Newton's Third Law in Rebounding Bodies: Historical Context, Classical Conceptualization, and Generalized Formulation

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Abstract:

Newton's third law of motion has historically been formulated and applied primarily in a qualitative manner and is commonly assumed to hold universally for macroscopic interactions. Over time, the applications of Newton's third law have been extended to a wide range of systems, including aerodynamics and aerospace propulsion. In this work, qualitative and preliminary quantitative observations are reported for freely falling and rebounding macroscopic bodies, highlighting systematic variations associated with geometric shape, material composition, and impact conditions. Simple rebound experiments show that spherical bodies can retrace their original line of fall and rebound to comparable heights under suitable conditions, whereas asymmetrical and flat bodies exhibit reduced rebound heights and oblique rebound trajectories. These observations indicate that interaction forces during impact are influenced by structural and material asymmetries at the macroscopic scale. Motivated by these experimental trends and supported by historical and conceptual analysis, a generalized form of Newton's third law is proposed in which the reaction force is modified by dimensionless coefficients accounting for shape, composition, target surface, and other interaction parameters, expressed as

Reaction $(F_{BA}) = -[K_{shape} \times K_{composition} \times K_{target} \times K_{other}]$ Action (F_{AB})

The generalized formulation reduces to the classical law in the symmetric ideal limit and provides an experimentally testable framework for investigating macroscopic deviations from ideal action–reaction symmetry.

Key Words. Third law, falling and rebounding bodies, shape, composition, and rocket.

I Introduction

Newton introduced the law in *Principia Mathematica*, illustrating it with simple examples during the era of natural philosophy [1]. Newton analyzed physical phenomena through the principles of proportions and proportionality [2], at a time when formal mathematical equations had not yet been developed.

When a player pushes a basketball against the ground and it rebounds, the interaction provides a simple, real-world, macroscopic demonstration of Newton's Third Law of Motion in a qualitative sense. The quantitative confirmation of the law is required in such cases. Examples of this nature are extensively cited in the scientific literature. In the *Principia*, Newton presented three qualitative examples to support and justify his Third Law of Motion. Newton [1], in his *Principia* (1686), stated:

"To every action there is an equal and opposite reaction, or the mutual actions of two bodies upon each other are always equal and directed to contrary parts."

Reaction = −Action (1)

In the second part of the law, Newton explained that the force exerted by the second body on the first body (reaction) equals the force exerted by the first body on the second body (action). The magnitudes of these forces are equal but directed oppositely along the same line of action. Action and reaction are forces, as emphasized by Newton through three qualitative illustrations supporting the validity of the law. In contemporary notation, action and reaction are not treated as physical quantities, since they are absent from the IUPAP-defined list of physical quantities.

In terms of force

Force of Action of Body B on Body A (F_{BA}) =

- Force of Action of Body A on Body B (F_{AB}) (1)

Action and reaction always occur in pairs equal in magnitude but opposite direction [2]. Newton's Third Law is universal, applying equally to all interacting bodies (projectiles and targets) regardless of their mass, shape, composition, material etc.; therefore, quantitative experimental verification of the law requires evaluation of several essential physical parameters.

1.1 Conditions For Complete Validity of the Third Law

For Newton's Third Law to hold fully:

(i) The reaction force must equal the action force in magnitude.

(ii)The reaction must act in the exact opposite direction to the action.

In mathematical equations, the opposite direction of the reaction force is represented by a negative sign in Eq. (1) and in the subsequent related expressions, such as Eq. (2). Thus, for the law to be valid, both conditions must be satisfied simultaneously. If the magnitudes of action and reaction are equal but their directions differ, the law cannot be considered fully satisfied. Therefore, the fulfillment of both conditions is essential for the complete validity of the law. Directional observations are especially important in interactions involving bodies of varying shapes.

1.2 Newton's definition of body or mass in Principia

Newton opens the *Principia* with Definition 1 for quantity of matter (mass or body), which lays the foundation for the subsequent formulations [1].

The Quantity of matter is the measure of the same arising from its density and bulk conjunctly.

Further, Newton stated that it is this quantity that I mean hereafter everywhere under the name of **body** or mass. Newton illustrated the concept of mass using examples such as snow, dust, and powdered substances. Thus, Newton formulated his laws based on macroscopic examples of mass and motion in Principia. In his first two illustrations of the third law, Newton described interactions involving stones, a horse, and a finger. Atoms, molecules, and subatomic particles were unknown or speculative in Newton's time.

1.3 Newton's three original illustrative Examples in Principia (1686)

After defining the law in *Principia* [1], Newton illustrated it with three simple qualitative examples.

Whatever draws or presses another is as much drawn or pressed by that other.

A body is drawn or pressed when an external force acts upon it, as described by Newton in the *Principia*.

(i) Horse and Stone: If the horse pulls the stone tied to the rope, then the stone also pulls the horse equally backward.

(ii) Finger and Stone: If a finger presses a stone, the finger is also pressed by the stone.

In both examples, Newton considered small forces acting on a system that remained at rest.

Newton formulated the principle of action and reaction in terms of forces—manifested as pushes or pulls. However, the notions of "action" and "reaction" themselves are not physical quantities per se, as they lack explicit association with units and dimensions like velocity, acceleration, force etc. Thus, Newton established physics as a distinct scientific discipline, separating it from natural philosophy.

(iii) Movement of Projectile and Target after interaction: In the third example of the third law [1] p.20, Newton stated [1].

"If a body impinges upon another, and by its force ***change the motion of the other****; that body also (because of the quality of the mutual pressure)* ***will undergo an equal change****, in its own motion,* ***towards the contrary part ".***

Therefore, throughout his illustrations, Newton assumed that the reaction (force exerted by the second body) always equals the action (force exerted by the first body) and acts in the opposite direction.

Thus, Newton imposed strict conditions on interacting bodies, stating that the mutual forces they exert on each other are always equal in magnitude and opposite in direction, irrespective of the characteristics and physical properties of the interacting bodies. In the third illustration, he broadened the discussion to interactions between macroscopic bodies as they move following the interactions.

