EXTENDED ESSAY

International Baccalaureate

PHYSICS

Topic: Fluid's density effect on falling objects

Research Question: To what extent does the density of a fluid through which a small object is falling, affect the time it takes to reach the ground?

Pages: 28

Word Count: 3982

Table of Contents

1. Introduction

I have often been intrigued by the way objects fall in different media. For example, a small pebble dropped into water sinks much more slowly than the same pebble dropped through air. This everyday observation highlights a fundamental question in physics: how does the medium – specifically the density of a fluid – influence a falling object's motion? Historically, Galileo Galilei laid the groundwork for answering this question by demonstrating that, in the absence of air resistance, objects of different masses fall with the same acceleration[1]. On Earth, this acceleration due to gravity is approximately 9.81 m/s^2, acting uniformly on all masses. However, in a real fluid (like air or water), a falling object encounters additional forces from the fluid that can dramatically alter its motion[2].

When a small object falls through a fluid, it is subject not only to gravity but also to forces imposed by the fluid itself. In fact, there are three forces in this situation: the object's weight (gravity) acting downward, and both drag (a resistive force) and buoyant force (upthrust) acting upward. Drag arises from the object moving through the fluid and depends on the object's speed, size, and shape, as well as the fluid's properties[3]. Crucially, drag is greater in a denser fluid – the resistance is directly proportional to the fluid's density[4]. The buoyant force also increases with fluid density, effectively reducing the net force pulling the object

---

[1] Conover, E. (2020). *Galileo's famous gravity experiment holds up, even with individual atoms*. [Online] Science News, 28 Oct 2020. Available at: https://www.sciencenews.org/article/galileo-gravity-experiment-atoms-general-relativity-einstein

[2] Elert, G. (n.d.). *Aerodynamic Drag*. [Online] The Physics Hypertextbook. Available at: http://physics.info/drag/

[3] Physics LibreTexts. (n.d.). *Acceleration Due to Gravity*. [Online] Available at: https://phys.libretexts.org/Bookshelves/Physical_Science/Book%3A_Physical_Science_for_Educators/09%3A_Motion/9.3%3A_Motion_in_One-Dimension/9.3.8%3A_Acceleration_Due_to_Gravity

[4] OpenStax College Physics. (2012). *College Physics*. Houston, TX: OpenStax. Section 12.6: Motion of an Object in a Viscous Fluid. [Online] Available at: https://openstax.org/details/books/college-physics

down. Because of these fluid forces, an object will fall more slowly in a denser medium, taking a longer time to reach the ground than it would in a less dense fluid.

As this topic sits at the intersection of classical mechanics and fluid dynamics, studying how fluid density affects falling time is both scientifically intriguing and practically relevant. Understanding this relationship provides insights into designing objects to move through fluids (from parachutes in air to submersibles in water) and predicting motion in different environments such as varying planetary atmospheres. In this extended essay, a computer simulation is employed to drop a small object (modeled as a sphere) through fluids of various densities, allowing precise control of conditions and exploration of scenarios – from near vacuum to much denser media – beyond the reach of simple laboratory experiments. By analyzing the resulting falling times, the relationship between fluid density and an object's time to reach the ground can be quantified. Thus, this essay addresses the research question: **"To what extent does the density of a fluid through which a small object is falling affect the time it takes to reach the ground?"**

2. Hypothesis

In the absence of any fluid (a vacuum), all objects fall with the same acceleration due to gravity regardless of their masses. This was famously demonstrated by Galileo and in the Apollo 15 experiment, where a hammer and a feather dropped in vacuum hit the ground simultaneously[5]. On Earth, however, falling objects are also influenced by forces from the surrounding fluid (air or liquid), which cause deviations from this uniform acceleration. Drag (fluid resistance) and buoyant force (upthrust) oppose the downward force of gravity and can significantly slow an object's fall. I expect that the density of the fluid through which an

[5] **NASA (2023).** *The Apollo 15 Hammer-Feather Drop.* NASA Science – Moon Exploration. [online] Available at: https://science.nasa.gov/resource/the-apollo-15-hammer-feather-drop/ (The Apollo 15 Hammer-Feather Drop - NASA Science)

object falls is a major factor determining its falling time. A higher fluid density means more mass (or particles) per volume in the fluid, so the object experiences greater resistance as it pushes through[6]. According to fluid dynamics, the drag force on an object is directly proportional to the fluid's density[7]. Likewise, a denser fluid exerts a larger buoyant force on the object (by Archimedes' principle) since a greater weight of fluid is displaced[8]. These increased upward forces in a higher-density fluid should reduce the net downward acceleration of the object and lower its terminal velocity (maximum steady falling speed). Consequently, it will take **longer** for the object to reach the ground. I therefore predict that as the fluid density increases, the falling time of a small object increases – in other words, denser fluids cause objects to fall more slowly. In an extreme case, if the fluid's density approaches the density of the object, the object would become nearly buoyant and fall only very slowly (approaching zero terminal velocity), greatly prolonging or even preventing it from reaching the ground. Thus, the density of the fluid is expected to have a direct and significant impact on increasing an object's time of fall.

