecular interactions. When the distance between two molecules is considerable, they exhibit weak van der Waals attractions; when the distance is reduced to a certain extent, the repulsive forces between their electron clouds rapidly increase; a collision is a process of relative motion resulting from the combined effects of attraction and repulsion. This implies that molecules do not possess absolutely distinct, insurmountable, fixed boundaries; rather, molecular boundaries are generated through interaction and are both conditional and permeable. Changes in conditions such as temperature and pressure alter the rate of molecular motion and the strength of interactions, thereby altering the size of the effective collision diameter. This relativity of microscopic boundaries corresponds to the relativity of the boundaries of things at a philosophical level: everything has its own qualitative characteristics and boundaries, but these boundaries are not absolute or fixed; rather, they are relative and permeable. Things interpenetrate and interconnect through their relationships, and under certain conditions, they can transform into one another. This also confirms the conditional nature of relationships: concrete relationships always depend on specific conditions; when conditions change, the nature, mode, and degree of the relationship will also change accordingly.

The tension between attraction and repulsion during the collision process gives rise to the contradictory dynamics of interaction; throughout the entire molecular collision process, there is a constant interplay of these two opposing yet interdependent forces. As molecules approach one another, attractive forces draw them closer; however, if they come too close, repulsive forces cause them to separate. The interaction between these attractive and repulsive forces determines the collision trajectory, the form of energy transfer, and whether a reaction will occur. This is particularly true of collisions in chemical reactions: the breaking of old chemical bonds requires overcoming the attractive forces between atoms and thus exhibits repulsive behavior, whilst the formation of new chemical bonds relies on the attractive forces between atoms and thus exhibits attractive behavior. Without attractive forces, molecules could not approach one another to interact; without repulsive forces, molecules would shrink indefinitely and be unable to maintain their independence. Therefore, the unity of opposites between attraction and repulsion is precisely the intrinsic driving force behind the motion of molecular collisions. This mechanism profoundly illustrates that contradiction is the fundamental driving force behind the development of things: the connections between things are, at their core, contradictory in nature, embodying both unity and struggle. These two aspects are jointly inherent in these connections, driving the motion, change, and development of things; the developmental nature of universal interconnection stems precisely from this contradictory tension within the connections themselves [5].

Bidirectional collisions and dynamic equilibrium embody the interdependence of connections and the spiral nature of development. Collisions within a molecular system are never unidirectional interactions, but rather bidirectional ones. In reversible chemical reactions, whilst reactant molecules collide to form products, product molecules also collide to reform reactants; when the rates of the forward and reverse reactions are equal, the system reaches a state of chemical equilibrium. This equilibrium is not static or absolute, but rather a dynamic equilibrium: molecular collisions are constantly taking place, and the transformation of matter is constantly occurring; it is merely that the macroscopic concentration remains relatively stable. Physical processes such as dissolution and crystallization, evaporation and condensation, are likewise the result of a dynamic equilibrium of bidirectional collisions. This mechanism of bidirectional, mutually constitutive relationships demonstrates that the interactions between things are reciprocal; whilst one party acts upon the other, it is also subject to a reaction from the other party. Within these interconnections, things are not passively shaped in a unidirectional manner, but rather actively and mutually shape one another—that is, they are mutually constitutive. The disruption and re-establishment of dynamic equilibrium drive material systems to transform from one state to another, exhibiting the characteristics of a spiraling ascent in development. Ecological balance, economic equilibrium, and social stability in the macroscopic world are, in essence, all forms of this bidirectional, mutually constitutive dynamic equilibrium; the disruption and reconstruction of this equilibrium drive the evolution and development of the system.

4. The contemporary value of the philosophy of universal interconnection from the perspective of micro-interactions

Interpreting the philosophical implications of universal interconnection through the mechanism of molecular collisions is not merely a simple scientific analogy; rather, it lays a scientific foundation for the dialectical materialist conception of interconnection at the level of microscopic reality, promotes a shift in philosophical thinking from a focus on entities to a focus on interactions, and provides more incisive intellectual tools for understanding and transforming the real world.

Viewed from this perspective, it transcends reductionist thinking and prompts a shift in ontology towards an interaction-centered approach; Since the modern era, it has been customary to employ reductionist thinking to break things down into isolated entities and then study the properties of those entities to elucidate the nature of the whole. However, the mechanism of molecular collisions clearly demonstrates that interaction is more ontologically fundamental than entities themselves; properties such as molecular kinetic energy and internal energy are only manifested and transformed during collisions and interactions, whilst chemical properties only become apparent when molecules collide and react with one another. Without interaction, isolated molecules would remain mere abstract concepts devoid of any concrete reality. This implies that the essence of things does not lie within isolated entities themselves, but rather in the interconnections and interactions between them. This interaction-centered ontology not only deepens the principle of universal interconnection in dialectical materialism but also resonates with current trends in contemporary complex systems science and relational ontology. It enlightens us that our understanding of things must not be confined to the entities themselves, but must delve deeper into the networks of connections between them, grasping their essence and laws through these interactive relationships.

The mechanism of microscopic collisions bridges the laws governing the connection between the microscopic and macroscopic levels, thereby deepening our understanding of complex systems. Previous interpretations of universal connections have largely remained at a macroscopic, qualitative level, lacking concrete explanations of the intrinsic mechanisms by which these connections generate systemic properties and drive the evolution of systems. Research into molecular collisions has revealed the pathway by which micro-level random interactions give rise to macro-level ordered patterns, thereby bridging the gap between micro-level mechanisms and macro-level laws. This integration holds universal methodological significance for understanding various complex systems: to comprehend macro-level social phenomena, one must delve into the interactive behavior of individuals; to understand macro-level ecological laws, one must grasp micro-level species interactions and material cycles; and to analyze macro-level economic operations, one must examine the transactional behavior of micro-level market actors. Of course, interactions at different levels follow different laws, and the laws governing molecular collisions cannot be directly applied to higher-level systems such as society; however, the underlying logic—including mediating effects, emergence and co-construction—possesses universal methodological value across different levels.

The conceptualization of interconnected thinking provides important intellectual guidance for contemporary social practice. In today's world, characterized by the deepening development of globalization and digitalization, human society is more closely interconnected than ever before, with all manner of risks and opportunities spreading rapidly through networks of interconnections. Understanding universal interconnectedness from the perspective of collision and interaction enables us to grasp the operational logic of contemporary society more profoundly. In ecological governance, it is essential to recognize the deep interdependence between the various elements of an ecosystem, thereby avoiding the superficial solutions resulting from isolated governance; in social governance, we must attach importance to the cumulative effects of individual interactions and achieve macro-level governance objectives by optimizing micro-level interaction mechanisms; and in international relations, we must grasp the mutually constitutive relationships between nations and achieve win-win cooperation through two-way interaction. This interconnected thinking, grounded in micro-level mechanisms, offers more practical guidance than abstract philosophical principles and provides a solid intellectual foundation for addressing complex real-world problems.

Disclosure statement

The author declares no conflict of interest.

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