

# PhyT2V: LLM-Guided Iterative Self-Refinement for Physics-Grounded Text-to-Video Generation

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## A. Details of Evaluation Setup

Since our proposed technique of PhyT2V does not involve any efforts of retraining the T2V model, in this section we describe details about our evaluation setup of the LLM inference for CoT and step-back reasoning.

In our evaluations, we use 4 T2V generation models, including CogVideoX-5B[5], CogVideoX-2B[5], OpenSora[6] and VideoCrafter [1]. We choose to use these models as they are all built with transformer based diffusion model, which enhanced the semantic adherence by using the cross attention mechanism, and hold a high score on both the VideoPhy dataset and PhyGenBench dataset leader board. We use Tarsier[3] as the video captioning model for it achieves state of art on multiple video question answering datasets, which ensure the precise and detail of the video captioning step in our approach.

Since PhyT2V improves the quality of generated videos through text prompt refinement, we use the Promptist[2] and GPT-4o[4] as the prompt enhancers, with the same model hyper-parameter setting for the baselines to maintain the consistency between the baseline and our approach. The diffusion model generated video length is setted as 6 second and 8 frames per second with frame resolution  $720 \times 480$ .

To fit the maximum token input length of the T2V model, we limit the word length of the refined prompts to 120, by instructing the ChatGPT4 o1-preview model that is used as the LLM for reasoning. To formatting the output and storage in our approach, the ChatGPT4 o1-preview model are instructed to output in JSON format and output results in each step are saved in a CSV file by row. The ChatGPT4 o1-preview is called by using the API with the input prompt separated into system prompt and user prompt to identify the instruction part and the rest of the original prompt for ChatGPT. The first and second step output is embedded to the third step prompt template by replacing the pre-defined place holder.

## B. More Examples of Physics-Grounded Videos Generated by PhyT2V

### B.1. Examples of Generated Videos in Different Categories of Physical Rules

In this subsection, we present the additional comparison examples of generated videos of CogVideo-5b on the VideoPhy and PhyGenBench dataset, Fig 1, 2, 3 show the additional comparison of video generation result on fluid to fluid, solid to fluid, solid to solid cases on VideoPhy dataset, Fig 4, 5, 6 show the additional comparison of video generation result on force, optics and thermal cases on PhyGenBench dataset.

### B.2. Refinement process details

In this subsection, we present the prompt refinement detail by the CogVideo-5b with PhyT2V on the VideoPhy and PhyGenBench dataset, Fig 9, 8, 7 show the prompt refinement details of fluid to fluid, solid to fluid, solid to solid cases on VideoPhy dataset, Fig 10, 11, 12 show prompt refinement details of force, optics and thermal cases on PhyGenBench dataset.

## C. Ablation study details

### C.1. Model size

We found that the PhyT2V approach can unleashing more power of physical-grounded video generation on a larger model as the result shown by comparing the CogVideo-2b and CogVideo-5b in Figure 13 .

### C.2. Prompt template component

In this section some part of the prompt template component is removed to show the necessity of the corresponding components as shown in Figure14, 15, 16. Without the role indicator sentence, the generated output content is lake of precise information, without the in-context examples, the GPT can not generated the output in an expected format.

## D. Failure cases

PhyT2V may be ineffective in two categories of cases.

First, many T2V models exhibit temporal flickering or inconsistent object trajectories, due to absence of long-term temporal coherence mechanisms in model design. Even if prompts are refined to emphasize smooth temporal transitions or continuous motions, these requirements may not be achieved due to model’s limitations.

Second, T2V models are typically trained on large datasets, which often lack samples of rare or complex physical phenomena. Hence, these models struggle in scenarios that are underrepresented in the training data. Even with highly specific prompts, the T2V models may still fail to extrapolate effectively to these underrepresented cases.

For some specific generation content categories, we found that even with the PhyT2V refined several rounds, the diffusion model still failed to precisely generating human body, especially on human hands as shown in Figure 17.

## References

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- [4] Deshun Yang, Luhui Hu, Yu Tian, Zihao Li, Chris Kelly, Bang Yang, Cindy Yang, and Yuexian Zou. Worldgpt: a sora-inspired video ai agent as rich world models from text and image inputs. *arXiv preprint arXiv:2403.07944*, 2024. [1](#)
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- [6] Zangwei Zheng, Xiangyu Peng, Tianji Yang, Chenhui Shen, Shenggui Li, Hongxin Liu, Yukun Zhou, Tianyi Li, and Yang You. Open-sora: Democratizing efficient video production for all, 2024. [1](#)

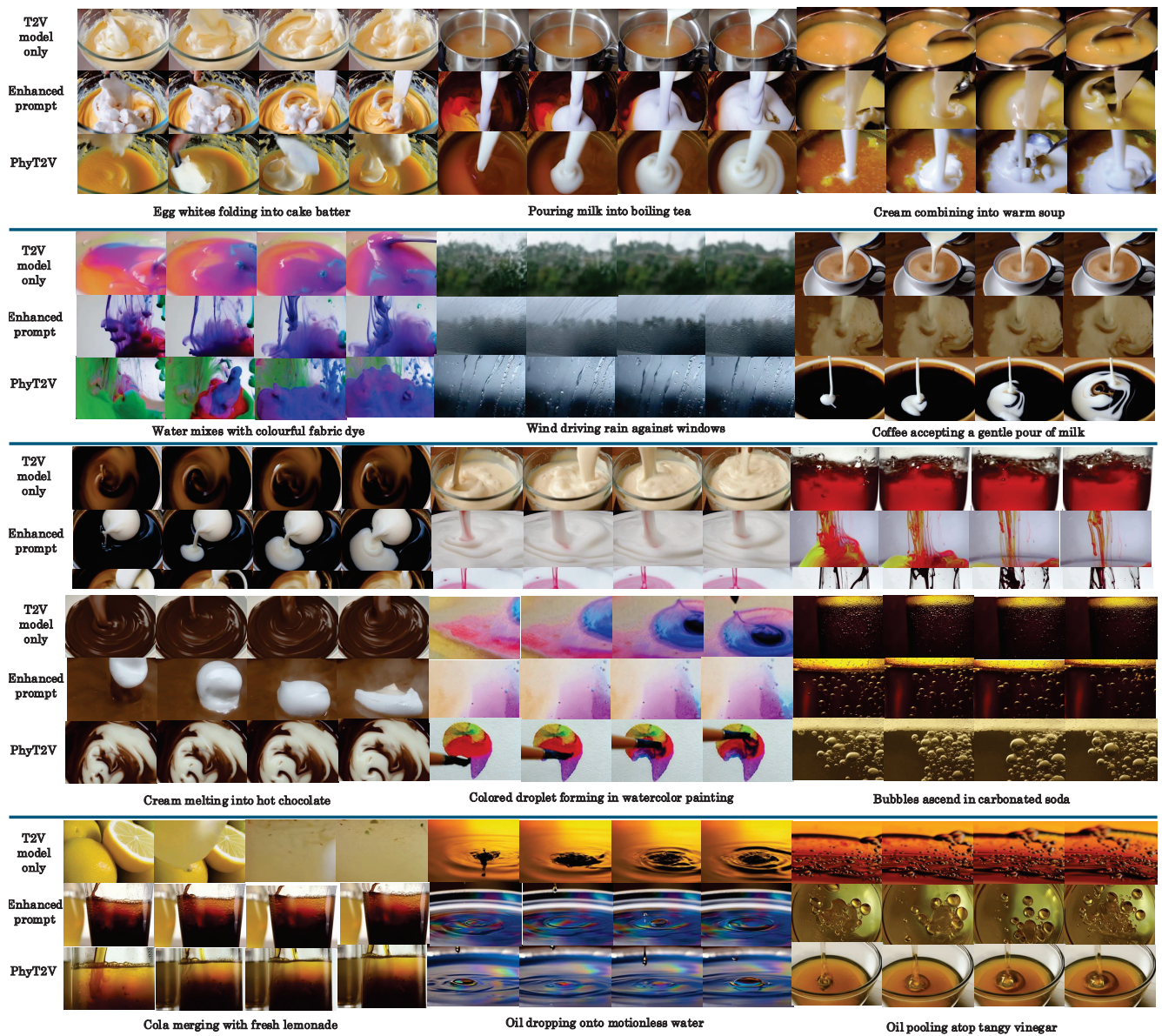
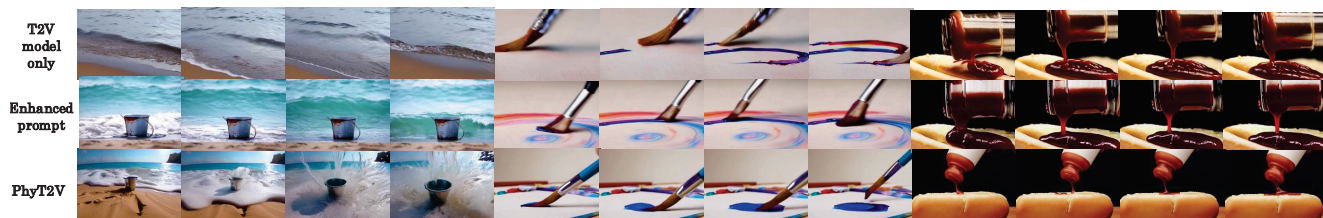