If a body A (projectile) of mass M_p exerts a force on body B (target) of mass M_t; body A experiences an equal and opposite change in motion. u_1, u_2 are initial velocities, and v_1, v_2 final velocities for projectile and target. Then,

[Change in motion of the body B (target) when the body A (projectile) impinges on it] or [action] =

- [Change in motion of the body A (projectile) when it impinges on body B due to mutual interactions] or [reaction] (2) or $[M_t v_2 - M_t u_2] = - [M_p v_1 - M_p u_1] = - M_p v_1 + M_p u_1$

$$M_p u_1 + M_t u_2 = M_p v_1 + M_t v_2 \qquad (2)$$

In the above equation, motion is represented by the quantity of motion, namely, momentum. So, the third example of Newton's third law of motion leads to the law of conservation of momentum.

Equation (2) may be verified experimentally by conducting real-world tests using practically achievable parameter values. Therefore, multiple sets of experimental observations with different feasible parameter combinations are required to validate Eq. (2**).** At the macroscopic scale, interaction outcomes depend on the geometrical and material properties of the colliding bodies (see Sec. 2), as well as on the characteristics of the contact surface. Since these factors are not incorporated into Eq. (2), experimental validation is essential to assess its applicability. For simplicity, if M_t and M_p are equal, then

$$u_1 + u_2 = v_1 + v_2 \qquad (3)$$

If the target is at rest, i.e., $u_2 = 0$, then Eq. (3) becomes

$$u_1 = v_1 + v_2 \qquad (4)$$

Equations (2), (3), (4), and other similar related expressions need to be experimentally verified using a broad range of parameter variations. There is no evidence in the existing literature that quantitative macroscopic experiments have been conducted to confirm Eqs. (2–4) or similar equations.

The law of conservation of momentum [3] is also explained with the help of the equation of the second law of motion.

$$F=\frac{dp}{dt} \qquad (5)$$

If F=0 , then p =constant or initial momentum (mu) = final momentum (mv) (6)

2.0 Applicability of the Definition and Equation of the Law.

The definition and equation of Newton's Third Law are assumed to apply universally to all bodies (, such as solids, liquids, gases, and semi-fluids, without regard to their mass, shape, material, or composition [4-6].

The bodies may have different possible shapes, e.g., spheres, semi-spheres, cylinders, triangles, polygons, cones, long, thin pipes, flat, sheets, or arbitrary shapes. The interacting bodies, may differ in physical properties such as including composition, material nature, elasticity, flexibility, mass, asymmetry, and size or related properties, the law is equally applicable in all cases. Newton's Third Law is assumed to remain valid in all such interactions.

However, modern highly elastic materials, e.g., Super Ball, Waboba Moon Ball, Super High Bounce Balls (Laboratory-grade polybutadiene), may also be considered in experiments as the law is valid for all bodies. The synthesis of additional highly elastic materials beyond those previously described is currently underway. They will represent potential additional systems when finalized, for experimental verification of Newton's third law.

Further, Newton's Third Law is increasingly being investigated in diverse and complex systems, including active matter, where internal energy sources break reciprocity [7]. Thus, the understanding of Newton's third law of motion is a continuous and evolving process that cannot be regarded as complete.

Target (second body): Newton's formulation is presented in a broad form that does not specify the physical characteristics of the second interacting object (target), referring to it simply as a body. In his definition, Newton refers only to 'bodies,' a general term encompassing both projectile and target. The law implies without addressing the characteristics of body (projectile) and second body (target), the reaction will be equal to action but in opposite direction. Moreover, the law does not explicitly address the nature of the interacting surface, for example, in horizontal impact interactions.

In practice, the distinction between projectile and target is crucial for applying the law of action and reaction across diverse phenomena. Furthermore, Newton should have distinctly defined the characteristics of interacting bodies (projectile and target) when formulating the third law during the era of natural philosophy. When the law is examined critically in the context of broader theoretical and experimental considerations, the characteristics of the target (second body) should be described with respect to those of the projectile (first body).

Moreover, whether an object functions as a target depends on the projectile; for example, a stretched sheet of paper may act as a target for a small body but not for a stone. Thus, the projectile and the target may be considered relative to each other. Projectile–target pairs must be selected carefully and cannot be treated arbitrarily. This discussion pertains specifically to interactions between bodies at the macroscopic scale. The Eq.(1) only accounts for F_{AB} and F_{BA} , and does not incorporate other relevant factors, such as the physical properties of the projectile or the target, such as shape, composition and other involved factors, etc. This aspect needs to be critically discussed.

2.1 Two categories of applications of Newton's third law are recognized.

Newton illustrated the Third Law with three qualitative examples in the *Principia* (1686), as discussed above. Subsequent scientists extended its applications to a variety of physical phenomena. Initially, the law was applied in classical mechanics, for example, to bouncing balls, rowing, and similar systems. In the 20th century, the third law was applied to entirely different contexts, such as rockets, airplanes, and propulsion systems. With the passage of time, theoretical and experimental systems have advanced, and the applications of Newton's third law can be broadly categorized into action–reaction motion systems and aerospace and propulsion systems.

(i) Action reaction Motion Systems. In the *Principia* (1686), Newton presented only three applications, largely qualitative in nature. Then the following scientists extended the application of the law in other examples such as bouncing balls, swimming, rowing, walking, jumping from a boat, balloon deflation, swimming fish, and gun recoil, etc.

These represent contact-based action–reaction interactions. Although such examples serve to illustrate the action–reaction principle, they rarely provide quantitative verification—an essential criterion for establishing scientific validity in physics education and research. However, rigorous experimental verification of Newton's Third Law across diverse physical systems remains technically challenging and often requires high-precision instrumentation.

(ii) **Aerospace Propulsion Systems**. These constitute highly advanced and technically sophisticated applications of Newton's Third Law developed in the 20th and 21st centuries. These include rockets, fireworks, spacecraft, airplanes, missiles, helicopters, drones, and gliders, among others.

In aerospace and rocket propulsion systems, the exhaust gases expelled at high velocity produce the reaction force that propels the vehicle forward. This is a direct consequence of Newton's Third Law of Motion**.** Aeronautical and astronautical engineers and scientists apply Newton's third law in these systems.