---

[6] The Physics Classroom (n.d.). *Newton's Laws – Lesson 3: Free Fall and Air Resistance.* [online] Available at: https://www.physicsclassroom.com/class/newtlaws/Lesson-3/Free-Fall-and-Air-Resistance (The Physics Classroom Website) (The Physics Classroom Website)

[7] Force in Physics – Drag (2024). *"Drag (physics)"* (online article). [online] Available at: https://forceinphysics.com/drag-physics/ (Drag (physics) - Force in Physics)

[8] LibreTexts Physics (2021). *"Archimedes' Principle – Buoyant Force,"* in *University Physics Vol. 1*. [online] Available at: https://phys.libretexts.org/Bookshelves/University_Physics/Physics_(Boundless)/10:_Fluids/10.3:_Archimedes_Principle (10.3: Archimedes' Principle - Physics LibreTexts)

3. Theory

3.1 Weight on Falling Objects

A force is defined as an agent that can change the state of an object, whether it is at rest or moving. It has both magnitude and direction, making it a vector quantity[9]. Forces play a crucial role in determining the motion of bodies undergoing free fall. In 1687, Newton established a relationship between force and a change in momentum, which is known as Newton's Second Law of Motion[10]. For a constant mass, a force (N) can be obtained from the equation:

$$F = \frac{mv_2 - mv_1}{t} \text{ and } F = ma$$

where m is the mass of the object, v_1 and v_2 are initial and final velocities, t is time, and a is acceleration.

Entities descending towards Earth are attracted towards Earth's core by a gravitational pull. Such a situation can be attributed to Earth's gravitational field, which is quantifiable in terms of weight[11]. In a lack of external factors, all bodies have a common acceleration of about 9.81 m/s^2. Real environmental circumstances add two counterforces that oppose a body from falling: drag and buoyancy. Bodies with equal mass can have different free fall durations, which are dependent on properties of a surrounding fluid. The goal of research in this paper is to determine the impact that fluid density has on these counterforces as well as on a duration in which a body will fall on Earth.

[9] Chemistry LibreTexts. (2021). 14.3: Laminar and turbulent flow. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Biological_Chemistry/Concepts_in_Biophysical_Chemistry_(Tokmakoff)/04%3A_Transport/14%3A_Hydrodynamics/14.03%3A_Laminar_and_Turbulent_Flow
[10] Concepts of Physics. (n.d.). Stokes law and terminal velocity: Concepts and problems. Concepts of Physics. https://concepts-of-physics.com/mechanics/stokes-law-and-terminal-velocity.php
[11] Conover, E. (2020). Galileo's famous gravity experiment holds up, even with individual atoms. Science News. https://www.sciencenews.org/article/galileo-gravity-experiment-atoms-general-relativity-einstein

3.2 Drag Forces on Falling Objects

Although weight is in the direction of motion, a body moving downwards in a fluid is met with two opposite forces: viscous drag and upthrust. Viscous drag is a retarding force that is in opposition with the body's motion[12], whereas upthrust is a fluid exerted on a body that is in suspension[13]. The two forces slow down the body as it falls until it reaches its terminal speed, which is a constant speed at which its forces are balanced. Figure 1 represents these two forces in operation.

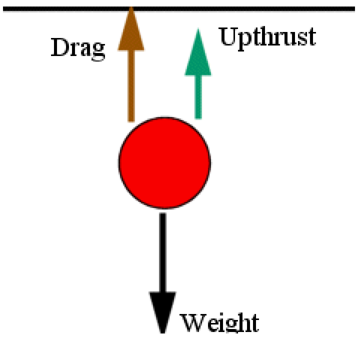


Figure 1 – Forces acting on falling objects[14]

Terminal velocity is a key concept in physics. It is attained once the net force experienced by a falling body is reduced to zero, leading to a halting in its rate of acceleration and making it move at a stationary speed[15]. The drag is made up of two key elements: pressure stress as well as shear stress. Pressure stress is developed because of a difference in pressure over the body surface, leading to pressure drag[16]. The formation of turbulence in fluid following a body is known as a separation zone. The resultant is a rising lifting force known as upthrust

[12] Lumen Learning. (n.d.). Motion of an object in a viscous fluid. Lumen Learning. https://courses.lumenlearning.com/atd-austincc-physics1/chapter/12-6-motion-of-an-object-in-a-viscous-fluid/

[13] Edgar. (2021). How to model free-falling bodies with fluid resistance. WeTheStudy. https://wethestudy.com/mathematics/how-to-model-free-falling-bodies-with-fluid-resistance/

[14] Fowler, M. (n.d.). Stokes' law. University of Virginia. https://galileo.phys.virginia.edu/classes/152.mf1i.spring02/Stokes_Law.htm

[15] NASA Glenn Research Center. (n.d.). Newton's laws of motion. NASA. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/

[16] Khan Academy. (2018). What is buoyant force? Khan Academy. https://www.khanacademy.org/science/physics/fluids/buoyant-force-and-archimedes-principle/a/buoyant-force-and-archimedes-principle-article

in common terms[17]. The differential pressure exerted at upper as well as bottom surfaces on a body is held accountable in its development[18]. Figure 2 also explains in more detail.