Figure 1. Video generation example on fluid to fluid specific prompt in VideoPhy dataset

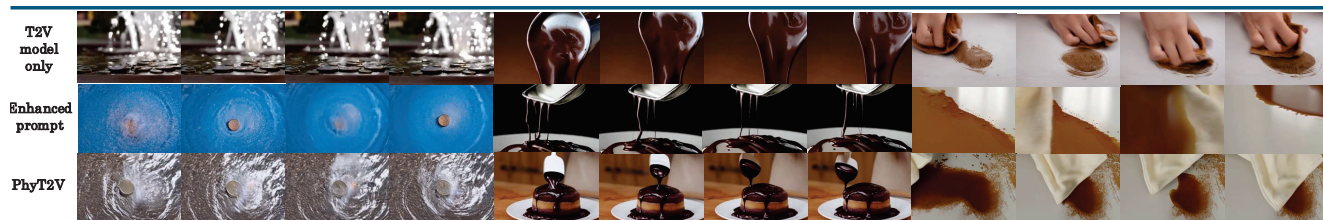




A bucket scoops up sea water at the beach

A paintbrush brushes a stroke of watercolour paint on canvas

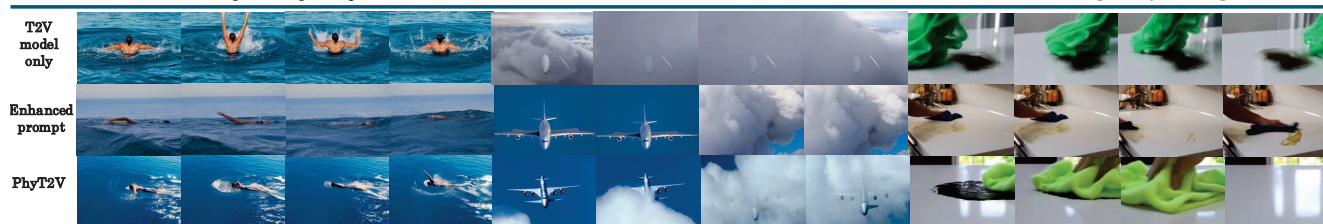
A sauce bottle drizzles ketchup onto a fresh hotdog



A coin drops into a sparkling fountain

A scooper drizzles melted chocolate onto a dessert

A cotton cloth wipes away a coffee spill



A swimmer glides through the calm ocean waves

An airplane zooms through a patch of fluffy clouds

A rag wipes an oil stain off the kitchen countertop



A plastic spoon stirs a cup of hot cocoa

Juice being poured into a glass for quenching thirst

A mechanic pours oil onto a piece of sandpaper



A brush dips into watercolor on a palette

A French fry dipping into tangy ketchup

Ketchup squirting out of a sauce bottle onto a burger



Juice spilling from a cup onto the floor

A paint roller spreading fresh paint onto a wall

Water flows out from a towering dam



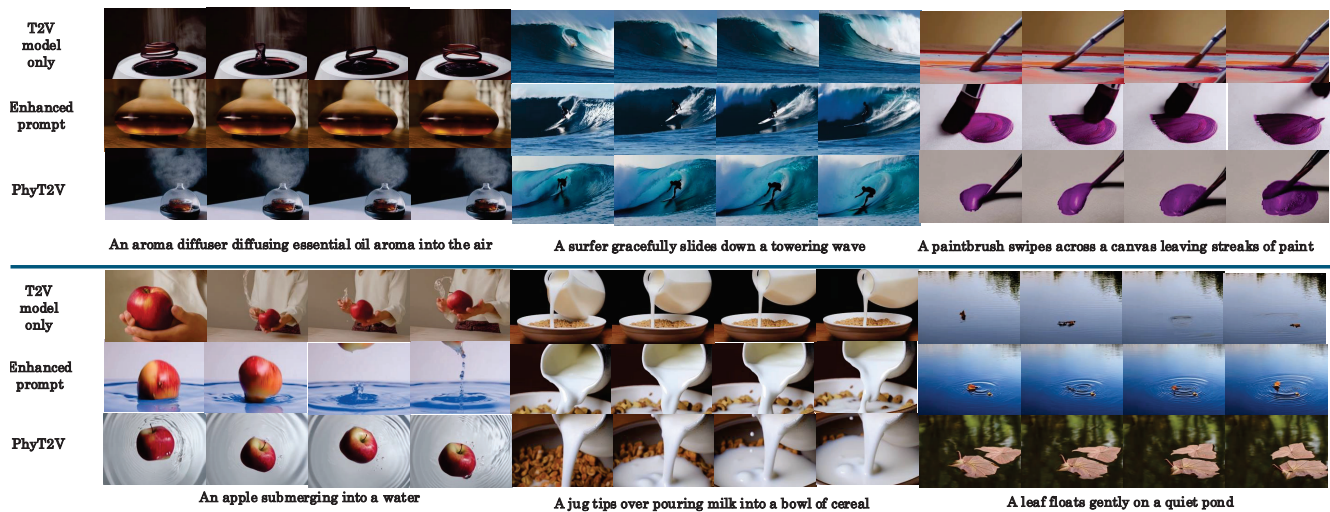
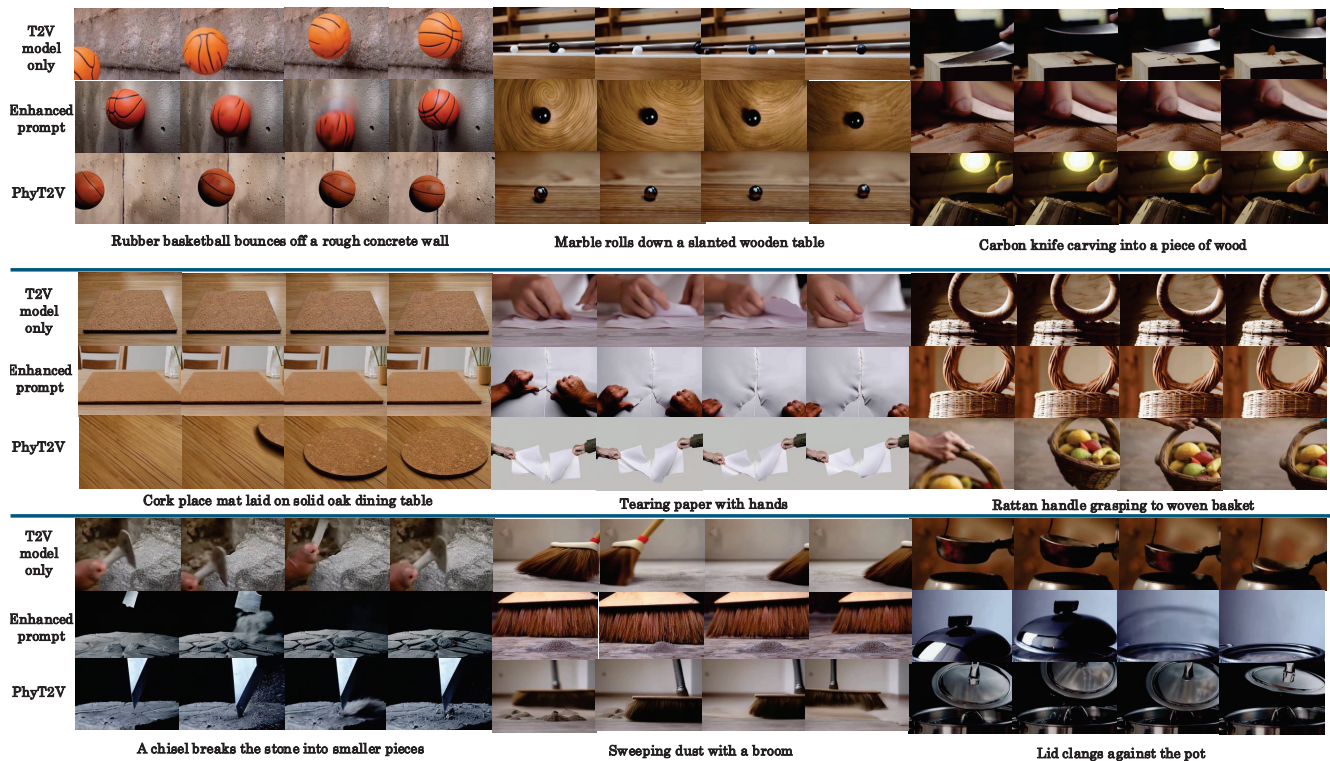


Figure 2. Video generation example on solid to fluid specific prompt in VideoPhy dataset