The current work examines the quantitative behavior of falling and rebounding bodies, a topic that has not yet been systematically studied. The qualitative nature of Newton's third law in typical applications may be interpreted through various approaches

(a) By the sixteenth century, arquebuses and muskets were increasingly employed in English armies; however, Newton's writings do not make any reference to such firearms. The recoil velocity of the gun is given by

$$v_{gun} = - m_{bullet} . v_{bullet} / m_{gun} \qquad (7)$$

Although Eq. (7) has been repeatedly presented and discussed in theoretical frameworks, there is no reported experimental validation of it in the existing literature. The understanding of theoretical deductions becomes complete only when they are rigorously validated through experimental confirmation. Equation (7) is practically based on the third application of Newton's third law under idealized conditions.

(b) Using Newton's third law, the ideal rocket equation [8] was derived by Russian teacher Konstantin Tsiolkovsky in 1897 and published in his paper *"Exploration of Outer Space by Means of Rocket Devices"* in 1903. The velocity of the rocket at any instant is given by

$$\Delta V = V_e \ln M_0 – V_e \ln M = V_e \ln M_0/M \qquad (8)$$

All quantities in Eqs. (7)–(8) have their conventional physical meanings as used in elementary mechanics. The Eq.(8) has undergone several refinements by aeronautical scientists over the years to improve its applicability and precision. A physical law is regarded as universally valid only when it is repeatedly and independently verified across all relevant physical regimes. Here, it is emphasized that quantitative experiments on falling and rebounding bodies should be carried out at the macroscopic level to properly understand the law.

3.0 Historical Context before and after Principia.

Before Newton, Descartes (1644) presented a Third Law of Nature in a simple, descriptive form of physical events. Newton published the Third Law of Motion in *Principia* (1687) with three qualitative illustrative examples. Later, scientists applied the third law to various action–reaction motion systems in a qualitative manner. In the 20th century, scientists applied the third law to aerospace propulsion systems.

(i) Descartes' Third Law of Nature [9]: The third law of nature, as formulated by Descartes, appeared in 1644 in *Principles of Philosophy* (Chapter 2, Paragraph 40, p.34), predating Newton's version by about four decades.

The third law of nature: (a) if one body collides with another that is stronger than itself, it loses none of its motion; (b) if it collides with a weaker body, it loses the same amount of motion that it gives to the other body.

Both Descartes and Newton have discussed colliding bodies. The third application of Newton's Third Law of Motion quantitatively defines the relationship between interacting bodies in terms of action and reaction, i.e., forces that are equal in magnitude and opposite in direction, whereas Descartes' law offers only a qualitative description of the physical event.

(ii) During Newton's lifetime (1642–1727), mathematical equations were not prevalent in scientific inquiries, and natural phenomena were largely interpreted through qualitative reasoning and description. Newton interpreted phenomena geometrically by the method of **ratios or proportions [2].** Newton originally stated the law in Latin in Philosophiae Naturalis Principia Mathematica, and it was later translated into English by Andrew Motte, encouraged by his brother Benjamin Motte, a publisher who saw the book's commercial potential.

The English translation was published in 1729, two years after the death of Newton. Newton did not alter the definition of the third law for approximately 40 years (1686–1726), nor did he provide additional clarification beyond its original statement as illustrated in the 1686 Principia. The second and third editions of the *Principia* were published by Newton in 1713 and 1726, respectively. Newton stated the second law in proportionality form and the third law in equality form. For comparison, Principia's Second Law (1686) states as

"The alteration of motion is ever proportional to the motive force impressed, and is made in the direction of the right line in which that force is impressed."

(iii) Swiss Leonhard Euler started relating force with mass and acceleration in 1736 in the book Mechanica [10]. Euler [11,12] published the equation F=ma in 1776 when he was working at the Imperial Academy of Sciences in St. Petersburg, Russia**.** F = ma was published in the treatise *Nova methodus motuum corporum rigidorum determinandi* (A New Method for Determining the Motions of Rigid Bodies) in the journal Academia Scientiarum Imperialis Petropolitana (Imperial Academy of Sciences in Saint Petersburg) at pages 222-224 (E479).

As previously mentioned, the conceptual limitations of that era prevented Newton from formulating mathematical equations.

(vi) The gravitational acceleration (g=9.80665 m/s^2) was measured in 1888 by the Geographic Services of the French Army [13]. In 1901**,** at the 3rd General Conference on Weights and Measures (CGPM), weight was formally defined as mg. In Euler's equation F = ma, when the acceleration a replaces the acceleration due to gravity g, the resulting expression W = mg represents the weight of the body near the Earth's surface. Realistically, this became the greatest breakthrough in classical mechanics related to the quantitative aspects of Newton's third law.

Thus, expressing Newton's Third Law in precise mathematical form (for falling and rebounding bodies) became practically feasible only about 215 years after the publication of the *Principia*. In the case of a body falling and rebounding towards the surface, the action can be regarded as the gravitational pull of the Earth on the body, quantitatively given by its weight, mg.

(v) The equation for freely falling and rebounding bodies became feasible about 125 years ago, in 1901. In this period, Newton's third law was established as a fundamental law at a qualitative level. Historically, the law has been reinforced largely through qualitative examples, which were acceptable in the early development of mechanics but fall short of today's expectations for quantitative verification.

However, fundamental quantitative experiments on falling and rebounding bodies have not yet been systematically performed. The successful completion of these experiments would mark a breakthrough, potentially enabling more precise and quantitative observations in related phenomena.

(vi) Earliest origins of rocket motion and applications of Newton's Third Law in such extended cases.

Gunpowder-propelled devices, primarily used for recreational purposes such as fireworks, were developed in China around the 9th century A.D., nearly 700 years before Newton's *Principia***.**

Rockets were employed in warfare for the first time during the Mongol-Chinese conflict in 1232, using gunpowder (solid fuel); their motion was completely uncontrolled after ignition, similar to fireworks. The earliest recorded fireworks display in England occurred at the wedding of King Henry VII and Elizabeth of York in 1486. Despite these developments, Newton (1642–1727) did not discuss rockets in the ***Principia*** or elsewhere, nor did he mention his Third Law to explain their motion.