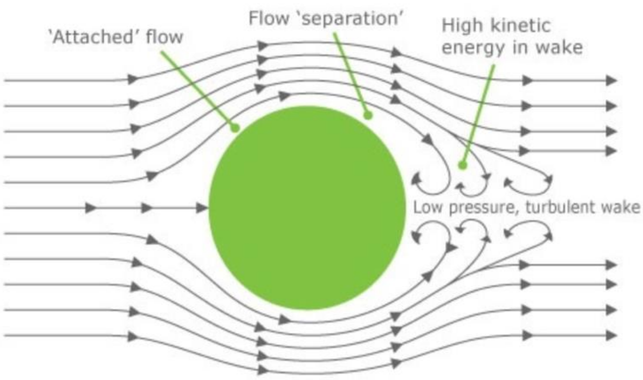


Figure 2 – Buoyant force due to varying pressure[19]

To measure upthrust, Archimedes' Principle is utilized, which states that a body which is placed in a fluid experiences a buoyant force equal in magnitude to that which is equal to displaced fluid. The buoyant force can be quantified by the following equation:

$$F_b = \rho g V$$

where p is the fluid's density, g is gravitational acceleration, and V is the displaced volume[20].

Simultaneously, the resistance that is met in a fluidic medium is a consequence of fluid molecule-surface collision. The resistance is affected both by surface area as well as body speed[21]. In addition, fluid flow properties contribute considerably towards resistance faced. Fluid flow is generally categorized into two forms: laminar as well as turbulent. In laminar

[17] P.E., C. Y. (2022). Why does flow become turbulent? EngineerExcel. https://engineerexcel.com/why-does-flow-become-turbulent/
[18] Princeton University. (2019). Drag of blunt bodies and streamlined bodies. Princeton University. https://www.princeton.edu/~asmits/Bicycle_web/blunt.html
[19] Saylor Academy. (n.d.). The behavior of real gases. Saylor Academy. https://saylordotorg.github.io/text_general-chemistry-principles-patterns-and-applications-v1.0/s14-08-the-behavior-of-real-gases.html
[20] Science Learning Hub. (2011). Causes of aerodynamic drag. Science Learning Hub. https://www.sciencelearn.org.nz/resources/1346-causes-of-aerodynamic-drag
[21] StudySmarter UK. (n.d.). Drag force: Definition, examples & formula. StudySmarter. https://www.studysmarter.co.uk/explanations/physics/dynamics/drag-force/

flow, fluid particles travel in parallel streams, leading to a smooth motion with no turbulence. In turbulent flow, fluid particles have a haphazard as well as non-coherent motion[22]. The difference between these two forms is depicted in Figure 3.

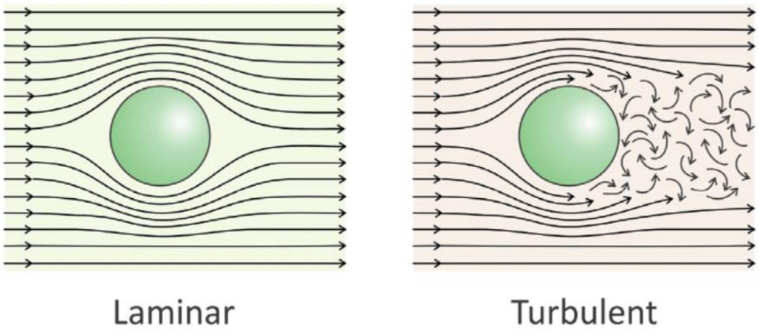


Figure 3 – Laminar versus Turbulent flow[23]

To determine whether an object will experience laminar or turbulent flow, we calculate the **Reynolds number**, which depends on the object's velocity, fluid density, and viscosity. It is defined as:

$$N_R = \frac{\rho v r}{\mu}$$

where N_R is the Reynolds number, ρ is fluid density (kg/m³), v is object velocity (m/s), r is the sphere's radius (m), and μ is dynamic viscosity (kg/m·s)[24] . For values below 2000, flow is generally laminar, while higher values indicate turbulence[25].

In circumstances in which a body moves in laminar flow, resistance is equal to its velocity. In circumstances in which turbulent flow is experienced, resistance is equal to the square of its

[22] Testbook. (n.d.). Which of the following cannot be changed by applying force? Testbook. https://testbook.com/question-answer/which-of-the-following-cannot-be-changed-by-applying--6019157998ccc2e8317599c5
[23] The Editors of Encyclopaedia Britannica. (2018). Density: Definition, units, & formula. Encyclopaedia Britannica. https://www.britannica.com/science/density
[24] The Efficient Engineer. (2020, May 12). Understanding laminar and turbulent flow [Video]. YouTube. https://www.youtube.com/watch?v=9A-uUG0WR0w
[25] The Kid Should See This. (2012). The Apollo 15 hammer and feather drop on the Moon (1971). The Kid Should See This. https://thekidshouldseethis.com/post/apollo-15-hammer-feather-drop-moon

velocity[26]. Because these diameters of these spheres as well as fluid densities are relatively small, it can be assumed that a small Reynolds number (less than 2000) is realized. Therefore, according to Stokes' Law, it is possible to determine a small spherical body's drag:

$$F = 6\pi\mu r v$$

Stokes' Law assumes that at a given time, the drag force (N) is equal to dynamic viscosity (kg/m·s), radius (m), and relative speed of the body (m/s)[27]. The relation above holds true in case of spherical bodies moving in a free fall at a small Reynolds (N_R < 2000)[28].

Considering that fluid interaction is affected by the density in its surroundings, in this study we will look at how much a variable impacts a spherical body's fall duration.

3.3 Fluid Characteristics

A fluid can be referred to as a material in a gaseous or liquid state that deforms permanently with external stress[29]. Every fluid will have a definite density, which is a measure of mass in a unit amount of space. The calculation is as follows:

$$\rho = \frac{m}{V}$$

where ρ is density (kg/m³), m is mass (kg), and V is volume (m³)[30].

