International Baccalaureate Diploma Program

PHYSICS EXTENDED ESSAY

How does the change of environmental mediums (water, honey, dish soap) affect a free-falling object's terminal velocity?

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INTRODUCTION

I was interested in skydiving for a long time. I used to wonder how these people could not exceed a certain speed despite accelerating over time, and how they could land without anything to them despite their high speed. The terminal velocity and shots, which we also see in physics, increased my curiosity and I decided to do research on this subject.

Terminal velocity has fascinated scientists throughout the centuries and is still an active area of research today. In this article, I will explore the concept of terminal velocity, and the effect of environmental mediums on terminal velocity. In final, I will support my exploration with a real-life experiment to observe the change vividly.

What is terminal velocity?

"Terminal velocity is the maximum velocity of an object can reach while falling through a fluid, such as air or water. That happens when the gravitational force working on the object in downward direction equals the sum of upward forces (drag and buoyancy) preventing it's fall." [1] An object moving at terminal velocity means zero acceleration and constant speed as the net force on it is zero.

For example, the terminal velocity of an average 80 kg human body is about 66 meters per second (= 240 km/h = 216 ft/s = 148 mph). To reach terminal velocity, object needs enough falling time that means enough distance to fall. For example, a human body generally needs to fall about 450 meters (1,500 feet) of height before it reaches terminal velocity. Such a fall takes roughly 12 seconds.

Terminal Velocity Formula

The formula for the terminal velocity of a falling object (**V_t**) can be calculated from the body's mass **m**, the density of the fluid in question (**p**, in kg/m^3, e.g., 1.225 for air), the cross-sectional area projected by the object (**A**), and the gravitational (or equivalent) force **g** in m/s^2 according to the following equation:

$$V_t = \sqrt{\frac{2mg}{\rho A C_d}}$$ [2]

This equation works only for **objects falling through air** or in other cases where the buoyancy force is negligible due to the large difference between the density of the fluid and the falling object.

"Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (liquid or gas). It is not generated by a force field, in the sense of a gravitational field or an electromagnetic field, where one object can affect another object without being in physical contact." **[3]** Hardest thing to estimate in this process is drag coefficient. This value can be determined empirically, usually by the help of a wind tunnel. Some examples of drag coefficients are 1.0 for a cube or a skydiver falling flat on his belly, 0.5 for a sphere and 0.04 for an aerodynamic wing. A coefficient of drag of **0.294** should work relatively well for a human body falling headfirst whereas feet first it should be around 0.70. To make the formula well-working, the determined drag coefficient value mustn't change a lot during the fall. While working with speeds such winds under 30 m/s for airflow near and faster than the speed of sound, we must be careful while applying drag coefficients calculated. Because at such speeds the occurrence of shock waves on the object causes a large increase in the drag coefficient so either a different coefficient should be used, or a coefficient which compensates for compressibility effects.

The terminal velocity equation shows that an object with a large cross-sectional area or high drag coefficient would fall more slowly than an equivalent object with a smaller cross-sectional area or lower drag coefficient. If a skydiver spreads their hands in the area, they would fall slower than if they curl into a ball or drop head-first or feet-first. It also says that all else being equal, a lighter object has a lower terminal velocity since it takes less time for the force of gravity to be balanced by the air resistance / drag force. They are the reason parachutes work: they vastly increase the cross-sectional area while their form is such that it significantly increases the coefficient of drag.

Velocity with Drag (Sinking Object)

For the description of an object sinking from a rest position, both the buoyant force and viscous resistance must be included.

$F_b = mg\frac{\rho'}{\rho}$ $\quad$ $F_{drag} = -6\Pi a\eta v$ **[4]** $\quad$ $F_{net} = mg' - 6\Pi a\eta v$

For an object that is acted upon by its weight, mg, and subject to a drag force proportional to its velocity -bv, the general form for the velocity is given by the expression below. For an object in a fluid, an effective force mg' to account for the buoyancy of the fluid must be used. For viscous drag, the drag coefficient b may be expressed in terms of the viscosity of the fluid. This velocity expression may then be integrated to obtain an expression for the distance.

$$v = v_0 e^{-t/\tau} + v_t\left[1 - e^{-t/\tau}\right]$$ **[5]**

$v_0 e^{-t/\tau}$

The effect of the initial velocity fades with time with a decay rate determined by the characteristic time. The more drag, the faster the initial velocity becomes insignificant in determining the motion.