(vii) After the publication of Newton's *Principia* (1687), his Third Law of Motion quickly became a cornerstone of European physics. Universities such as Cambridge, Oxford, Paris, Naples and Göttingen incorporated Newtonian mechanics into their curricula, educating scholars and engineers who applied these principles in research, technology, and practical sciences. Beginning in the early 1800s, the British East India Company's schools, military academies, and surveying programs systematically incorporated European scientific knowledge, including the principles of Newtonian mechanics, into colonial India's education system. This foundation paved the way for the formal inclusion of Newton's laws in the curricula of the first modern Indian universities e.g. Calcutta, Bombay, and Madras, established in 1857.

It is pertinent to note that the acceleration due to gravity, g=9.8005 m s^{-2}, was experimentally determined in France in 1888, and the concept of weight was formally defined in 1901. By this time, Newton's laws had already been incorporated into academic curricula worldwide, about one and half century before.

(viii) In 19th century, the gliders were considerably well developed. Otto Lilienthal (1848–1896) was a German aviation pioneer known as the "Father of Gliding". Wright Flyer I, invented by Wright brothers in 1903 fundamentally relied on Newton's Third Law of Motion for its flight. Here, wings produce lift and the flyer is controlled by elevators, wing wrapping and rudder etc. A glider flies without an engine, while the Wright Flyer was the first aircraft to fly using an engine and propellers. In 1907, Paul Cornu (France) achieved one of the first manned vertical lifts using a twin-rotor craft i.e., practical perception of a helicopter.

(ix) Goddard refined the ideal rocket equation in 1919 in a monograph [14], introducing a generalized form as follows.

$$\Delta V = V_e \ln \frac{M0}{M} - \int_0^t g\,dt - \int_0^t \frac{D(v)}{m}\,dt \qquad (9)$$

where V_e is the effective velocity, M_0 and M are the initial and final masses, g is the acceleration due to gravity, D is the drag force, t is the burn time, etc.

In 1926, Goddard became the first astronautical pioneer to experimentally launch a liquid-fueled rocket (often called Nell), achieving a flight lasting about 2.5 seconds. The fuel consisted of **gasoline (fuel)** and **liquid oxygen (oxidizer)**. By further improving the design, Goddard extended the rocket's flight time to approximately 22.3 seconds in 1937.

Although technology and knowledge have since advanced in astronautical engineering and computational modeling, space missions may succeed or fail, yet Newton's third law, formulated about 340 years ago in the *Principia*, remains valid. In such experiments, technological advancement is equally crucial.

Thus, Newton's Third Law of Motion finds diverse applications across science and engineering.

3.1 Why has Newton's Third Law Not Been Quantitatively Confirmed in rebound experiments?

Various reasons can be discussed to explain why the law has not been quantitatively studied in action–reaction motion systems.

First, Newton's Third Law was originally formulated without a mathematical expression and was interpreted only qualitatively in the *Principia*, where Newton illustrated it using three examples. The law was subsequently applied to various other analogous cases, albeit only qualitatively.

Second, a spherical body appears to rebound toward its original position in the opposite direction after striking a surface under certain conditions and this behavior seems consistent with the law, but only qualitatively. Thus, scientists did not quantitatively confirm the law in many other cases due to the experimental complexity associated with the interactions and composition of different bodies. Hence, the law was established qualitatively in many situations.

Third, the precise acceleration due to gravity, g, was determined in 1888, enabling a mathematical treatment only after the standardized definition of weight (mg) became established in 1901. By this time, the law was widely regarded as qualitatively verified. Now, quantitative applications of the law, along with methods, have been discussed for falling and rebounding bodies in the past 125 years, when equations became feasible.

Fourth, in the 20th and 21st centuries, the law enabled significant development in rockets, aircraft, and propulsion systems, which redirected focus toward astronautical engineering and computer-based design, rather than fundamental experimental assessments in the category of Action-Reaction Motion systems.

Because the applicability of the law was regarded as exceptionally precise and reliable in space programs, little attention was directed toward testing it through simple experiments involving falling and rebounding bodies.

The analysis identifies unexplored experimental tests of Newton's third law, especially for rebounding bodies of equal mass and composition but differing shapes. The conclusions are therefore preliminary and call for dedicated experimental investigation. Thus, carefully designed experiments involving rebounding bodies are scientifically essential for a direct quantitative understanding of the law in action-reaction motion systems.

4.0 Observations and Mathematical Basis of Rebound Experiments.

Falling and rebounding bodies with identical mass and composition but different shapes are essential for quantitative verification of the third law, as qualitative results alone are insufficient. In definition and equation law only involves F_{AB} bad F_{BA}, not other factors. For simplicity, these experiments are presented at the initial stage, after which more complex experiments can be discussed and performed.

Basic qualitative observation: In everyday qualitative demonstrations, a spherical body may, under certain conditions, rebound to its point of release, effectively retracing its initial path; thus, action and reaction are the same in magnitude but opposite in direction. Therefore, the upward rebound can be considered an observable consequence of the reaction stipulated in Newton's third law. Thus, the reaction exerted by the body is quantitatively manifested as its rebound distance. This argument supports the validity of Newton's third law.

However, the bodies of identical mass and material or composition, but with **different shapes (**e.g., spheres, semi-spheres, cylinders, triangles, polygons, cones, long thin pipes, sheets, arbitrary shapes, etc.**),** rebound to different heights and directions. A flat body is observed to rebound to the minimum height, whereas irregular bodies show variable and unpredictable rebound heights and angles. All observations must be explained quantitatively and in a mutually consistent manner.

Bodies with the same mass and composition may differ in shape. These qualitative observations serve as the primary motivation for quantitative confirmation of the third law at the macroscopic level, thereby prompting further both theoretical and scientific discussions [16-17].

Quantitative Explanation: It is not scientifically justified to rely indefinitely on such qualitative observations as evidence for Newton's third law that a body falls as action and, as a reaction, it rebounds upward.