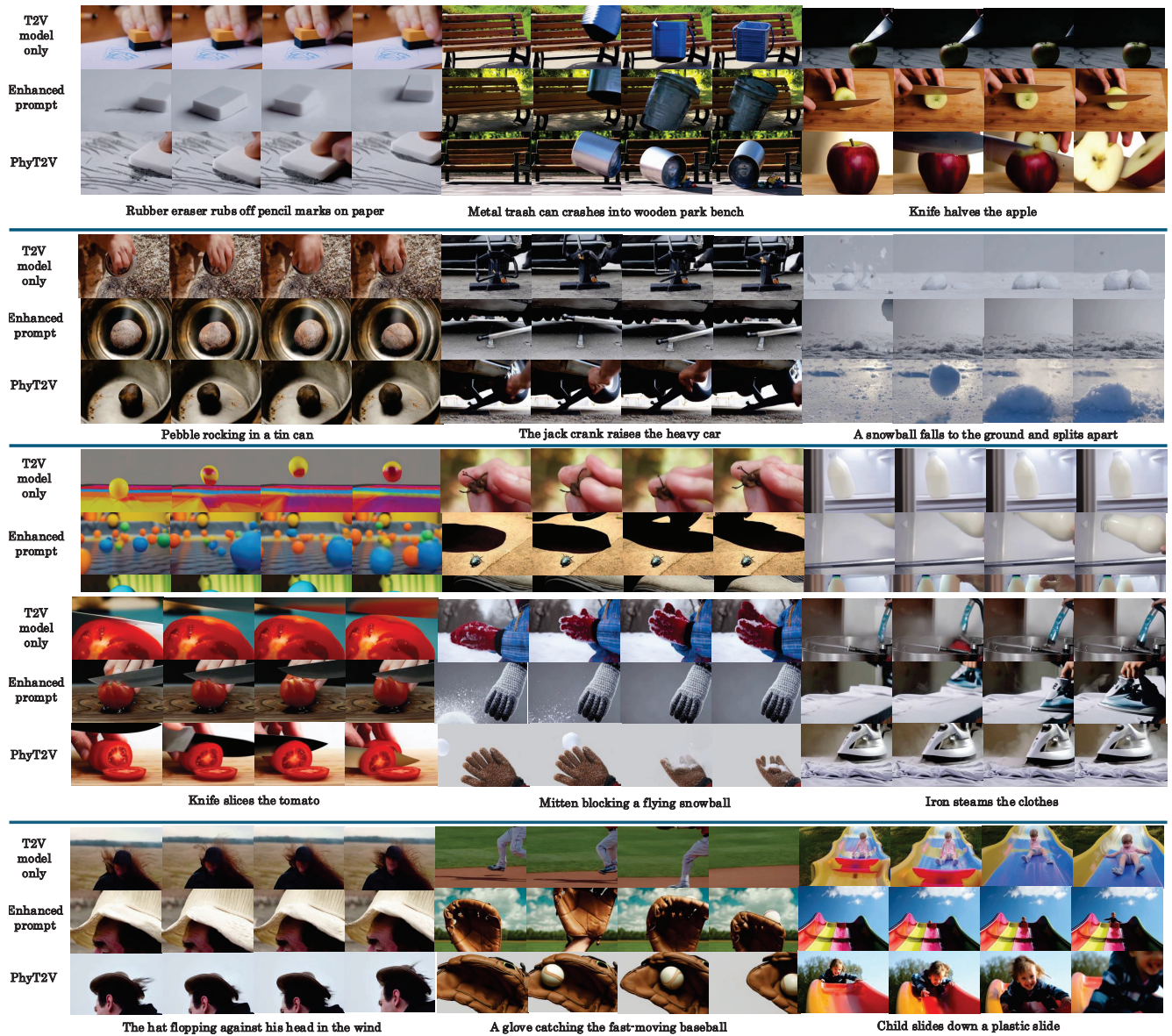


Figure 3. Video generation example on solid to solid specific prompt in VideoPhy dataset



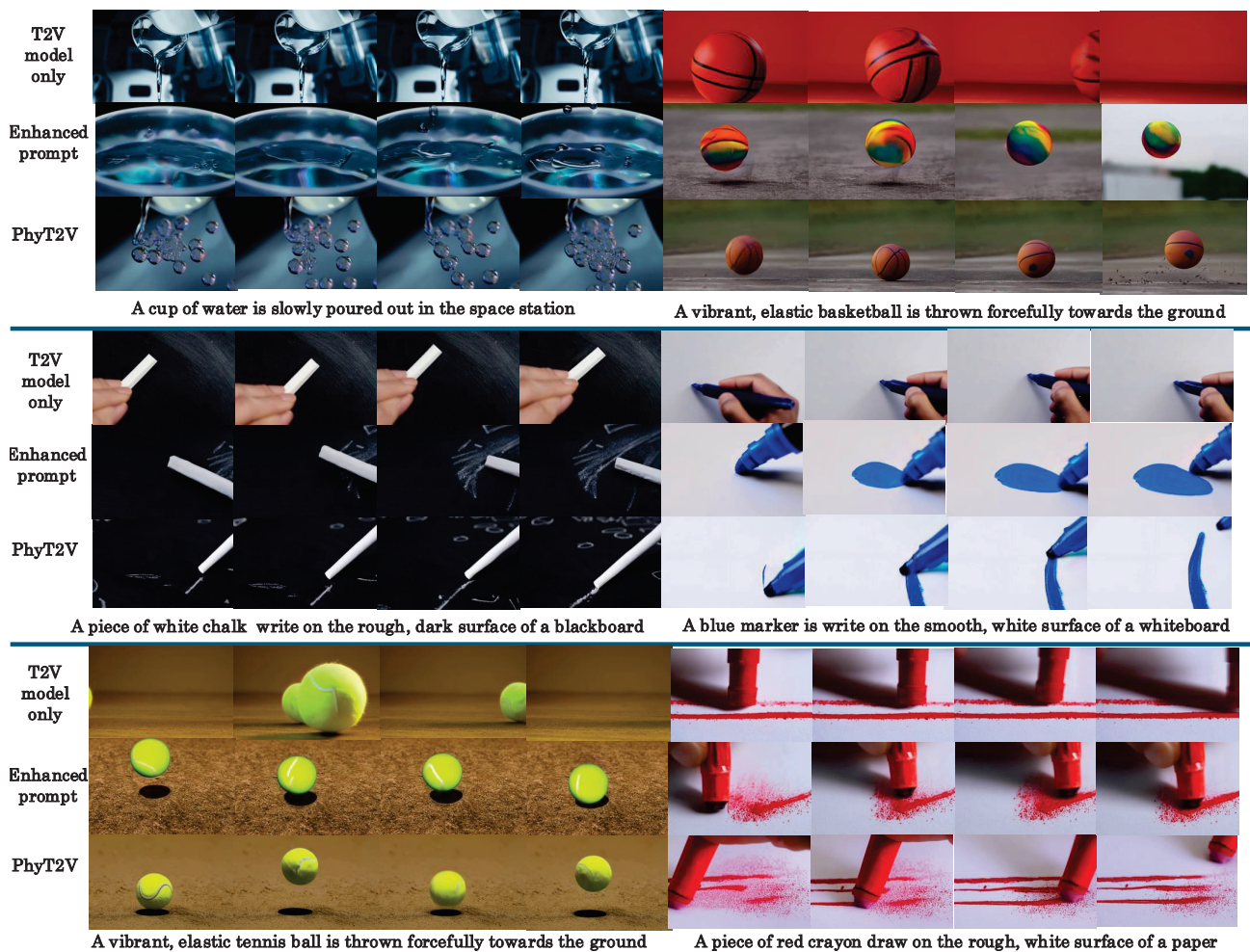


Figure 4. Video generation example on force specific prompt in PhyGenBench dataset