τ

Characteristic time (time constant). $\tau = \frac{m}{b} = \frac{m}{6\Pi a\eta}$

$v_t\left[1 - e^{-t/\tau}\right]$

With time, the velocity approaches the terminal velocity. The greater the drag, the smaller the terminal velocity. But with greater drag, the characteristic time is shorter, so the velocity approaches the terminal velocity faster.

v_t

Terminal velocity. $v_t = \frac{mg'}{6\Pi a\eta}$

For an object that is acted upon by its weight, mg, and subject to a drag force proportional to its velocity -bv, the general form for the distance traveled is given by the expression below. For an object in a fluid, you must use an effective force mg' to account for the buoyancy of the fluid. For viscous drag, the drag coefficient b may be expressed in terms of the viscosity of the fluid. You can take the derivative of this distance expression to obtain an expression for the velocity.

$$y = v_t t + v_0 \tau\left[1 - e^{-t/\tau}\right] + v_t \tau\left[e^{-t/\tau} - 1\right] \text{ [6]}$$

$v_t t$

For very long times, the distance approaches that of constant velocity at the terminal velocity.

$v_0 \tau\left[1 - e^{-t/\tau}\right]$

The initial velocity would provide a penetration depth even in the absence of a driving force like gravity. That penetration distance is $v_0 \tau$.

$v_t \tau\left[e^{-t/\tau} - 1\right]$

This term corrects for the fact that it takes some time for the velocity to approach the terminal velocity, and therefore the first term $v_t t$ overstates the distance traveled. If $v_0 > v$ then the second term is larger and provides a positive correlation to $v_t t$.

A sinking (falling) object will approach terminal velocity when the net force approaches zero.

$$v_{terminal} = \frac{mg'}{b} = v_t$$

For motion with initial velocity v_0, the expression for velocity becomes

$$v = v_0 e^{-bt/m} + \frac{mg'}{b}\left[1 - e^{-bt/m}\right] \text{ [7]}$$

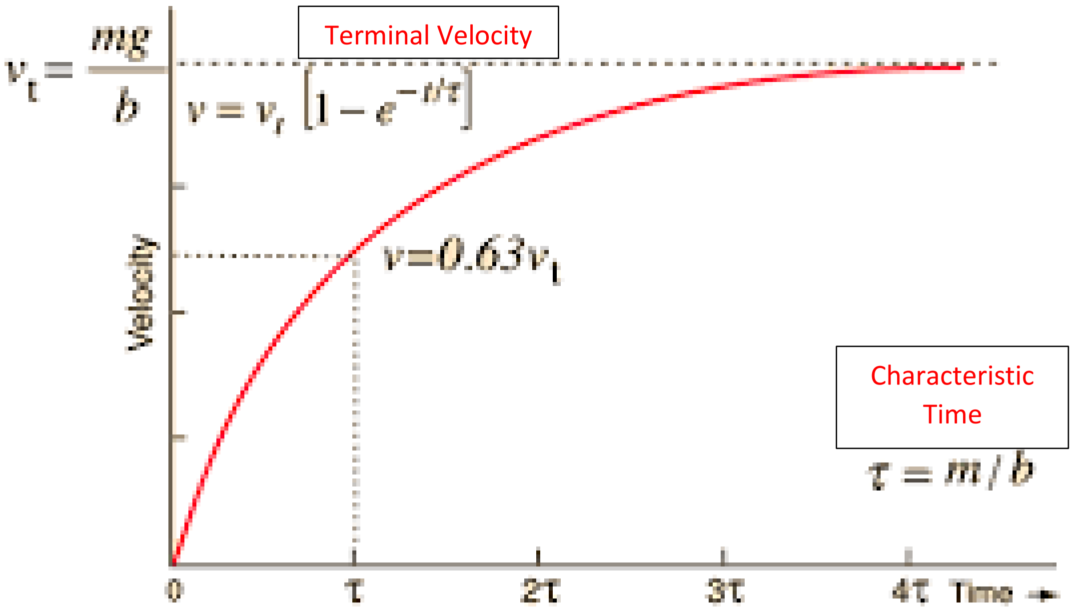
and expressed in terms of the terminal velocity v_t and the characteristic time τ = m/b, it takes the form

$$v = v_0 e^{-t/\tau} + v_t\left[1 - e^{-t/\tau}\right] \text{ [8]}$$

The distance travelled in time t is

$$y = v_t t + v_0 \tau\left[1 - e^{-t/\tau}\right] + v_t \tau\left[e^{-t/\tau} - 1\right] \text{ [9]}$$

Velocity Graph, Linear Drag



graph 1: Velocity Graph – Linear Drag (Resource: http://hyperphysics.phy-astr.gsu.edu/hbase/lindrg2.html#c3)

This behavior of velocity as a function of time would be expected for an object released from rest in a viscous medium where the resistance was proportional to velocity. The g value would be adjusted if there was significant buoyancy, and usually is then written g'.