Newton expressed the concept of *action* in terms of force, i.e., push or pull in the first two examples as given in Principia Mathematica. Let the body fall from point A_0 at height H (1 m). Then it must reach at the bottom at time 0.45 s i.e.

$$t = \sqrt{\frac{2s}{g}} = 0.45s \qquad (10)$$

In first two examples Newton expressed action in terms of push or pull i.e. force. When a body falls freely under gravity, the downward force acting on it is gravitational force or its weight, represented by mg.

(i) In this context, the *action* corresponds to the force, i.e., the gravitational force or weight acting on the body. Consequently, for bodies of identical mass (1kg) the magnitude of the action remains constant (mg), irrespective of shape and other physical attributes.

Action = Force = weight (mg) = 9.8 newtons (11)

(ii) According to Newton's third law, a reaction force arises during the mutual interaction between a body and a surface; its magnitude equals that of the action (i.e., 9.8 N) and is directed upward, opposite to the action (denoted by a negative sign).

Reaction = -Action = -9.8 newtons (12)

Let h denote the rebound height of the body. For simplicity, the bodies are assumed to have the same mass and composition and to be non-deformable; only their shapes are varied.

(i) **Spherical bodies:** The spherical body (symmetrical) rebounds to the original point A_0 at height H, in the opposite direction; it describes ideal or standard conditions. Hence, the law is completely obeyed under some conditions, the height from the body falls (H), and the height to which the body rebounds (h) are equal (H=h=1m). Thus, in this case, the magnitudes of the action and reaction are exactly equal, as the body rebounds upward to its original height (H) in the opposite direction. So, the reaction is manifested in terms of rebound distance

Action = -Reaction = -9.8 newtons. (opposite direction) (13)

Here, the negative sign indicates the opposite direction of the rebounding body.

As the body rebounds to the original point (H=h), retracing its original trajectory, then the 'Rebound Angle' (RA) may be regarded as zero. Under standard or ideal conditions, Newton's Third Law is completely satisfied in the case of a spherical body.

(ii) **Bodies of different shapes:** The rebounding behavior of bodies with different geometries—including spheres, hemispheres, cylinders, triangular and polygonal bodies, cones, elongated pipes, thin sheets, and other arbitrary shapes- is not similar to spherical bodies.

In real-world conditions, bodies of different shapes rebound to lower heights (h) and distinct angles. Such qualitative observations can be repeatedly confirmed through numerous daily-life experiences. This implies that the experimental reaction possesses different magnitudes and directions in such cases than predicted by Newton's third law. Theoretically, in Eqs. (12–13), the action and reaction forces are equal when the masses of all bodies are the same. A flat body is typically observed to rebound to the minimum height, whereas an irregular body exhibits variable and unpredictable rebound heights and angles. The aim of the discussion is to quantitatively interpret and explain these observations. When the masses of the bodies are equal, the gravitational force acting on each is the same, i.e., mg, leading to equal and opposite reaction forces in accordance with Newton's third law. However, experimentally, the reaction in such cases does not manifest in the same way as for a spherical body.

(iii) Factors responsible for reduced rebound height (h) and varying rebound angles

(a) Loss of energy during interactions.

This factor may be systematically evaluated within this context. The causes for bodies rebounding to a lower height h include energy losses, such as heat energy, sound energy, other associated forms, and additional significant effects depending on interacting bodies. An effort should be made to minimize the energy losses as much as possible. Non-deformable bodies must be selected to achieve conceptual simplicity.

These energies must be carefully quantified, and it should be examined whether they are solely responsible for bodies rebounding to a reduced height, or if other factors demand consideration in the quantitative analysis.

(b) **Asymmetry of body:** The asymmetry of the body may be responsible for the body rebounding at different and nonzero angles. Newton's third law is independent of effects arising from physical asymmetry, such as differences in shape or size, as it accounts for F_{AB} and F_{BA} only.

(c) Other inherent factors. Thus, additional factors beyond F_{AB} and F_{BA} are likely responsible for the observed anomalous behavior, yet remain unaccounted for within the existing law scientific framework. These factors include the shape and compositions, material properties of the interacting bodies, and other relevant experimental parameters involved either implicitly or explicitly. These factors may be assessed using varied observations and systematic critical evaluation. This aspect is discussed in section (6.0).

(iv) **Time of fall and rebound to maximum height:** Newton's third law stipulates that the action and reaction forces ($\mathbf{F_{AB}}$ and $\mathbf{F_{BA}}$) are equal in magnitude and opposite in direction. Under ideal conditions, if a spherical body of mass 1 kg falls from a height of 1 m and reaches the floor from point $\mathbf{A_0}$ in 0.45 s (action is 9.8 newtons) as in Eq. (10), it should rebound (reaction is 9.8 newtons but in opposite direction) and return to point $\mathbf{A_0}$ in the same duration. This deduction is expected to be valid only under idealized conditions.

Because the motion of falling and rebounding bodies has not been analyzed quantitatively in the existing literature, the practical relevance of the time of descent to the point of impact and the time of rebound to the maximum height has remained largely unrecognized.

Had the law been experimentally verified for falling and rebounding bodies, or attempts been made toward this, fundamental aspects such as the difference between the time of fall to the surface and the time of rebound to the maximum height would have been recognized much earlier. Newton's third law (Reaction = -Action) can manifest differently under varied conditions e.g. rebound heights, time to rebound to maximum height etc. The angle of rebound reflects the direction of reaction.

(v) **Angle of rebound.** Newton's third law states that the magnitude of the reaction equals that of the action, and its direction is exactly opposite to the action. In Eq. (1), the negative sign is introduced externally to denote the opposite direction of the reaction force.

For freely falling bodies, a spherical ball rebounds along the line of fall, while bodies of other shapes, such as semi-spheres, cylinders, triangles, polygons, cones, long thin pipes, flat sheets, or arbitrary forms, rebound at angles deviating from the line of fall. For these bodies, the rebound angles vary depending on the specific conditions of impact. These variations must be fully harnessed to realize their maximum potential, and this behavior must be analyzed and discussed in detail following experimental measurements.