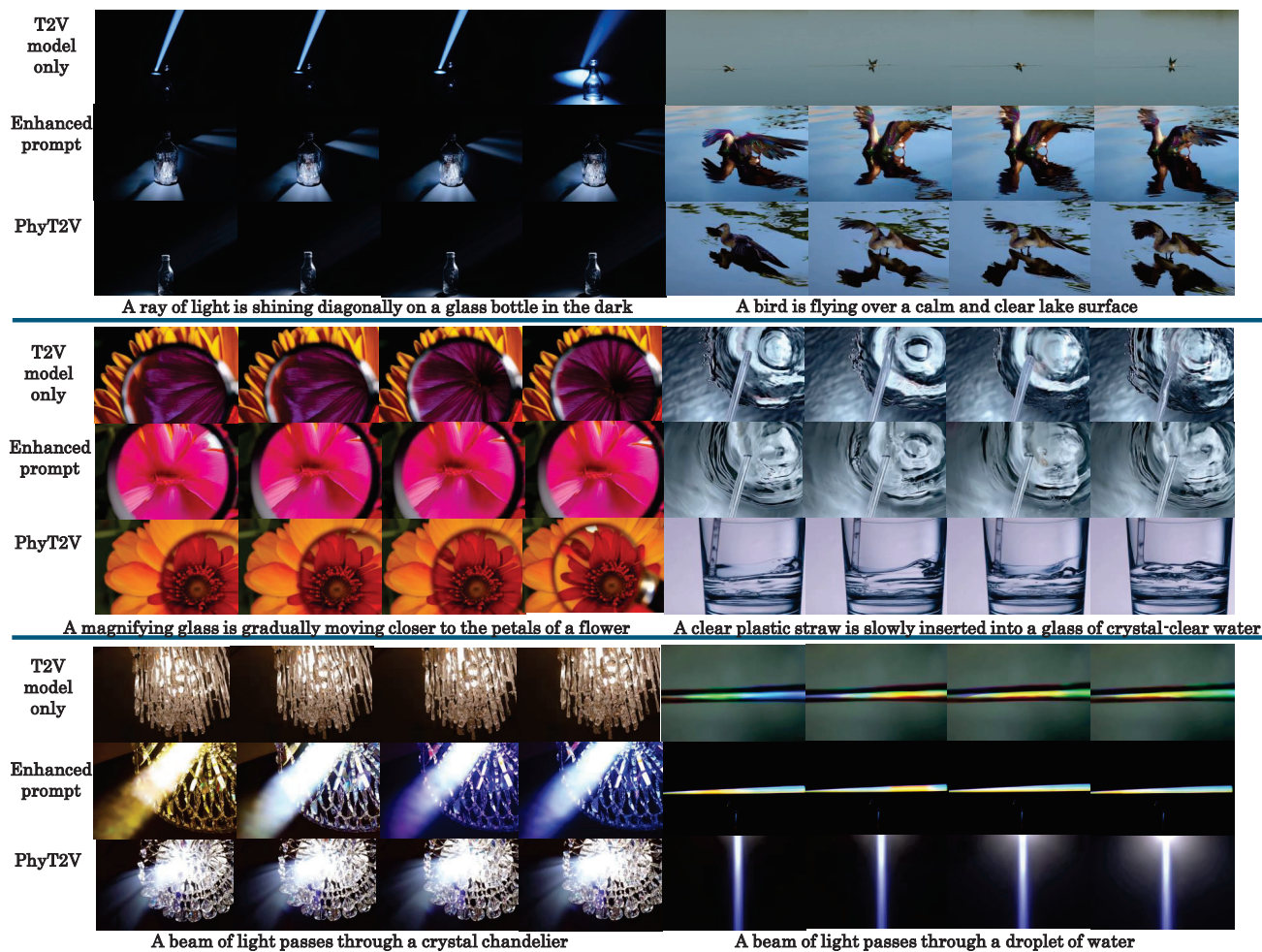


Figure 5. Video generation example on optics specific prompt in PhyGenBench



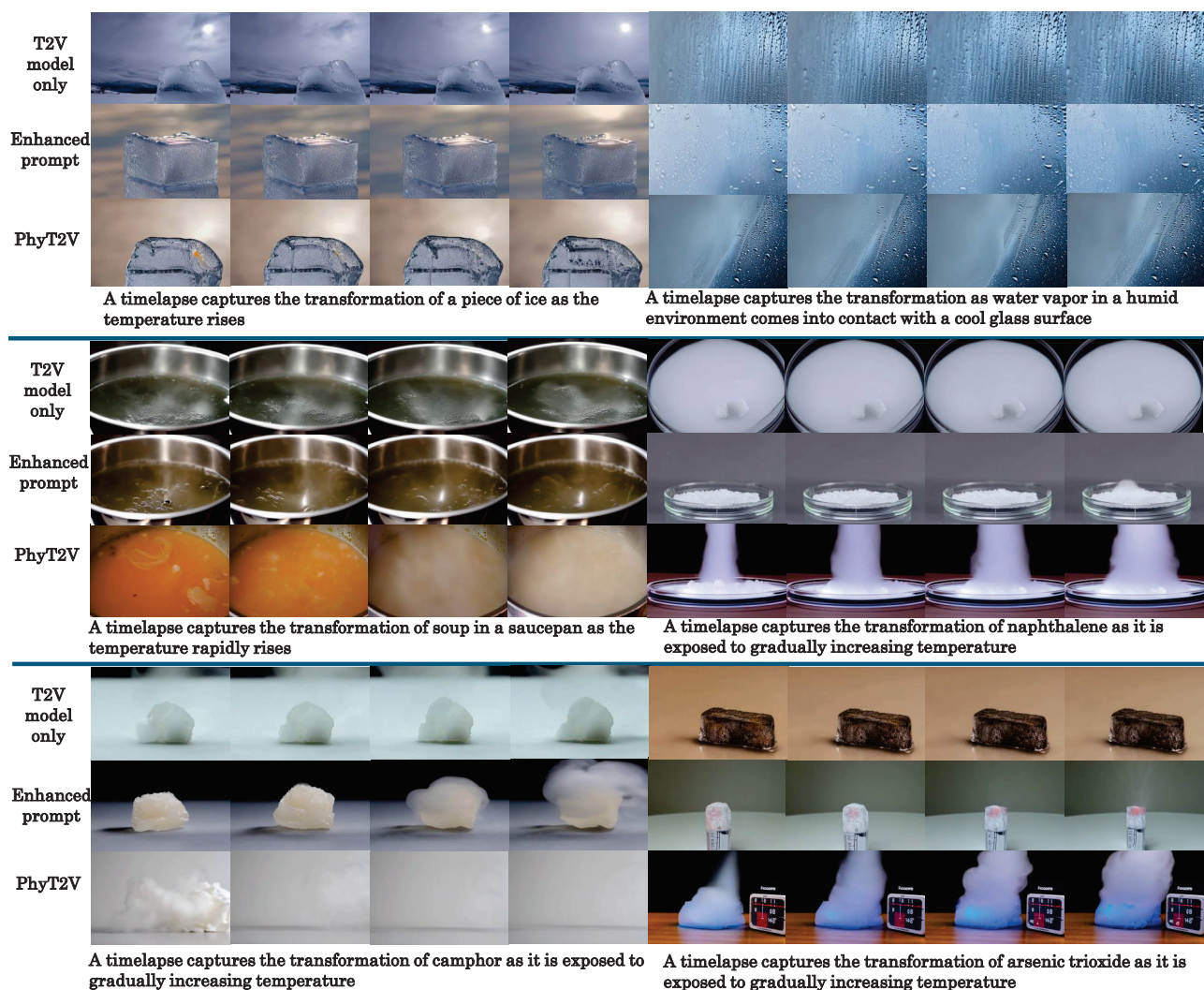
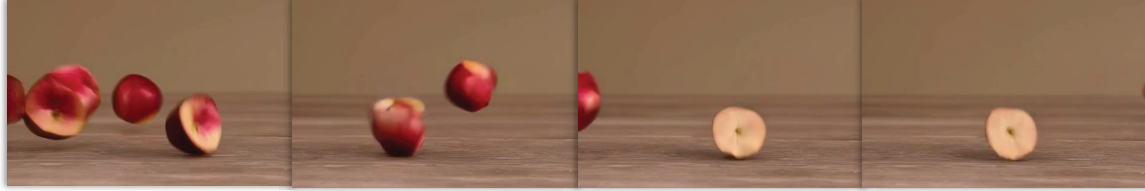


Figure 6. Video generation example on thermal specific prompt in PhyGenBench

Original prompt: An apple falls and bounces on the hard ground.



Physical law:

The key physical laws governing the apple's behaviour include Newton's Laws of Motion, the Law of Conservation of Energy, and the principles of partially elastic collisions and gravitational acceleration. 1. Gravitational Acceleration (Newton's Second Law of Motion): The apple falls because it is acted upon by the force of gravity, which causes it to accelerate towards the Earth's surface. According to Newton's Second Law, the force acting on the apple equals its mass times the gravitational acceleration - commonly around  $9.8 \text{ m/s}^2$  on planet Earth. 2. Collision with the Ground (Partially Elastic and Inelastic Collisions): Upon hitting the hard ground, a collision occurs. The apple's largely inelastic nature means that a large portion of its energy gets absorbed in the form of heat and sound during collision, causing the apple not to bounce high. 3. Conservation of Energy: As the apple falls, it transforms potential energy into kinetic energy, with its velocity increasing continuously until impact. After bouncing, the apple follows the rules of projectile motion in gravity, accelerating upwards until it reaches a point where kinetic energy has been entirely converted back to potential energy - the point of zero velocity. The apple then starts falling again, continuing this process but with each bounce having less height due to energy losses in each collision.