[26] The Physics Classroom. (2019). Newton's law of universal gravitation. The Physics Classroom. https://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation
[27] TuitionPhysics. (n.d.). What is the relationship between density and pressure? TuitionPhysics. https://tuitionphysics.com/oct-2017/what-is-the-relationship-between-density-and-pressure/
[28] Unacademy. (n.d.). Analysing the different types of Stokes' law. Unacademy. https://unacademy.com/content/neet-ug/study-material/physics/analysing-the-different-types-of-stokes-law/
[29] Vedantu. (n.d.). Fluid. Vedantu. https://www.vedantu.com/physics/fluid
[30] Boldmethod. (n.d.). Density: Why it matters. Boldmethod. https://www.boldmethod.com/learn-to-fly/performance/density-altitude/

Fluid density varies with **temperature and pressure**. As pressure increases, molecules are compressed into a smaller volume, increasing the fluid's density[31]. Conversely, a rise in temperature causes molecules to gain energy and spread apart, reducing density[32]. Figure 4 illustrates these effects.

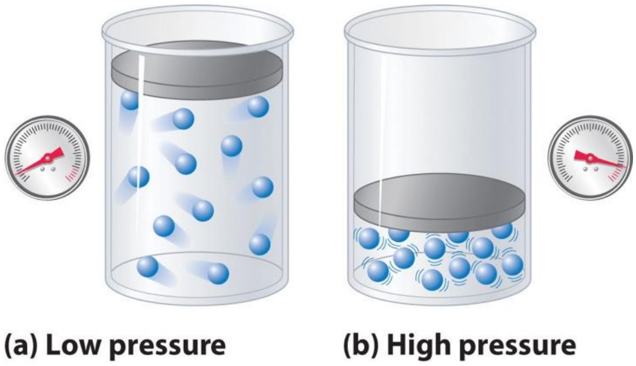


Figure 4 – Pressure effect on density[33]

Another crucial property is **viscosity**, which measures a fluid's resistance to deformation. A fluid with high viscosity (e.g., honey) resists motion more than one with low viscosity (e.g., water). Newton's Law of Viscosity describes the shear stress in a fluid:

$$\tau = \mu \frac{du}{dy}$$

where τ is shear stress (Pa), μ is dynamic viscosity (Pa·s), and $\frac{du}{dy}$ represents the velocity gradient perpendicular to the surface[34].

[31] Middle School Chemistry. (n.d.). Temperature and density | Chapter 3: Density. Middle School Chemistry. https://www.middleschoolchemistry.com/lessonplans/chapter3/lesson6

[32] UNAM. (n.d.). Free fall. Universidad Nacional Autónoma de México. http://www.objetos.unam.mx/fisica/caidaLibre/

[33] ScienceDirect. (n.d.). Reynolds number – An overview. ScienceDirect. https://www.sciencedirect.com/topics/engineering/reynolds-number

[34] ScienceDirect. (n.d.). Reynolds number – An overview. ScienceDirect. https://www.sciencedirect.com/topics/engineering/reynolds-number

A relationship between **kinematic viscosity** (ν) and **dynamic viscosity** (μ) exists:

$$\nu = \frac{\mu}{\rho}$$

where ν is kinematic viscosity (m^2/s)[35]. Unlike dynamic viscosity, kinematic viscosity accounts for the fluid's density. Since fluid properties influence how objects move through them, the effect of density on falling spheres is the primary focus of this investigation.

4. Variables

4.1 Independent Variable

- Fluid Density: Systematic variation in the medium through which the object moves is achieved by making use of fluids with known densities in each case. One sphere is used in each trial to maintain consistency. This variable is intentionally manipulated to determine its effect on the dependent variable. It is assumed that each fluid has an equal density in every part of its volume.

4.2 Dependent Variable

- Falling Time: This refers to the time elapsed between an object being dropped and touching down in the fluid, thus defining the variable in this research to be studied. This is an essential metric to determine to analyze the effect fluid density has upon motion.

[35] Vedantu. (n.d.). What is terminal velocity? What are the factors on which terminal velocity depends? Vedantu. https://www.vedantu.com/question-answer/terminal-velocity-what-are-the-factors-on-which-class-12-physics-cbse-60b4befb9289d425a8c87820

4.3 Controlled Variables

- To ensure generation of accurate and reliable results, the following factors should be maintained constant during the experimental phase through an online simulation to avoid unintentional variation affecting trends in collected data.

Controlled Variable	Reason for Control	Method of Control
Mass of the object (kg)	Ensures that variations in falling time are due to fluid density rather than mass differences.	Within the online simulator the same body will be tested for different fluid densities.
Volume of the object (m^3)	Affects buoyant force and drag, influencing falling time.	Within the online simulator the same body will be tested for different fluid densities.
Height of free fall (m)	Ensures that the initial potential energy remains constant across all trials.	Within the online simulator the body will be thrown from a specific height for all trials.
Initial velocity of body (m/s)	Variations in initial velocity could impact acceleration and terminal velocity.	Within the online simulator the body will be thrown from rest for all trials.
Dynamic viscosity of the fluid (kg/m·s)	Affects the resistance experienced by the object during free fall.	Within the online simulator the body will be thrown through air with different densities, but with a constant dynamic viscosity value.