The values of action, reaction, angle of rebound, time of fall to surface, and time of rebound to maximum height may be tabulated for analysis. Thus, the exploration and experimental verification of Newton's third law remains an ongoing scientific endeavor, continually advancing with emerging opportunities and technologies. Multiple factors influence measurements in experiments with freely falling and rebounding bodies, this puts constraints on verification of the law.

(vi) **Horizontal impact of the body with the target:** When a ball or body travels horizontally across a surface, strikes a target, and rebounds, frictional forces and energy dissipation (as heat and sound) become dominant factors that must be quantified along with other relevant parameters [16] 1In this case, the action force must be precisely measured using external instruments. The role of the target's characteristics becomes increasingly significant in this context. The use of asymmetrical bodies often results in irregular or unpredictable forward and backward motion, making the accurate measurement of associated quantities both challenging and extremely difficult. Similarly, experiments that involve varying the composition of bodies and targets are highly cumbersome to conduct with quantitative precision.

Therefore, falling and rebounding experiments involving bodies of identical mass and composition but different shapes are discussed first, owing to their simplicity and their fundamental importance in examining the validity of the Third Law. In addition, we come across far more complicated experiments to confirmation of Newton's third law.

4.1 Futuristic Experiments

In the future, such experiments may be performed in low-gravity environments, such as on the Moon, where the acceleration due to gravity is approximately one-sixth of Earth's value. The lower value of g increases the duration of free fall and modifies the time of ascent during rebound. At the International Space Station, or in other microgravity environments, such experiments may also be explored under conditions of weightlessness.

Furthermore, researchers are exploring elastic materials more advanced than Super Balls and Sky Balls to achieve even greater bounce performance. Thus, the law needs to undergo quantitative testing in such experimental situations. Thus, the concise formulation of Newton's third law underpins a wide range of experimental studies, highlighting both its applications and possible departures. These must be exploited or performed to its fullest extent.

5.0 Experiments with low-cost Equipment.

These experiments can be conducted using low-cost instrumentation such as USB cameras or photogate timers to accurately measure impact durations during collision. The digital inclinometers or angle finders to determine rebound angles with respect to the line of fall. The laser displacement sensors may be utilized to precisely record rebound heights.

The combined use of high-speed videography and laser-based sensing enables time-resolved tracking of the motion and ensures precise investigation of shape- and geometry-dependent rebound effects under controlled experimental conditions.

These experiments are relatively simple to execute and yield reproducible results, offering a practical approach to quantitatively validate Newton's third law at the macroscopic scale. At the same time, more complex action–reaction systems remain technically challenging. Thus, as the first step toward quantitative verification of action–reaction systems, experiments with falling and rebounding bodies are being explored.

6.0 Generalized form of Newton's Third Law

Qualitative observations cannot be accepted as universally valid for all situations. Therefore, rigorous quantitative experiments are necessary for reliable conclusions. Today, theoretical and experimental methods are far more advanced than in Newton's era of natural philosophy when the third law was originally proposed.

Newton's third law considers only F_{AB} and F_{BA}, whereas experimentally, in rebound experiments, the various other factors are also significant, as discussed in section (2.0). These elusive factors may be incorporated by generalizing or extending the law [4-6,15-19]. However, in this work, we primarily consider falling and rebounding bodies within action–reaction motion systems. Newton's third law may be expressed in a proportionality form, similar to Newton's second law of motion. Thus,

$$\textbf{Reaction} \propto \textbf{Action} \quad \textbf{or} \quad \textbf{Reaction } (F_{BA}) = -\,\textbf{K Action } (F_{AB}) \qquad \textbf{(14)}$$

where K is a coefficient of proportionality or phenomenological parameters. The coefficient K accounts for various elusive factors not incorporated in the original law, such as the shapes, sizes, asymmetry, compositions, material properties, physical characteristics of the bodies, the properties of the target, the nature of the surface, the interconversion of energy during interactions, and all other influential variables.

Such factors are equally significant in colliding bodies, as discussed. Thus, the value of K may be expressed in one of the following ways as

$$\text{K (coefficient or additional factor)} = K_{shape} \times K_{composition} \times K_{target} \times K_{other} \qquad (15)$$

($K_{shape} \times K_{composition} \times K_{target} \times K_{other}$) is an additional expression in Eq. (14) relative to Eq. (1), which implies the reaction may deviate from the action depending on various influencing factors and effects. Thus, action and reaction may or may not remain equal always. K is dimensionless, and its magnitude may deviate from unity from one observation to another, depending on the associated parameters. If the value of K is unity, then Eq.(14) reduces to Eq.(1). The value of K may be determined through standardization, calibration, or comparison, depending on the practicality and feasibility of the chosen method.

K_{shape} accounts for the influence of geometry, asymmetry, etc., $K_{composition}$ for the effect of specific compositions and material characteristics, K_{target} for all measurable effects of the target, and K_{other} for the influence or impact of all remaining factors, including the transformation of energy between interacting bodies etc.

The measurement of K_{other} is more challenging than determining other K_i's. Realistically, Eq. (14) becomes in comprehensive form as

Reaction (F_{BA}) = - K_{shape} x $K_{composition}$ x K_{target} x K_{other} **Action (F_{AB})** **(14)**

Thus, law may be defined as

"Every action has a proportional reaction; the magnitude and direction of the reaction would be precisely equal and opposite depending upon experimental factors such as the shape, size, characteristics, and other involved factors, etc., of the interacting bodies."

As already noted, the applications of Newton's third law may be broadly categorized into action–reaction motion systems and aerospace and propulsion systems. The present discussion is restricted to falling and rebounding bodies; no comments are offered regarding other cases where the law is well established and experimentally verified**.**

K is phenomenological parameter

The coefficient K in the generalized relation Reaction = −K Action serves as an effective, phenomenological parameter. Analogous to the coefficients in the Bethe–Weizsäcker mass formula or the coefficient of friction, it encapsulates complex interactions. Its value depends on shape, asymmetry, material, shape, interaction conditions etc., and approaches unity in idealized limits, recovering the conventional form of Newton's third law

6.2 Extension and development of laws is an established process.

Refinements and extensions or replacement of established laws are integral to scientific and physical progress.