Mismatch:

Apple vs. Apple Pieces: The user prompt describes an intact apple falling and bouncing on the ground. However, the video caption shows pieces of an apple falling and bouncing. This is a significant difference because the behaviour (including bouncing dynamics and deformation) of an intact apple and apple pieces upon impact would be expected to be quite different. Ground vs. Wooden Surface: The user prompt specifies the apple falls and bounces on 'hard ground.' In contrast, the video shows the apple pieces falling and bouncing on a 'wooden surface.' While we can assume both are 'hard,' we can't be sure they have the same hardness, which might affect the bouncing behaviour. Deformation of Apple: According to the user prompt, an intact apple is expected to fall and bounce without significant deformation. However, the video caption describes the apple pieces being compressed and crushed upon impact. This level of deformation is inconsistent with the user prompt description of a single apple bouncing.

Enhanced prompt:

A ripe, bold red apple, defying its tree's pull, is seen in mid-air above a rough, hard terrain. The apple plummets, obeying gravity's irresistible command. Its descent accelerates, and it nears the unforgiving ground with increasing speed. Collision is inevitable. Upon impact, it momentarily squashes, absorbing a portion of its kinetic energy, before exhibiting a modest upward recoil. This bouncing trajectory, though significantly less than its initial fall, is agreed upon with the stringent laws of energy conservation. With each bounce, it ascends lesser, painting a perfect illustration of energy transformation and loss amid the persistent pull of gravity.

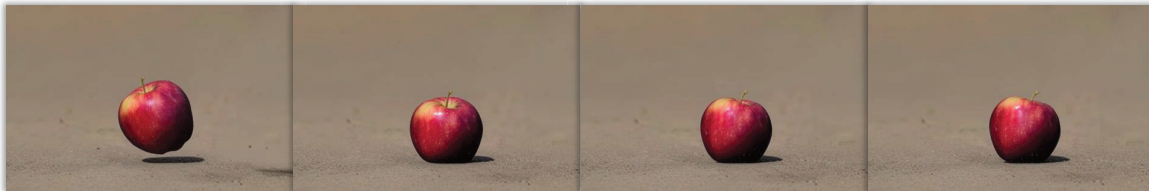


Figure 7. Refinement detail example on solid to solid specific prompt in VideoPhy dataset



Original prompt: A stone plunges into a fast-moving river, causing water to splash up.



Physical law:

The physics principles to note in this system include gravity, buoyancy, fluid resistance, and displacement of water by the falling stone. 1. Gravitational Acceleration (Newton's Second Law of Motion): The initial movement of the stone into the river is driven by gravity pulling on the stone's mass and creating acceleration. This leads to an initial downward motion of the stone. 2. Fluid Resistance: As the stone enters the water, it experiences fluid resistance which slows down its descent. This fluid resistance is proportional to the stone's velocity through the water and its size and shape. 3. Displacement of Water (Archimedes' Principle): As the stone plunges into the water, it displaces a volume of water equal to its own volume. According to the Archimedes' Principle, the buoyant force exerted on the stone is equal to the weight of the water displaced by the stone. The downward motion of the stone causes the water to be pushed aside and this sudden displacement causes the water to splash upwards. 4. Buoyancy: Depending on the mass and volume of the stone, buoyancy may play a role in determining whether the stone sinks or floats. A stone generally sinks because its density is greater than the water's density. However, if it is porous and air-filled, it could potentially float. The buoyant force working against gravity would determine the final resting position of the stone in the water.

Mismatch:

Object Interaction with Water: The user prompt specifies a stone 'plunging' into a fast-moving river, implying that the stone is being dropped or thrown into the water from an external source, causing a splash. However, the video caption portrays a different scenario, where a large rock is already partially submerged in the water, around which the water flows and splashes. Absence of Splashing Caused by Stone: In line with the user prompt's narrative, the stone plunging into the water should cause a disturbance in the water, resulting in a visible splash. This crucial detail is missing in the video caption, which only mentions that water splashes because it encounters an obstacle - the rock - which is already partially submerged in it. Static vs Dynamic Position of the Stone: The user's prompt assumes the stone is actively interacting with the river by being dropped into it. It's a dynamic process. In the video caption, on the other hand, the rock is static, remaining stationary in the river while the river's water flows around it.

Enhanced prompt:

A moderately-sized stone abruptly drops from the frame's upper edge onto a shimmering, fast-moving, and vigorous river, causing an impactful plunge. As it pierces the water's surface, the force causes a dramatic eruption of clear, sparkling droplets to violently splash upward. The displaced water ripples out in expanding concentric circles, effectively depicting the stone's powerful intrusion. The stone's downward trajectory continues unwavering, gradually obscured by the depth and swirling churn of the river. The re-arranged water reforms itself, concealing the stone beneath its ever-moving, turbulent surface, while the resulting splashes gradually fall back, a few rebellious droplets catching the light before surrendering to the relentless flow of the river.



Figure 8. Refinement detail example on solid to fluid specific prompt in VideoPhy dataset

Original prompt: Pouring milk into boiling tea.



Physical law:

The milk being poured into boiling tea should primarily follow the Law of Conservation of Mass and Energy, along with Thermodynamics and principles of fluid flow. 1. Conservation of Mass: As the milk is poured into the tea, the mass is conserved. This implies that the total mass of the milk and tea in the system remains constant during the process. 2. Thermodynamics (Heat Transfer): Due to the temperature difference between the milk and the boiling tea, heat will be transferred from the hotter object (the tea) to the cooler one (the milk). This heat transfer continues until both fluids reach a thermal equilibrium, where they have the same temperature. This process illustrates the Second Law of Thermodynamics, which states that heat will always move to areas of lower temperature until equilibrium is achieved. 3. Fluid Mechanics: The milk being poured is subjected to gravity and it flows via the principles of fluid dynamics, including viscosity and pressure. As per Pascal's Law, pressure applied to any part of a fluid transmits equally in all directions. Hence, the milk disperses throughout the tea. 4. Solubility: If viewed at the molecular level, the milk proteins and fats will disperse in the tea due to the natural molecular motion and interactions leading to the eventual homogeneous mixture of the two liquids. This highlights the principle of solubility and spontaneous mixing due to entropy increase.

Mismatch:

The user prompt specifies pouring 'milk into boiling tea', but the video caption depicts 'milk being poured into a pot of simmering broth'. The substance into which the milk is being poured does not match the user's provided prompt. Incorrect Physical Phenomenon: The video refers to buoyancy, describing the milk as initially floating because 'it is less dense than the broth'. This doesn't align with the real-life action of pouring milk into tea, where the milk will generally blend with the tea quickly rather than floating. Severity of Heat: 'Boiling tea' implies a higher heat level than 'simmering broth', affecting the interaction between the milk and the tea (or broth) at different heat levels. The mismatch in describing temperature might lead to different outcomes in the two scenarios.

Enhanced prompt:

In a stoneware mug filled with scalding, steaming tea, cool, smooth milk cascades in a steady stream. As the dense white liquid merges with the boiling, amber tea, the color begins to shift, transforming into a richer, creamier hue. Gradually, any initial vestiges of division fade until the fluid becomes one harmonious blend, their temperatures equalizing in the warmth of the mug. Thermodynamics, fluid dynamics, and solubility principles are brilliantly on display, illustrating a soothing preparation ritual. The final shot reveals the comforting, perfectly steeped tea, gently wafting a fragrant steam, ready to sip.

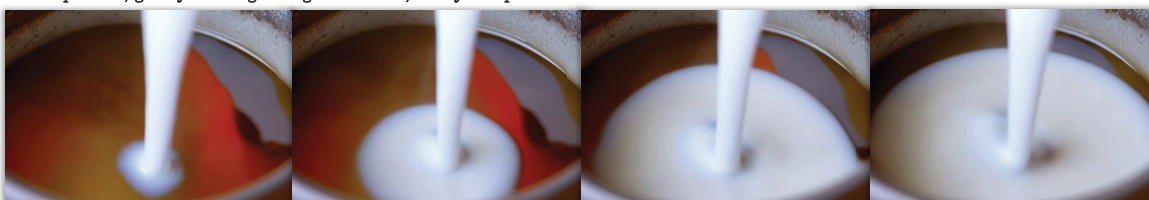


Figure 9. Refinement detail example on fluid to fluid specific prompt in VideoPhy dataset



Original prompt: A cup of water is slowly poured out in the space station.



Physical law:

While in the space station, the cup of water would be subject to several important physical laws including the Law of Conservation of Mass, Newton's Laws of Motion, and the principle of surface tension. 1. Law of Conservation of Mass: Regardless of its location in space, the mass of the water remains the same. When the water is poured out from the cup, it doesn't disappear; rather it distributes in the area around it. 2. Newton's Laws of Motion: In zero gravity environment, actions and reactions will have a more noticeable impact. When water is poured from the cup, the act of forcing the water out would also push the cup in the opposite direction. This reaction is dictated by Newton's Third Law of Motion, which states that for every action, there is an equal and opposite reaction. 3. Surface Tension & Formation of Spheres: In space, without the influence of gravity, liquids naturally form a shape that gives the least surface area, which is a sphere. This is due to the cohesive forces between the molecules of the liquid (surface tension) which pulls the molecules together, thus forming a sphere. This is why when water is released into space, it forms globules or spheres that float around rather than spreading out like in earth's gravity. 4. Law of Conservation of Momentum: If the water is poured forcefully from the cup, the sum of the momentum of the cup and water before being poured (if in relative rest, it is zero) and after being poured will be conserved.