<u>Research Question:</u>

How does the change of environmental mediums (water, honey, dish soap) affect a free-falling object's terminal velocity?

In this study, I will calculate the terminal velocity with my own experiment and the data I obtained, without using the formula I mentioned above. I will also prefer environmental mediums that have higher density level than air.

The reason is my hypothesis is **if the density of the medium increases terminal velocity and the required distance and time decreases**. For example: the density of water is higher than air, so that the object will reach the terminal velocity in a shorter time and at a shorter distance.

However, because of I change the drag coefficient by changing the medium, I will have to calculate a new friction coefficient. According to my assumptions, this phase will be one of the most challenging steps in my work.

<u>Hypothesis:</u>

If the density of the medium increases terminal velocity and the required distance and time decreases. Because the more increase of the density level equals the closer value to the object's density so object's sinking speed will slow down if the experimental medium's density level increases.

PLANNING

VARIABLES	
Dependent variable	Terminal velocity
Independent variable	Different environmental mediums that have different density levels (water, honey, dish soap)
Controlled Variable	Cross-section area of the object, weight of the object, initial speed of the object, temperature of the mediums.
Uncontrolled Variable	Oxygen and other particules in mediums

Table 1: Table of Variables

Controlled Variable	Reason	Measures taken
Cross-section area of the object	Increasing the cross-sectional area will increase the drag in the opposite direction to the motion of the object and decreasing it will decrease the drag. My goal is to keep the drag constant when the environment doesn't change.	Same object is used for all the mediums and all the trials.
Weight of the object	Increasing the weight of the object means increasing the terminal velocity and decreasing it will decrease. My goal is to see the change in terminal speed only from the change of the mediums.	The weight of the neodymium ball was measured and calculated, and the same ball was used in all experiments.
Initial velocity of the object	If an object has a higher initial velocity, it will experience a greater drag force due to the higher speed, which can cause it to reach its terminal velocity more quickly.	The object was released at the same height with an initial velocity of 0 by using a spoon in each trial.
Temperature of mediums	It can indirectly affect the initial velocity of an object in certain situations. If an object is launched from a spring or compressed gas, the temperature of the gas or spring can affect the force applied to the object and thus its initial velocity. This is because the pressure and elasticity of the gas or spring can be affected by temperature. Additionally, in the case of gases, the temperature can affect the speed of the gas molecules, which in turn can affect the drag force experienced by an object moving through the gas. This can affect the initial velocity of the object as well.	Before each experiment, the temperature of the environment was measured with a thermometer, and it was ensured that it did not change. Since the temperature can change over time, the experiments were carried out without interruption, in a short time and in the same environment.

Table 2: Table of Controlled Variables

Materials:

Material	**Properties (± uncertainty)**	**Quantity**
Graduated Cylinder	36 ± **0.05 cm** height, 2.5 ± **0.05 cm** radius, 707 ± $\%\mathbf{4.14}\ \boldsymbol{cm^3}$ volume (± **5ml TD 20℃°** $\boldsymbol{in\ calculations - company\ gave}$**)**	1
Medium 1: Dish Soap	1.100 ± **0.5** g/ $\boldsymbol{cm^3}$density	0.4 Liter
Medium 2: Honey	1.400 ± 0.5 g/ $\boldsymbol{cm^3}$density	0.4 Liter
Medium 3: Water	1 g/ $\boldsymbol{cm^3}$ density	0.4 Liter
neodymium magnet ball	1.1 ± **0.01g**	1
Professional Camera	24.2 MP	1
Thermometer	**± 0.5℃ (company gave)**	1
Chronometer	**± 0.01 second**	1
Precision Balance	**± 0.005g (company gave)**	1
Ruler (not digital)	**± 0.05 cm (half of the smallest digit)**	1

Table 3: Table of Materials

Calculation of Uncertainties:

Since the ruler is not a digital measuring instrument, half of the last digit is the uncertainty.

$$\frac{\mathbf{0.1}}{\mathbf{2}} = \mathbf{0.05}\ \boldsymbol{cm}$$

To calculate uncertainty of the volume, it was necessary to first find their percentiles and then add them all according to their exponents.