(i) Newton presented three qualitative examples in the *Principia* (1687) to illustrate the third law of motion. Subsequent scientists applied the law qualitatively to explain phenomena such as bouncing balls, swimming, the recoil of a gun, etc. In the 20th and 21st centuries, the law was also widely used in the explanation of aerospace and propulsion systems. Now attempts have been made to experimentally and quantitatively verify the law in falling and rebounding bodies at macroscopic level.

(ii) Newton's seventeenth-century corpuscular theory of light was eventually supplanted by the wave theory advanced by Young and Fresnel. Maxwell later in 1865 unified optical phenomena with electromagnetism, identifying light as an electromagnetic wave. During the twentieth century, quantum theory introduced photons, distinct from Newton's corpuscles. Contemporary physics describes light using quantum electrodynamics, a fundamentally different framework today. While the seeds were planted in the 1920s–1930s, the **complete quantum electrodynamical theory** emerged in the **1940s**.

(iii) Newton expressed the speed of sound in a medium (v) as

$$v = \frac{P}{D_m} \qquad (16)$$

Pierre-Simon Laplace in 1816 corrected this relation, yielding Equation (17), because Newton's expression did not produce the experimentally correct value for the speed of sound in air. Hence,

$$v = \gamma \frac{P}{D_m} \qquad (17)$$

where P denotes the pressure, D_m the density of the medium, and γ the ratio of specific heats (specific heat at constant pressure to that at constant volume). Equation (17) provides an accurate value for the speed of sound in air.

Realistically, Newton assumed that the propagation of sound waves is isothermal in nature; however, Laplace later demonstrated that the process is actually adiabatic.

(iv) Tsiolkovsky published Eq. (8), the ideal rocket equation, in 1903 on the basis of Newton's third law of motion. Goddard later extended this formulation in 1919 as Eq. (9) by incorporating the effects of gravity and aerodynamic drag. Consequently, Goddard's equation accounts for additional influences such as gravitational force and aerodynamic resistance.

(v) Furthermore, Newton's third law implies that F_{AB} and F_{BA} are the only significant factors governing the interaction of bodies in Eq. (1). In contrast, Eq. (14) shows that for falling and rebounding bodies, in addition to F_{AB} and F_{BA} factors such as shape, composition, asymmetry, the nature and properties of the target, and other associated parameters also become significant.

(vi) **This discussion aligns with the various historical development of scientific laws and with Mach's proposition in the 1880s and 1890s that the metaphysical nature of mechanical laws must be empirically tested.**

A generalized form of a theory is considered valid only when its predictions are consistently supported by repeated experimental evidence.

6.3 Experimental confirmation of Eq.(14)

The proposed experiments on falling and rebounding bodies will verify Eq. (14); this conclusion is based on qualitative observations. These experiments are novel and original because they have not been quantitatively documented in scientific literature for more than 340 years. The proposed experiments provide the simplest method to validate the generalized form of Newton's Third Law. Other related experimental techniques are comparatively much more complex.

At the qualitative level, if a spherical body rebounds to its original height, retracing its initial path under identical conditions, then the value of K will be unity, and Eq. (14) becomes identical to Eq. (1). If deviations from the third law are observed in experiments, then the role of K becomes critically important for interpreting the results. Then, in the next step, the value of K must be quantified and experimentally determined with precision. If a body of arbitrary shape (having the same mass and composition as the spherical body) rebounds ½ m under identical conditions, then K will be ½. Thus,

$$\text{Reaction} = -\tfrac{1}{2}\,\text{Action} \qquad (16)$$

The estimation of coefficients (K_{shape}, $K_{composition}$, K_{target}, and K_{other}) may be viewed as broadly analogous to determining the coefficients (volume, surface, Coulomb, asymmetry, etc.) in the Bethe–Weizsäcker semi-empirical liquid-drop formula (SEMF). These coefficients are experimentally fitted parameters. Thus, the origin of the generalized form of Newton's third law is related to existing scientific traditions of the development of the laws. However, supporting experimental results are required for the final validation of Eq. (14).

6.4 Area of touch or contact (AOT).

The area of touch (AOT) or contact can be defined as the actual area of the body (projectile, which may have various shapes) that directly touches, contacts, or strikes the floor. The areas of touch/contact may be identical for different bodies, e.g., sphere, long thin pipe, cone, needle-like shape, flat, irregular body, triangle, etc. The effect of AOT depends on the shape, size, symmetry, and other geometrical features of the body. The area of touch may be considered as a parameter associated with the body's shape in the following manner.

$$K_{shape} \propto \frac{1}{\textit{area of touch or contact}} \quad \text{or} \quad K_{shape} = \frac{k}{\textit{area of touch}} \qquad (17)$$

k depends on the properties of the bodies and the related experimental conditions.

Consider a flat body and a sphere (with the same mass and composition) both dropped identically onto the same surface. In the case of the flat body, the area of touch is larger than that of the sphere, so the value of K_{shape} is smaller, as in Eq. (17). Consequently, the reaction is reduced for the flat body in Eq. (14), and thus the flat body rebounds to a lower height (h<1m). The current value of K should be regarded as a qualitative estimate; rigorous and repeated experimentation is necessary to establish its accurate quantitative measurement.

7.0 The rebound experiments are different than those in Aerospace and Propulsion Systems.

The quantitative verification of Aerospace and Propulsion Systems (fireworks, rockets, spacecraft, missiles, and drones) is fundamentally different from Action–Reaction Motion Systems or contact-based action–reaction interactions (bouncing balls, swimming, rowing, walking, jumping, balloon deflation, and gun recoil). The former system was mainly developed in the 20th and 21st centuries due to the efforts of astronautical engineers in various subfields, and later was the earliest system of applications of Newton's third law of motion developed qualitatively.

The rockets are guided and stabilized through computer-controlled systems, whereas fireworks travel along uncontrolled and purely ballistic trajectories.

The cruise missiles function under continuous powered flight and utilize advanced guidance technologies, such as GPS, radar, and inertial navigation systems.

The motion of drones is regulated by onboard flight-control electronics, integrated sensors, and externally commanded inputs.

Airplanes are directed through pilot inputs or automatic control systems and operate along predetermined and navigationally defined flight paths.