Mismatch:

Absence of Zero Gravity Condition: The user prompt describes a cup of water being poured out in the space station, which would be an environment with negligible gravity – the 'zero-gravity' or microgravity environment. In microgravity, liquids like water form into spherical drops or spheres and float in place rather than producing a flowing stream downwards. However, the video caption describes the water being poured from a cup in a way that would only happen in a terrestrial setting with gravity: forming a stream and falling down with deformation due to gravity. Ignoring the Space-Station Setting: The user prompt specifies this action to be occurring in a space station. In contrast, the video caption makes no mention of the space station and erroneously depicts a possible laboratory setting implying gravity. Misrepresentation of Fluid Behavior in Microgravity: As there is virtually no gravity in the space station, the water would not flow out and fall as it does under the influence of gravity. It would float in the air as droplets or form larger blobs due to cohesive forces. Hence, the video's depiction of the water forming a stream and falling due to gravity conflicts with the user prompt's specification.

Enhanced prompt:

Amidst the ethereal tranquility of a space station, a cup gracefully tilts, gradually releasing an entrancing display of water. Unhindered by gravity, the water does not pour but emerges as perfect, shimmering spheres. Born of cohesion and surface tension, they form a mesmerizing constellation expanding from the cup's mouth. These watery orbs, imbued with spectral hues, disembark from the cup and peacefully float off in the surrounding area, embodying freedom, echoing the whisper of zero gravity that holds sway here. Each sphere, a miniature world to itself, adrift and unhurried, is testament to the complexities yet serenity of life in a space-bound microgravity environment.

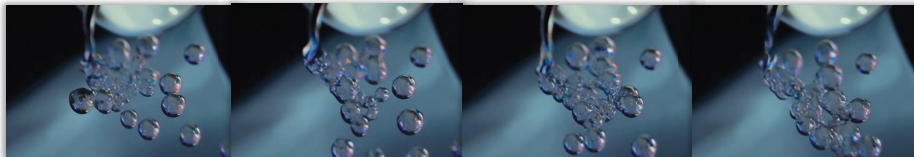
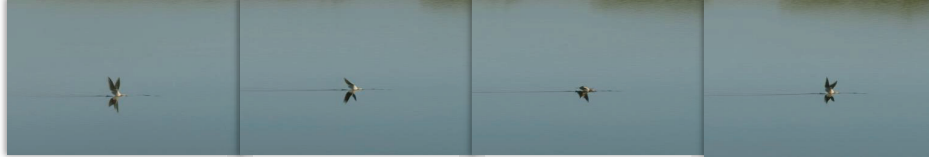


Figure 10. Refinement detail example on force specific prompt in PhyGenBench dataset

Original prompt: A bird is flying over a calm and clear lake surface, with the reflection of the bird appearing on the water surface.



Physical  
law:

The flight of the bird obeys various physical principles, notably Newton's Laws of Motion and the Law of Reflection while the reflection obeys the Law of Reflection and Refraction. 1. Bird Flight (Newton's Laws of Motion, Lift, and Drag Force): Three laws are particularly relevant. The first law of motion states that an object will remain at rest or in uniform motion unless acted upon by an external force. Therefore, bird must exert a force greater than or equal to its weight to maintain altitude and speed in flight. The third law of motion states that for every action, there is an equal and opposite reaction, which means that as a bird flaps its wings downward, a lifting force is generated that enables the bird to stay airborne. Lastly, the second law of motion, which states that the extent of acceleration depends on the object's mass and the amount of net force exerted on it, is applicable when the bird changes its flight speed or direction. Additionally, the bird must also overcome drag and gravity to maintain forward momentum. 2. Reflection of Bird (Law of Reflection): The light that enables us to see the bird's reflection comes from the sun, hitting the bird and then reflecting off the lake to our eyes. According to the Law of Reflection, the angle at which the light hits the bird (the angle of incidence) is equal to the angle at which it bounces off the lake's surface (the angle of reflection). 3. Distortion in Reflection (Refraction): Though not explicitly stated, we can infer that any distortions in the bird's reflection could be due to the physical property of water called refraction. Light speed changes when it moves from the air to water, causing the light to bend and hence the image to distort.

Mismatch:

Position and Motion of the Bird: The user prompt describes a celestial bird sailing across a tranquil lake, creating a moving reflection on the water surface as it modifies its flight path. However, the video caption depicts a bird standing stationary on the water surface, flapping its wings but not flying or sailing. Reflection on the Water Surface: The user prompt refers to an enchanting double image of the bird and its flight reflected on the mirror-like lake. On the contrary, in the video, the reflected image correlates only to the bird's stationary position and wing movements. Interplay of Light: The prompt speaks to a captivating light play, with sunlight glancing off the bird's plumage and the water's surface. This aspect is completely unaddressed in the video caption. Effects of Wind: The user prompt mentions a soft wind causing gentle ripples on the water's surface, distorting the bird's reflection. In contrast, the ripples in the video caption occur solely due to the bird's wing movement. Physics Misinterpretations: The video caption erroneously attributes the bird's ability to stand on water to surface tension, while in reality, most birds float on water due to their lightweight bodies and waterproof feathers. The physics laws of surface tension aren't accurately portrayed.

Enhanced  
prompt:

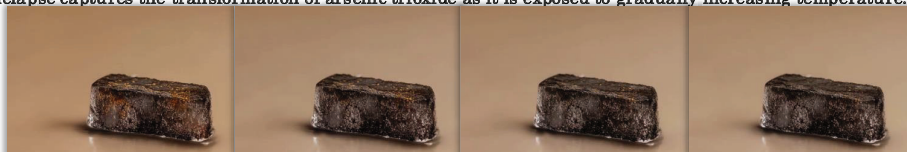
A celestial bird, feathered in iridescent plumage, effortlessly traces a majestic path across a tranquil and invitingly clear lake surface. The bird creates an enchanting double image, reflected with verisimilitude on the mirror-like water, revealing every intricacy of its sublime flight. The reflection of sunlight glimmers off the glossy plumage of the bird and the lustrous water surface, illuminating the scene with a captivating interplay of light. As the bird banks and alters its trajectory, the mirrored image dances and ripples with each movement, distorting tenderly under the soft breeze that ruffles the serene lake's surface.



Figure 11. Refinement detail example on optics specific prompt in PhyGenBench dataset



Original prompt: A timelapse captures the transformation of arsenic trioxide as it is exposed to gradually increasing temperature.



Physical law:

The key physical laws that arsenic trioxide obeys in this scenario are primarily focused within the realms of thermodynamics and phase transition. 1. Heat Transfer and Thermodynamics: As the arsenic trioxide is exposed to increasing temperature, it's subject to the principles of thermodynamics, specifically the first law of thermodynamics which essentially states that energy cannot be created or destroyed, but only transformed. In this case, the thermal energy is transferred from the surrounding area to the arsenic trioxide, causing the chemical to heat up. 2. Phase Transition: Arsenic trioxide should experience phase transition under sufficient heat. This is described by the phase transition theory, a subset of thermodynamics. Initially, arsenic trioxide at room conditions is in solid form, and as the thermodynamic equilibrium changes with heating, it undergoes a phase transition process, changing from solid to liquid, and eventually to gas, each phase bound by a certain range of temperature and pressure. The transformations are not instantaneous but happen over a period of time, thereby can be captured in a time-lapse video. 3. Expansion due to Heating: The arsenic trioxide may also physically expand as it heats, which is explained by the principle of thermal expansion. As arsenic trioxide heats up, its molecules move more rapidly, causing the substance to expand. However, this may be more apparent in larger masses of matter and may not show significant effect in a small amount of arsenic trioxide. 4. Gas Laws: If the arsenic trioxide reaches a gaseous state, it then follows the gas laws, including Charles's Law and Boyle's Law, which describe the relationships between the volume, pressure, and temperature of gases.

Mismatch:

Absence of Transformation and Temperature Change: The user prompt asks for a video illustrating the change in arsenic trioxide when exposed to a gradually increasing temperature starting from room temperature. In contrast, the video caption describes a static close-up shot of arsenic trioxide without any transformation or interaction with a varying temperature environment. Misplaced Emphasis on Camera Physics: The prompt requests a physics demonstration or experiment involving chemical transformation under temperature changes. However, the video caption instead focuses on the physics related to the camera's zoom and focus, such as light refraction and lens adjustments. These aspects, although they involve physics, are completely unrelated to the user prompt regarding the thermochemical behavior of arsenic trioxide, indicating a significant mismatch. Misinterpretation of User Prompt: The video caption does not address the desired timelapse showing how arsenic trioxide changes when the temperature rises from room temperature. Instead, it provides a static shot of the substance without transformation or interaction with temperature changes. This deviates from the user's request, which involves observation of physical changes under different thermal conditions.