$\frac{\mathbf{0.05}}{\mathbf{36}} \times \mathbf{100} = \mathbf{0.14}$ **Percentage Uncertainty of Height**

$\frac{\mathbf{0.05}}{\mathbf{2.5}} \times \mathbf{100} = \mathbf{2}$ **Percentage Uncertainty of Radius**

Formula of the volume for a cylinder is $\boldsymbol{Radius^2} \times\ \boldsymbol{\pi}\ \times \boldsymbol{Height}$**. So, the uncertainty for volume is 0.14 + 2 + 2 = %4.14** $\boldsymbol{cm^3}$

Calculation of the Mass of the Neodymium Magnet Ball:

Since the precision balance is a digital measuring instrument, last digit is the uncertainty which is 0.01g. Since the weight of a magnet is too small to scale, I reached a value by measuring them all together.

I have 162 neodymium magnet balls. I measured 180 ±0.005 grams. So, 1.1 ±0.005g is the mass of the 1 neodymium magnet ball.

Procedure:

1. First, I went over the marked areas with my own pen for every 10 ml in the graduated cylinder. I did this because the lines were more pronounced when taking images from the camera. I measured distance between each mark, and I found 0.5 cm.
2. I poured 400 ml of water into the container I marked.
3. I prepared my camera and fixed it via tripod.
4. I poured 400 ml of water into the graduated cylinder.
5. I started recording and grabbed a neodymium ball in one hand and left the ball unmoving above the water level.
6. I carefully recorded the drop of the ball.
7 When the ball touched the bottom of the container, I took the ball out of the container again with the help of other magnets.
8. I applied the same process in honey and liquid soap, five times in each medium.
9. When all trials finished, I connected my camera to my computer.
10. Used my camera’s program to record the full timeline of the video trials for the marked spots.

Justification and Risk Assessment:

1.2L of material was used in the experiment as 0.4L Water, 0.4L Honey, 0.4L Liquid soap, and these materials were poured back into their containers for reuse after the experiment so as not to waste. The reason why I chose these materials is that I can get different results because they are both easy to find and have different densities. In addition, absolutely no cutting or piercing tools were used in the experiment. The dish soap I used was kept out of sight because it was irritating when it came into contact with sensitive organs such as the eyes and the skin, and gloves were used during the experiment.

Raw Data

Position vs. Time Raw Data for Honey

Time (in second) ± 0.001s					
1. Trial	**2. Trial**	3. Trial	4. Trial	5. Trial	Position (in meter) ± 0.0005 m
0.000	0.000	0.000	0.000	0.000	0.200
3.165	3.170	3.160	3.168	3.162	0.195
6.348	6.353	6.343	6.351	6.345	0.190
9.481	9.486	9.476	9.484	9.478	0.185
12.762	12.767	12.757	12.765	12.759	0.180
15.772	15.777	15.767	15.775	15.769	0.175
18.886	18.891	18.881	18.889	18.883	0.170
22.658	22.663	22.653	22.661	22.655	0.165
25.446	25.451	25.441	25.449	25.443	0.160
28.486	28.481	28.471	28.479	28.473	0.155
31.658	31.663	31.653	31.661	31.655	0.150
34.881	34.886	34.876	34.884	34.878	0.145
38.022	38.027	38.017	38.025	38.019	0.140
41.699	41.704	41.694	41.702	41.696	0.135
44.754	44.759	44.749	44.757	44.751	0.130
47.883	47.888	47.878	47.886	47.880	0.125
50.561	50.566	50.556	50.564	50.558	0.120
53.763	54.758	54.748	54.756	54.750	0.115
56.341	56.346	56.336	56.344	56.338	0.110
59.945	59.950	59.940	59.948	59.942	0.105
63.211	63.216	63.206	63.214	63.208	0.100
66.473	66.478	66.468	66.476	66.470	0.095
69.851	69.856	69.846	69.854	69.848	0.090
72.767	72.772	72.762	72.770	72.764	0.085
75.658	75.663	75.653	75.661	75.655	0.080
78.996	79.001	78.991	78.999	78.993	0.075
82.213	82.218	82.208	82.216	82.210	0.070
85.322	85.327	85.317	85.325	85.319	0.065
88.641	88.646	88.646	88.644	88.648	0.060
91.622	91.627	91.617	91.625	91.619	0.055
94.338	94.343	94.333	94.341	94.335	0.050
98.115	98.120	98.110	98.118	98.112	0.045
101.712	101.717	101.707	101.715	101.709	0.040
104.645	104.650	104.640	104.648	104.642	0.035
107.229	107.234	107.224	107.232	107.226	0.030
110.484	110.489	110.479	110.487	110.481	0.025
113.281	113.286	113.276	113.284	113.278	0.020
117.141	117.146	117.136	117.144	117.138	0.015
120.648	120.653	120.643	120.651	120.645	0.010
123.428	123.433	123.423	123.431	123.425	0.005
126.331	126.336	126.326	126.334	126.328	0.000