Controlled Variable	Reason for Control	Method of Control
Gravitational acceleration (m^2/s)	Changes in gravitational acceleration would affect falling time.	Within the online simulator the body will be thrown through air with a constant gravitational acceleration of 9.81 m/s^2

5. Methodology

5.1 Experimental Setup

To investigate fluid density's effect on body descent dynamics, an experiment will be carried out through an online simulator[36]. Access to this facility is accessible through: http://www.objetos.unam.mx/fisica/caidaLibre/ This facility offers laboratory conditions ideal to neutralize potential risks. Experimentation entails testing diverse fluid densities through dropping identical spheres in various fluids to note differences in acceleration. Experimental results collected shall be compared to theoretical models, formulas, and previous work to validate present theory while analyzing to what degree fluid density impacts fall time. Figure 5 illustrates the used simulator.

[36] Universidad Nacional Autónoma de México (UNAM). (n.d.). Caída libre. UNAM. http://www.objetos.unam.mx/fisica/caidaLibre/

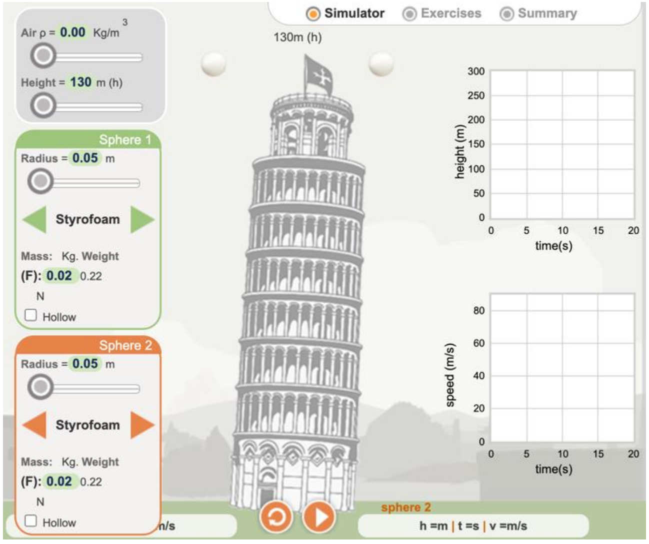


Figure 5 – Online simulation on display[37]

5.2 Procedure

To maintain consistency in measurements, determination of the sphere's original mass and diameter before starting the experiment is required. This process is used to ensure that these factors remain constant in every test run. Using a radius of 0.05 m will be used to achieve requirements necessary in applying Stokes' Law to viscous drag. Additionally, an initially minimal amount of mass is to be used to reduce the amount of gravitational force acting upon the object. This adjustment is used to reduce the amount of time needed by the object to achieve terminal velocity to simplify taking measurements to determine fluid density's effect upon descent time.

The selected sphere is composed of Styrofoam with an approximate mass of 0.02 kg and calculated density of 38.2 kg/m³ ([33]). First, an instant observation of velocity is to be carried out to determine the effect of fluid density upon acceleration. From an observation

[37] Universidad Nacional Autónoma de México (UNAM). (n.d.). Caída libre. UNAM. http://www.objetos.unam.mx/fisica/caidaLibre/

over an observation time of 6 seconds, both spheres can be confirmed to have achieved terminal velocity over this time.

After this point in time, altitude during descent is configured to the highest permissible altitude of 300 meters. This adjustment to top reachable altitude is done to ensure every object reaches its terminal velocity before making its final descent. Temporal measurements received by this process shall be used to determine fluid density's effect upon an object in free fall to the ground.

6. Results and Findings

6.1 Data Table Extracted

Time (s)	Object's velocity (m/s)
0	0
2	19.62
4	39.24
6	58.86

Table 1- Velocity variation with time for fluid density of 0 kg/m^3

Time (s)	Object's velocity (m/s)
0	0
2	15.05
4	19.06
6	19.70

Table 2- Velocity variation with time for fluid density of 0.3 kg/m^3

Time (s)	Object’s velocity (m/s)
0	0
2	12.31
4	13.85
6	13.97

Table 3- Velocity variation with time for fluid density of 0.6 kg/m^3

Time (s)	Object’s velocity (m/s)
0	0
2	10.77
4	11.39
6	11.41

Table 4- Velocity variation with time for fluid density of 0.9 kg/m^3

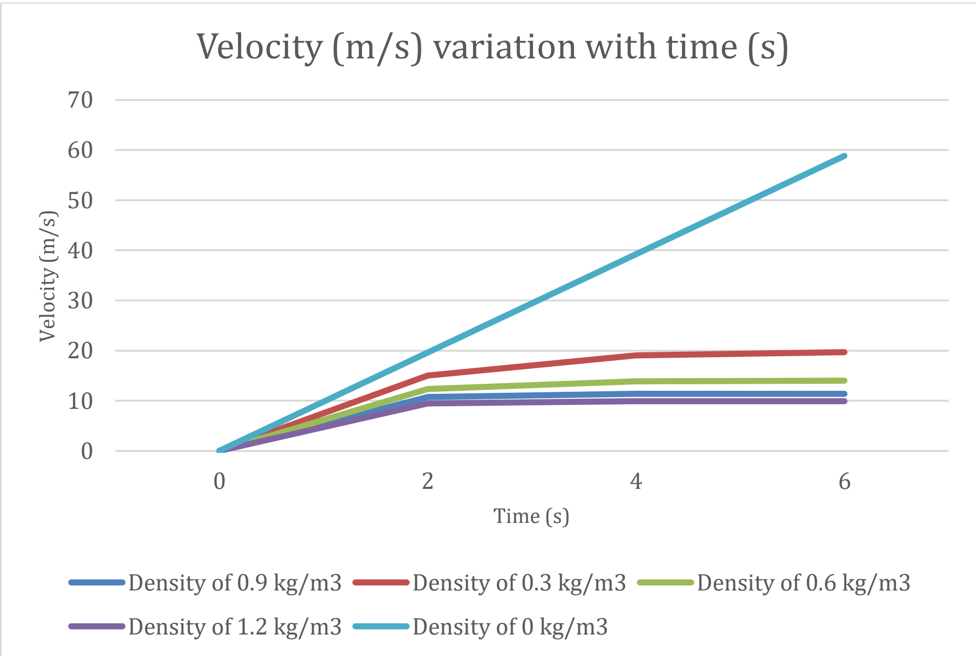
Time (s)	Object’s velocity (m/s)
0	0
2	9.49
4	9.88
6	9.89