Enhanced prompt:

A timelapse illustrates the transition of a crystalline lump of arsenic trioxide going through a radiant transformation. As the temperature gradually rises from room temperature, captured by a subtly placed thermometer, the seemingly motionless arsenic trioxide begins to stir. Initially, microscopic tremors agitate the lump as it slowly warms, and increasingly visible motions ensue as the temperature rises further. Solid arsenic oxide soon begins to liquefy, with sparkles capturing the process. Finally, the gas begins to wisps upwards. The entire spectacle reflects the grandeur of thermodynamics in action.



Figure 12. Refinement detail example on thermal specific prompt in PhyGenBench dataset

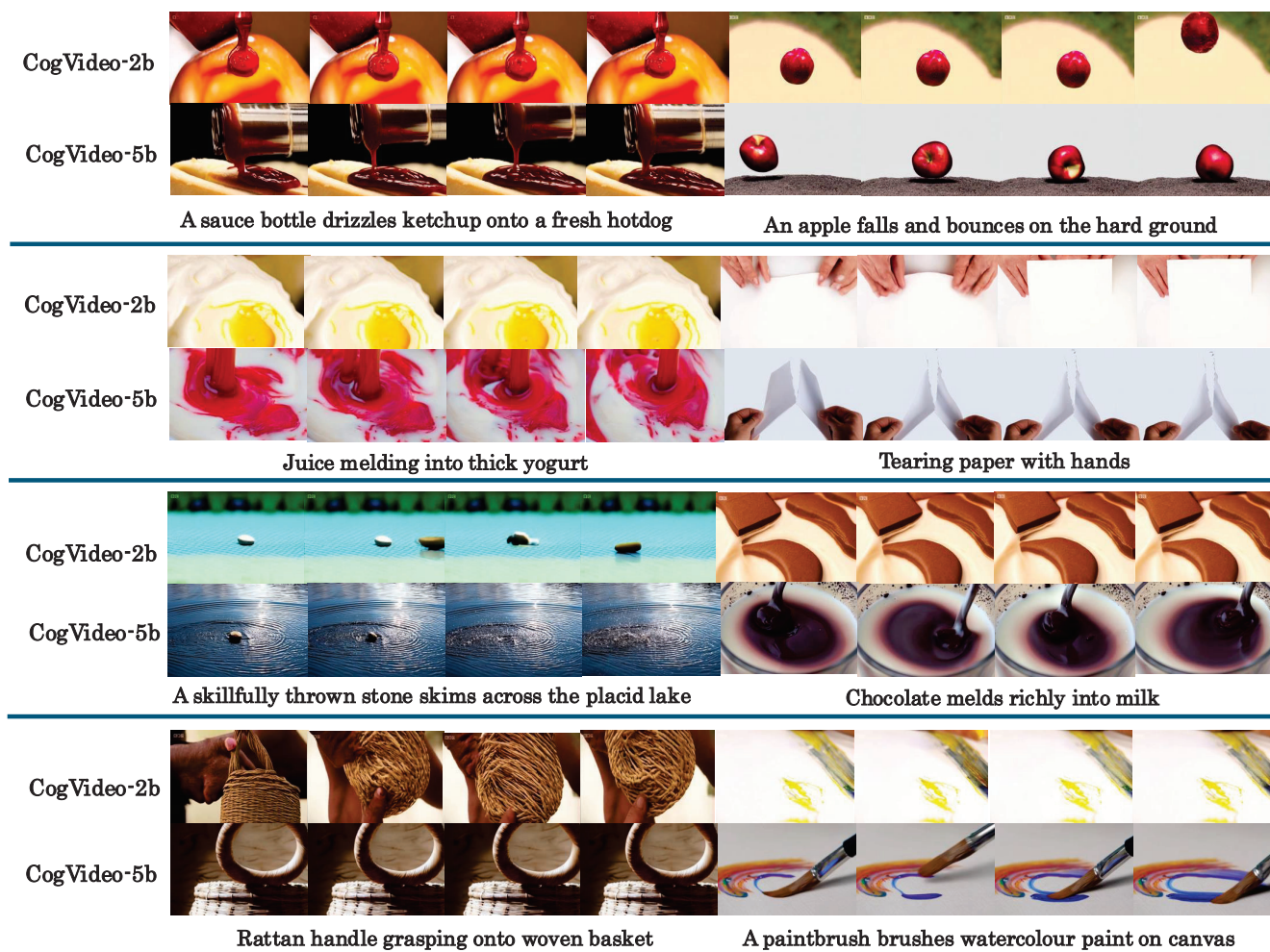


Figure 13. Ablation study on model size



Prompt	Output
<p>### Instruction</p> <p>You are a physics expert. Your task is to identify the main object in the given user prompt and provide the physical laws in reality the main object should obey with as much detail as possible in a descriptive way without giving formulas. Some in-context examples are provided for your reference, and you need to finish the current task.</p> <p>### In-context examples</p> <p>User prompt: a rubber ball hits the ground and then bounces up</p> <p>Main object: rubber ball,</p> <p>Physical law: The primary physical law that should be obeyed by the video is Newton's Law of Motion along with the Law of Conservation of Energy, particularly focusing on elastic collisions and gravitational acceleration. 1. Gravitational Acceleration (Newton's Second Law of Motion): As the rubber ball falls toward the ground, it is acted upon by the force of gravity. According to Newton's Second Law, the force acting on the ball is the product of its mass and the gravitational acceleration, typically <math>9.8 \text{ m/s}^2</math> near the surface of the Earth. 2. Collision with the Ground (Elastic and Inelastic Collisions): When the ball hits the ground, a collision occurs. In reality, rubber balls exhibit partially elastic behavior, meaning that some energy is lost to heat and deformation during the impact. This leads to a bounce with less energy than the initial fall, and the ball does not reach the original height from which it was dropped. 3. Conservation of Energy: As the ball falls, its potential energy is converted into kinetic energy, the velocity of the ball keeps increasing until the impact. Once the ball bounces back up, it follows the rules of projectile motion under gravity, accelerating upwards until the velocity reaches zero at its highest point, where all kinetic energy has been converted back to potential energy. The ball then begins its downward motion again, repeating the cycle but with diminishing height due to energy loss at each bounce.</p> <p>### Current task</p> <p>User prompt: An apple falls and bounces on the hard ground. Let's think step by step.</p>	<p>Main object: apple</p> <p>Physical law:</p> <ol style="list-style-type: none"> <li>1. Gravitational Acceleration As the apple falls, it is influenced by the force of gravity. Gravity pulls the apple downward, causing it to accelerate toward the Earth. The apple's acceleration due to gravity is constant near the Earth's surface, regardless of its mass. Its velocity increases steadily during free fall unless influenced by air resistance.</li> <li>2. Air Resistance (Drag Force) While the apple is falling, it encounters air resistance, a force opposing its motion. The magnitude of air resistance depends on the apple's shape, size, and speed, as well as the density of the air. If the apple falls from a sufficient height, it may reach terminal velocity—a constant speed where the downward force of gravity equals the upward drag force.</li> <li>3. Impact with the Hard Ground When the apple hits the ground, it undergoes a collision. This interaction is governed by:  <ul style="list-style-type: none"> <li>Newton's Third Law of Motion: The apple exerts a force on the ground, and the ground exerts an equal and opposite force on the apple.</li> <li>Impulse and Momentum: During the collision, the apple's momentum changes rapidly over a short period, depending on its velocity and mass.</li> <li>Deformation and Elasticity: The apple, being a soft object, deforms on impact. The ground, being hard, undergoes minimal deformation. The extent to which the apple regains its shape determines the height of its bounce.</li> </ul> </li> <li>4. Conservation of Energy Before the fall, the apple has gravitational potential energy due to its height above the ground. As it falls, this potential energy is converted into kinetic energy.  <ul style="list-style-type: none"> <li>At the moment of impact, some of the kinetic energy transforms into other forms: <ul style="list-style-type: none"> <li>Elastic Potential Energy (as the apple compresses and deforms).</li> <li>Thermal Energy (heat generated due to internal friction in the apple and at the contact surface).</li> <li>Sound Energy (the noise created upon impact).</li> </ul> </li> </ul> </li> </ol> <p>During the bounce, the elastic potential energy in the apple partially converts back into kinetic energy. However, some energy is lost, resulting in a lower bounce height.</p> <ol style="list-style-type: none"> <li>5. Coefficient of Restitution (COR) The apple's ability to bounce depends on the COR, a measure of how elastic the collision is. For the apple-ground system, the COR is less than 1, indicating an inelastic collision where energy is lost to deformation and other processes.</li> <li>6. Post-Bounce Motion After bouncing, the apple follows a parabolic trajectory dictated by gravitational forces. Its upward motion decelerates due to gravity until it momentarily stops at its maximum height. If the apple bounces multiple times, each subsequent bounce will be shorter due to cumulative energy losses.</li> </ol>