A glider moves in the atmosphere using aerodynamic lift and gravity, not by engines or propellers. The Airbus Perlan 2 has achieved the highest altitude ever, 76,124 feet. Gliders are typically constructed from lightweight materials and feature cambered (curved upper surface and flatter lower surface), high-aspect-ratio wings, a streamlined fuselage, and a conventional tail, which together optimize lift, minimize drag, and ensure stable flight. This design is consistent with the generalized coefficient K, as it explicitly accounts for the body's shape (K_{shape}), material composition ($K_{composition}$), K_{other} etc. The combination of aerodynamic geometry and low-mass construction directly influences the glider's ascent in rising air and descent in still air**,** reflecting how variations in shape and material modify the effective action–reaction forces as expressed in Eq. (14).

Thus, diverse experiments dealing with action-reaction systems may be individually confirmed as their nature is different from Aerospace and Propulsion Systems.

8.0 Conclusions

Newton's Third Law is a fundamental principle of physics and underlies many applications across physics, various branches of engineering, mathematics, and related fields. Here, a specific application of the law is examined in the context of falling and rebounding bodies. Preliminary observations suggest that rebound behavior depends systematically on geometric shape, material composition, and impact conditions. The spherical bodies largely follow classical action–reaction behavior, whereas asymmetric or flat bodies show measurable deviations. Motivated by these trends, a generalized formulation of Newton's third law is proposed within its classical domain, introducing dimensionless coefficients that represent structural and material asymmetries, target properties, and other interaction parameters The analysis identifies quantitatively unexplored experimental tests of Newton's third law, particularly for rebounding bodies of identical mass and composition but different shapes at the macroscopic level. The conclusions therefore emphasize the need for dedicated experimental investigations. Rigorous quantitative experiments guided by this framework are recommended to systematically test macroscopic deviations from Newton's third law, enhance conceptual understanding of rebound phenomena, and provide insights relevant to classical mechanics, aerodynamics, and propulsion.

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References

[1] I Newton, *Mathematical Principles of Natural Philosophy*, Vol. 1, Book I (Middle Temple Gate in Fleet Street, London, 1729) pp. 19–20.
https://books.google.co.in/books?id=Tm0FAAAAQAAJ&pg=PA1&redir_esc=y&hl=en#v=onepage&q&f=false
[2] R Resnick and D Halliday, *Physics Part I* (Wiley Eastern Limited, New Delhi, 1992) pp. 87–88, 216–217.
[3] A A Blagonravov (Ed), *Collected Works of K. E. Tsiolkovsky*, section "K. E. Tsiolkovsky: The Founder of Modern Dynamics" (Stvo Akademii Nauk SSSR, Moscow, 1954) pp. 1–10.
http://epizodsspace.airbase.ru/bibl/inostr-yazyki/tsiolkovskii/tsiolkovskii-nhedy-t2-1954.pdf
[4] K Ishimoto, *Odd elastohydrodynamics: Non-reciprocal living material in a viscous fluid*, **PRX Life** 1, 023002 (2023), doi:10.1103/PRXLife.1.023002.

[5] R Descartes, *Principia Philosophiae* (Ludovicus Elzevir, Amsterdam, 1644).

[6] I B Cohen, *The Principia* (University of California Press, Berkeley, 1999) pp. 116–117

[7] L Euler, *Mechanica*, Vol. 1, Chap. 2 (1735) pp. 63–64 (E15).
https://www.17centurymaths.com/contents/mechanica1.htm

[8] L Euler, *Nova methodus motum corporum rigidorum degerminandi* (E479) (1775) pp. 223–224.
https://scholarlycommons.pacific.edu/cgi/viewcontent.cgi?article=1478&context=euler-works

[9] IOP (Institute of Physics, England), *The development of Newton's first law* (2024).
https://spark.iop.org/development-newtons-first-law (2024)

[10] A Sharma, *The genuine effects of the shape of the body in Newton's third law of motion lead to its generalization*, **Science Talks** 10 (2024) 100334, doi:10.1016/j.sctalk.2024.100334.
https://doi.org/10.1016/j.sctalk.2024.100334=
https://www.sciencedirect.com/science/article/pii/S2772569324000422?via%3Dihub

[11] A Sharma, *Shape dependent form of Newton's third law of motion*, **Journal of Physics Education** 38 (2024).
https://physedn.in/jpe/article/view/16/12

[12] A Sharma, *The Principia's third law of motion: In original and generalized forms*, **Physics Essays** 29(1), 23–26 (2016),
doi:10.4006/0836-1398-29.1.23.

[13] A Sharma, *Role of characteristics of bodies in Newton's third law of motion*, in SM18 Program Book (American Association of Physics Teachers, Washington DC, 2018) pp. 150–151.
https://aapt.org/Conferences/sm2018/upload/SM18Program_Final_A.pdf

[14] R H Goddard, *A method of reaching extreme altitudes*, Smithsonian Miscellaneous Collections 71(2) (1919).
Smithsonian miscellaneous collections

[15] A Sharma, Abstract in *Proceedings of the 38th Annual Convention of the Indian Association of Physics Teachers* (16–18 October 2024).

[16] A Sharma, *Elastic collisions in one dimension at the macroscopic level and Newton's third law of motion*, **Acta Ciencia Indica** XXV(P), 113–116 (1999).

[17] A Sharma, *Generalization of Newton's 340-year-old third law: An open challenge for experimental verification using low-cost methods*, **Journal of General Science** (2025).
https://www.gsjournal.net/Science-Journals/Research%20Papers-Mechanics%20/%20Electrodynamics/Download/10360

[18] A Sharma, *Shape-dependent deviations from Newton's third law: Qualitative observations and a generalized equation*, paper to be presented at the **International Conference of Physics Education (IUPAP)**, IIT Ropar, 16–22 December 2025.

[19] A Sharma, *Roles of shape, composition, and target interactions in rebounding bodies, gun recoil, and elastic collisions: Toward a generalization of Newton's third law*, paper to be presented at the **International Conference of Physics Education (IUPAP)**, IIT Ropar, 16–22 December 2025.