Table 5- Velocity variation with time for fluid density of 1.2 kg/m^3

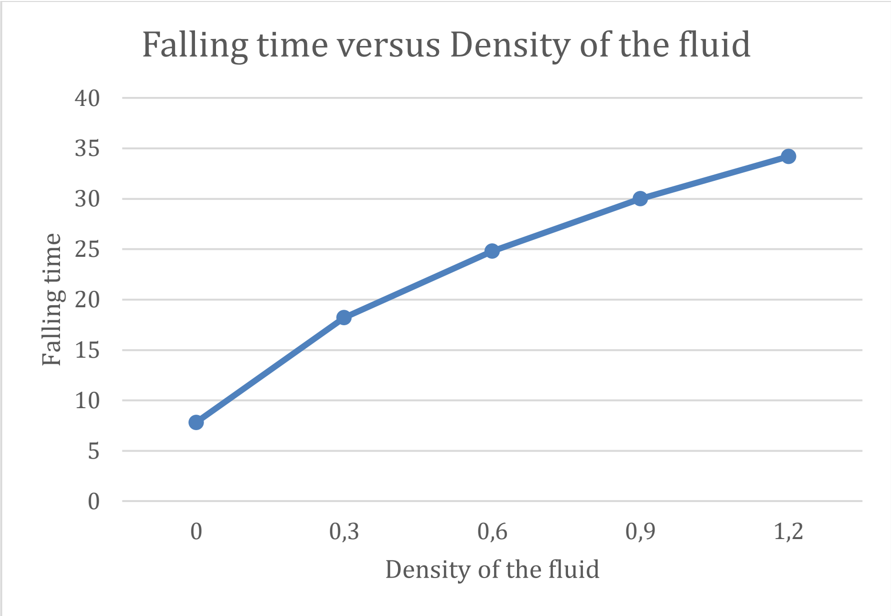
Density of the fluid (kg/m^3)	Falling time (s)
0	7.82
0.3	18.2
0.6	24.8
0.9	30
1.2	34.2

Table 6- Total falling time for each fluid's density value

6.2 Graphs Obtained from Data



Graph 1- Displaying velocity variation with time



Graph 2 – Displaying total falling time for each fluid density value

6.3 Data Analysis

The data collected and related graph forms present unmistakable proof that fluid density is related to an increased termination velocity in an object in free fall, leading to decreased duration in free fall. In every situation, excluding where fluid density was equal to zero, an object achieved its termination velocity. When fluid resistance was non-existent (0 kg/m^3), neither was present to oppose motion in an object in the form of an upthrust nor in an opposing direction in the form of drag. This meant only gravitational pull was in effect. This condition ensured continuous acceleration since opposing forces to change direction were non-existent. Across every series of tests carried out, the weight force was always equal to 0.1962 N while the drag force was variable in accordance with fluid density. Larger forces of drag decreased the resultant in direction motion, thus causing decreased acceleration and termination velocity. When given an equal dropping point of 300 m, this eventually led to an increased duration in free fall.

To better understand the influence of fluid density, we focus on small spherical objects that have reached terminal velocity. At this point, the forces acting on the object are balanced, leading to the equation:

$$mg = 6\pi\mu rv + \rho gV$$

where m is the object's mass, g is gravitational acceleration, μ is dynamic viscosity, r is the object's radius, v is terminal velocity, ρ is fluid density, and V is the volume of the sphere. This equilibrium in forces is shown in Figure 6.

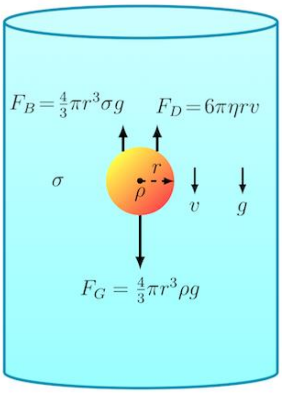


Figure 6 – Forces acting on a falling object[38]

A comprehensive review of diverse resources[39] justifies computation of the formula of terminal velocity by using the volume formula for a sphere:

$$\rho_{obj}\left(\frac{4}{3}\pi r^3 g\right) = 6\pi\mu r v_T + \rho_F\left(\frac{4}{3}\pi r^3 g\right)$$

[38] Concepts of Physics. (n.d.). Stokes' law and terminal velocity. Concepts of Physics. https://www.concepts-of-physics.com/mechanics/stokes-law-and-terminal-velocity.php
[39] Concepts of Physics. (n.d.). Stokes' law and terminal velocity. Concepts of Physics. https://www.concepts-of-physics.com/mechanics/stokes-law-and-terminal-velocity.php

By rearranging this equation, we obtain:

$$\rho_F = \rho_{obj} - \frac{9v_T\mu}{2r^2g}$$

or equivalently,

$$v_T = \frac{2r^2(\rho_{obj} - \rho_F)}{9\mu}$$

where ρ_{obj} is the object's density, ρ_F is the fluid density, and v_T is the terminal velocity.