Figure 14. The original prompt and output

Prompt	Output
<p>### Instruction</p> <p>Your task is to identify the main object in the given user prompt and provide the physical laws in reality the main object should obey with as much detail as possible in a descriptive way without giving formulas. Some in-context examples are provided for your reference, and you need to finish the current task.</p> <p>### In-context examples</p> <p>User prompt: a rubber ball hits the ground and then bounces up</p> <p>Main object: rubber ball,</p> <p>Physical law: The primary physical law that should be obeyed by the video is Newton's Law of Motion along with the Law of Conservation of Energy, particularly focusing on elastic collisions and gravitational acceleration. 1. Gravitational Acceleration (Newton's Second Law of Motion): As the rubber ball falls toward the ground, it is acted upon by the force of gravity. According to Newton's Second Law, the force acting on the ball is the product of its mass and the gravitational acceleration, typically <math>9.8 \text{ m/s}^2</math> near the surface of the Earth. 2. Collision with the Ground (Elastic and Inelastic Collisions): When the ball hits the ground, a collision occurs. In reality, rubber balls exhibit partially elastic behavior, meaning that some energy is lost to heat and deformation during the impact. This leads to a bounce with less energy than the initial fall, and the ball does not reach the original height from which it was dropped. 3. Conservation of Energy: As the ball falls, its potential energy is converted into kinetic energy, the velocity of the ball keeps increasing until the impact. Once the ball bounces back up, it follows the rules of projectile motion under gravity, accelerating upwards until the velocity reaches zero at its highest point, where all kinetic energy has been converted back to potential energy. The ball then begins its downward motion again, repeating the cycle but with diminishing height due to energy loss at each bounce.</p> <p>### Current task</p> <p>User prompt: An apple falls and bounces on the hard ground. Let's think step by step.</p>	<p>Main object: apple</p> <p>Physical law:</p> <ol style="list-style-type: none"> <li>1.Gravitational Acceleration (Newton's Second Law of Motion):  <ul style="list-style-type: none"> <li>As the apple falls toward the ground, it is acted upon by the force of gravity. This force causes the apple to accelerate downward at a constant rate, typically <math>9.8 \text{ m/s}^2</math> near the Earth's surface. The apple's velocity increases steadily as it descends due to this constant acceleration.</li> </ul> </li> <li>2.Collision with the Hard Ground (Inelastic Collision):  <ul style="list-style-type: none"> <li>When the apple hits the hard ground, a collision occurs. Unlike a rubber ball, the apple is less elastic and more prone to deformation upon impact. The collision is primarily inelastic, meaning a significant portion of kinetic energy is lost to internal deformation, heat, and sound. This results in a less pronounced bounce compared to more elastic objects.</li> </ul> </li> <li>3.Conservation of Energy:  <ul style="list-style-type: none"> <li>During the fall, the apple's gravitational potential energy is converted into kinetic energy, increasing its speed until impact. Upon collision with the ground, some kinetic energy transforms into other forms of energy: Heat Energy: Generated due to internal friction within the apple's structure. Sound Energy: Produced from the noise of the impact. Energy of Deformation: Used in changing the shape of the apple upon impact. If the apple bounces, the remaining kinetic energy propels it upward, but it will not reach the original height due to these energy losses.</li> </ul> </li> <li>4.Newton's Third Law of Motion:  <ul style="list-style-type: none"> <li>During the collision, the apple exerts a force on the ground. The ground exerts an equal and opposite force back on the apple. This reaction force can cause the apple to bounce back upward, depending on how much kinetic energy remains after the impact.</li> </ul> </li> <li>5.Air Resistance:  <ul style="list-style-type: none"> <li>As the apple falls and potentially bounces upward, it experiences air resistance. Air resistance opposes the motion of the apple through the air, reducing its acceleration during the fall. During the upward motion after a bounce, air resistance works against the apple's ascent, causing it to slow down more quickly.</li> </ul> </li> <li>6.Material Properties and Deformation:  <ul style="list-style-type: none"> <li>The apple's ability to bounce is influenced by its material properties, such as elasticity and structural integrity. Being less elastic, the apple absorbs more energy through deformation upon impact. This absorption of energy reduces the amount of kinetic energy available to propel the apple back upward, resulting in a lower bounce height compared to elastic objects like rubber balls.</li> </ul> </li> <li>7.Energy Dissipation:  <ul style="list-style-type: none"> <li>Energy lost during the collision and subsequent motions ensures the apple will not bounce back to its original height. Over successive bounces (if any), the apple's kinetic energy continues to decrease due to ongoing energy losses. Eventually, the apple comes to rest as all its kinetic energy is dissipated through deformation, heat, sound, and overcoming air resistance.</li> </ul> </li> </ol>

Figure 15. The prompt without the role indicator and output

**Prompt**

### Instruction  
 You are a physics expert. Your task is to identify the main object in the given user prompt and provide the physical laws in reality the main object should obey with as much detail as possible in a descriptive way without giving formulas.  
 ### Current task  
 User prompt: An apple falls and bounces on the hard ground.  
 Let's think step by step.

**Output**

**Main Object:**  
 The main object in this scenario is the apple.

**Physical Laws Governing the Apple's Motion**  
 Let us analyze the motion of the apple step by step:  
**Step 1: Initial Fall (Gravitational Pull)**  
 The apple starts its motion due to gravity, which exerts a constant downward force. Gravity pulls the apple toward the Earth, causing it to accelerate uniformly. This is governed by Newton's Second Law of Motion, where the net force on the apple results in an acceleration proportional to its mass.

**Step 2: Interaction with Air (Air Resistance)**  
 As the apple falls, it moves through the air and experiences air resistance, a force that opposes its downward motion. Air resistance depends on factors like the apple's speed, surface area, and shape, as well as the density of the air. If the apple falls from a sufficient height, it could reach a state called terminal velocity, where the upward force of air resistance balances the downward force of gravity, causing it to fall at a constant speed.

**Step 3: Impact with the Ground (Collision Dynamics)**  
 When the apple strikes the hard ground, it undergoes a collision. The interaction involves several physical principles: **Newton's Third Law of Motion:** The apple exerts a force on the ground, and the ground exerts an equal and opposite force on the apple. **Momentum Transfer:** The apple's momentum changes rapidly due to the impact. The exact nature of this change depends on the time duration of the collision and the material properties of the apple and the ground. **Deformation and Elasticity:** The apple deforms upon impact due to its soft and elastic nature. The hard ground, being rigid, undergoes negligible deformation.

**Step 4: Energy Transformation at Impact**  
 As the apple falls, its gravitational potential energy is converted into kinetic energy. Upon hitting the ground, part of the kinetic energy is transformed into: **Elastic Potential Energy:** Stored as the apple compresses during the collision. **Thermal Energy:** Generated through internal friction within the apple and at the contact point. **Sound Energy:** Produced as the collision generates noise. Energy losses during the impact mean that the apple does not fully regain its initial potential energy.

**Step 5: The Bounce (Coefficient of Restitution)**  
 The apple rebounds after the impact, driven by the release of elastic potential energy stored during its deformation. The height of the bounce is determined by the coefficient of restitution (COR), which measures the elasticity of the collision. For an apple-ground interaction, the COR is less than 1, indicating that the collision is inelastic, with significant energy losses. Consequently, the apple bounces to a height lower than its original drop point.

**Step 6: Post-Bounce Motion**  
 After the bounce, the apple follows a parabolic trajectory determined by gravity. Its upward motion slows as it loses kinetic energy and eventually stops momentarily at its peak height. The apple then falls back under the influence of gravity. If subsequent bounces occur, each is progressively shorter due to cumulative energy losses to heat, sound, and internal deformation. The apple eventually comes to rest due to friction and dissipation of energy.

**Relevant Physical Laws**  
 1. **Newton's Laws of Motion.** First Law: The apple remains at rest or in motion unless acted upon by a force (gravity, air resistance, ground collision). Second Law: The net force on the apple results in its acceleration toward the Earth. Third Law: During the collision, the ground exerts an equal and opposite force on the apple.  
 2. **Law of Universal Gravitation.** The gravitational force between the Earth and the apple governs its downward motion.  
 3. **Energy Conservation and Transformation.** Energy is converted between potential energy, kinetic energy, and other forms (elastic potential, thermal, sound). Energy losses due to inelasticity reduce the height of subsequent bounces.  
 4. **Air Resistance Principles.** Drag forces oppose the apple's motion, particularly during free fall.  
 5. **Collision Dynamics and Elasticity.** The behavior of the apple during and after impact is influenced by the deformation, energy losses, and the coefficient of restitution. By analyzing the motion in these steps, the apple's fall, impact, and bounce can be fully described.

Figure 16. The prompt without the in-context example and output



Figure 17. Failure case example on human hand related video generation