This relationship implies that while fluid density is not in direct proportion to terminal velocity, dependency can be established where increased fluid density is related to decreased terminal velocity. This decline in terminal velocity implies that the forces acting upon the object during fall acquire equilibrium sooner, thus shortening the acceleration phase while prolonging overall fall time.

The results confirm that an increase in fluid density is related to an increase in drag forces, thus reducing the net force during motion. This results in an increased acceleration rate and an increased fall time. This is confirmed by the visual displays in the graph. Graph 1 illustrates that an increase in fluid density is related to decreased acceleration in the object, eventually leading to a decreased terminal velocity. Additionally, Graph 2 strengthens this by providing an increased fall time in fluids with greater fluid density.

Therefore, based upon an observation of empirical observation, theoretical expressions, and graphing, by reasoning logically it can be deduced that an increase in fluid density next to an object creates an extended time to descend.

7. Evaluation

Due to word count limitations in this work, various factors influencing the relationship between fall duration and fluid density have been excluded to keep things concise. However, the following limitations apply to this work:

- The simulation computer programs used timed to three decimal figures, thus introducing a systematic uncertainty that was probably affecting slightly the accuracy of measurements.
- Despite the dependency of both factors on temperature, these factors were hypothesized to remain constant to maintain independent status.
- The data was collected from a single simulation run. Comparing results with a different simulation tool would enhance reliability.
- The requirement to halt the simulation to register velocity at regular intervals led to random errors due to transient speed fluctuations. Using an automated computer program to monitor velocity continuously over time would have improved overall accuracy in measurements.

8. Conclusion

This research depicts that fluid density is an essential consideration in determining the time an object takes to fall. From the results, identical objects experience differences in acceleration in accordance with fluid density in which they travel. Though gravity acting in the direction of motion is constant irrespective of fluid density variation, resisting forces opposing motion change considerably with fluid density variation. As fluid density is increased, resisting forces get greater in magnitude, thus reducing the net force in motion direction to act upon an object, ultimately reducing acceleration. This results in an increased fall time to touch ground. The results support that increased fluid density is related to increased fall time in little spheres.

9. **Bibliography**

- Conover, E. (2020). *Galileo's famous gravity experiment holds up, even with individual atoms*. [Online] Science News, 28 Oct 2020. Available at: https://www.sciencenews.org/article/galileo-gravity-experiment-atoms-general-relativity-einstein
- Elert, G. (n.d.). *Aerodynamic Drag*. [Online] The Physics Hypertextbook. Available at: http://physics.info/drag/
- Physics LibreTexts. (n.d.). *Acceleration Due to Gravity*. [Online] Available at: https://phys.libretexts.org/Bookshelves/Physical_Science/Book%3A_Physical_Science_for_Educators/09%3A_Motion/9.3%3A_Motion_in_One-Dimension/9.3.8%3A_Acceleration_Due_to_Gravity
- OpenStax College Physics. (2012). *College Physics*. Houston, TX: OpenStax. Section 12.6: Motion of an Object in a Viscous Fluid. [Online] Available at: https://openstax.org/details/books/college-physics
- **NASA (2023).** *The Apollo 15 Hammer-Feather Drop.* NASA Science – Moon Exploration. [online] Available at: https://science.nasa.gov/resource/the-apollo-15-hammer-feather-drop/ (The Apollo 15 Hammer-Feather Drop - NASA Science)
- The Physics Classroom (n.d.). *Newton's Laws – Lesson 3: Free Fall and Air Resistance.* [online] Available at: https://www.physicsclassroom.com/class/newtlaws/Lesson-3/Free-Fall-and-Air-Resistance (The Physics Classroom Website) (The Physics Classroom Website)

- Force in Physics – Drag (2024). *"Drag (physics)"* (online article). [online] Available at: https://forceinphysics.com/drag-physics/ (Drag (physics) - Force in Physics)
- LibreTexts Physics (2021). *"Archimedes' Principle – Buoyant Force,"* in *University Physics Vol. 1*. [online] Available at: https://phys.libretexts.org/Bookshelves/University_Physics/Physics_(Boundless)/10:_Fluids/10.3:_Archimedes_Principle (10.3: Archimedes' Principle - Physics LibreTexts)
- Chemistry LibreTexts. (2021). 14.3: Laminar and turbulent flow. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Biological_Chemistry/Concepts_in_Biophysical_Chemistry_(Tokmakoff)/04%3A_Transport/14%3A_Hydrodynamics/14.03%3A_Laminar_and_Turbulent_Flow
- Concepts of Physics. (n.d.). Stokes law and terminal velocity: Concepts and problems. Concepts of Physics. https://concepts-of-physics.com/mechanics/stokes-law-and-terminal-velocity.php
- Conover, E. (2020). Galileo's famous gravity experiment holds up, even with individual atoms**.** Science News. https://www.sciencenews.org/article/galileo-gravity-experiment-atoms-general-relativity-einstein
- Lumen Learning. (n.d.). Motion of an object in a viscous fluid. Lumen Learning. https://courses.lumenlearning.com/atd-austincc-physics1/chapter/12-6-motion-of-an-object-in-a-viscous-fluid/
- Edgar. (2021). How to model free-falling bodies with fluid resistance. WeTheStudy. https://wethestudy.com/mathematics/how-to-model-free-falling-bodies-with-fluid-resistance/

- Fowler, M. (n.d.). Stokes' law. University of Virginia. https://galileo.phys.virginia.edu/classes/152.mf1i.spring02/Stokes_Law.htm
- NASA Glenn Research Center. (n.d.). Newton's laws of motion. NASA. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/
- Khan Academy. (2018). What is buoyant force? Khan Academy. https://www.khanacademy.org/science/physics/fluids/buoyant-force-and-archimedes-principle/a/buoyant-force-and-archimedes-principle-article
- P.E., C. Y. (2022). Why does flow become turbulent? EngineerExcel. https://engineerexcel.com/why-does-flow-become-turbulent/
- Princeton University. (2019). Drag of blunt bodies and streamlined bodies. Princeton University. https://www.princeton.edu/~asmits/Bicycle_web/blunt.html
- Saylor Academy. (n.d.). The behavior of real gases. Saylor Academy. https://saylordotorg.github.io/text_general-chemistry-principles-patterns-and-applications-v1.0/s14-08-the-behavior-of-real-gases.html
- Science Learning Hub. (2011). Causes of aerodynamic drag. Science Learning Hub. https://www.sciencelearn.org.nz/resources/1346-causes-of-aerodynamic-drag
- StudySmarter UK. (n.d.). Drag force: Definition, examples & formula. StudySmarter. https://www.studysmarter.co.uk/explanations/physics/dynamics/drag-force/
- Testbook. (n.d.). Which of the following cannot be changed by applying force? Testbook. https://testbook.com/question-answer/which-of-the-following-cannot-be-changed-by-applying--6019157998ccc2e8317599c5
- The Editors of Encyclopaedia Britannica. (2018). Density: Definition, units, & formula. Encyclopaedia Britannica. https://www.britannica.com/science/density

- The Efficient Engineer. (2020, May 12). Understanding laminar and turbulent flow [Video]. YouTube. https://www.youtube.com/watch?v=9A-uUG0WR0w
- The Kid Should See This. (2012). The Apollo 15 hammer and feather drop on the Moon (1971). The Kid Should See This. https://thekidshouldseethis.com/post/apollo-15-hammer-feather-drop-moon
- The Physics Classroom. (2019). Newton’s law of universal gravitation. The Physics Classroom. https://www.physicsclassroom.com/class/circles/Lesson-3/Newton-s-Law-of-Universal-Gravitation
- TuitionPhysics. (n.d.). What is the relationship between density and pressure? TuitionPhysics. https://tuitionphysics.com/oct-2017/what-is-the-relationship-between-density-and-pressure/
- Unacademy. (n.d.). Analysing the different types of Stokes’ law. Unacademy. https://unacademy.com/content/neet-ug/study-material/physics/analysing-the-different-types-of-stokes-law/
- Vedantu. (n.d.). Fluid. Vedantu. https://www.vedantu.com/physics/fluid
- Boldmethod. (n.d.). Density: Why it matters. Boldmethod. https://www.boldmethod.com/learn-to-fly/performance/density-altitude/
- Middle School Chemistry. (n.d.). Temperature and density | Chapter 3: Density. Middle School Chemistry. https://www.middleschoolchemistry.com/lessonplans/chapter3/lesson6
- UNAM. (n.d.). Free fall. Universidad Nacional Autónoma de México. http://www.objetos.unam.mx/fisica/caidaLibre/
- ScienceDirect. (n.d.). Reynolds number – An overview. ScienceDirect. https://www.sciencedirect.com/topics/engineering/reynolds-number

- Vedantu. (n.d.). What is terminal velocity? What are the factors on which terminal velocity depends? Vedantu. https://www.vedantu.com/question-answer/terminal-velocity-what-are-the-factors-on-which-class-12-physics-cbse-60b4befb9289d425a8c87820
- Universidad Nacional Autónoma de México (UNAM). (n.d.). Caída libre. UNAM. http://www.objetos.unam.mx/fisica/caidaLibre/
- Concepts of Physics. (n.d.). Stokes' law and terminal velocity. Concepts of Physics. https://www.concepts-of-physics.com/mechanics/stokes-law-and-terminal-velocity.php

10. Appendix

Appendix 1:

Where G is 6.67$*\ 10^{-11}$ N m/kg^2,M the mass of the Earth $6 * 10^{24}$ kg and r the radius of the Earth 6378000 m

$$F = \frac{GMm}{r^2} \text{ and } F = ma$$

$$ma = \frac{GMm}{r^2}$$

$$a = \frac{GM}{r^2}$$

$$a = \frac{6.67 * 10^{-11} * 6 * 10^{24}}{6378000^2} \cong 9.81 \text{m}/s^2$$

Appendix 2:

Volume of a sphere:

$$\frac{4}{3}\pi r^3$$

Where r, is the radius of the sphere (m)

$$\rho = \frac{m}{V}$$

$$\rho = 0.02 * (\frac{4}{3}\pi(0.05)^3)^{-1} \cong 38.2 \text{ kg}/m^3$$

Appendix 3:

$$F = ma$$

$$F = 9.81 * 0.02 = 0.1962\ N$$