Table 4: Position vs. Time Raw Data for Honey

Position vs. Time Raw Data for Water

Time (in second) ± 0.001s					
1. Trial	**2. Trial**	3. Trial	4. Trial	5. Trial	Position (in meter) ± 0.0005 m
0.000	0.000	0.000	0.000	0.000	0.200
0.082	0.085	0.081	0.080	0.082	0.195
0.112	0.115	0.111	0.110	0.112	0.190
0.137	0.140	0.136	0.135	0.137	0.185
0.158	0.161	0.157	0.156	0.158	0.180
0.175	0.178	0.174	0.173	0.175	0.175
0.194	0.197	0.193	0.192	0.194	0.170
0.208	0.211	0.107	0.106	0.208	0.165
0.224	0.227	0.223	0.222	0.224	0.160
0.234	0.237	0.233	0.232	0.234	0.155
0.251	0.254	0.250	0.249	0.251	0.150
0.261	0.264	0.260	0.259	0.261	0.145
0.273	0.276	0.272	0.271	0.273	0.140
0.284	0.287	0.283	0.282	0.284	0.135
0.296	0.299	0.295	0.294	0.296	0.130
0.304	0.307	0.303	0.302	0.304	0.125
0.315	0.318	0.314	0.313	0.315	0.120
0.326	0.329	0.325	0.324	0.326	0.115
0.334	0.337	0.333	0.332	0.334	0.110
0.343	0.346	0.342	0.341	0.343	0.105
0.352	0.355	0.351	0.350	0.352	0.100
0.361	0.364	0.360	0.359	0.361	0.095
0.369	0.369	0.368	0.367	0.369	0.090
0.379	0.382	0.378	0.377	0.379	0.085
0.387	0.390	0.386	0.385	0.387	0.080
0.395	0.398	0.394	0.393	0.395	0.075
0.401	0.404	0.400	0.399	0.401	0.070
0.410	0.413	0.409	0.408	0.410	0.065
0.417	0.420	0.416	0.415	0.417	0.060
0.425	0.428	0.424	0.423	0.425	0.055
0.433	0.436	0.432	0.431	0.433	0.050
0.439	0.442	0.438	0.437	0.439	0.045
0.447	0.450	0.446	0.443	0.447	0.040
0.454	0.457	0.453	0.452	0.454	0.035
0.461	0.464	0.460	0.459	0.461	0.030
0.466	0.469	0.465	0.464	0.466	0.025
0.473	0.476	0.472	0.471	0.473	0.020
0.481	0.484	0.480	0.479	0.481	0.015
0.487	0.490	0.486	0.485	0.487	0.010
0.493	0.494	0.492	0.491	0.493	0.005
0.501	0.504	0.500	0.499	0.501	0.000

Table 5: Position vs. Time Raw Data for Water

Position vs. Time Raw Data for Dish Soap

Time (in second) ± 0.001s					
1. Trial	**2. Trial**	3. Trial	4. Trial	5. Trial	Position (in meter) ± 0.0005 m
0.000	0.000	0.000	0.000	0.000	0.200
0.297	0.301	0.298	0.295	0.294	0.195
0.594	0.598	0.595	0.592	0.591	0.190
0.877	0.881	0.878	0.875	0.874	0.185
1.202	1.206	1.203	1.200	1.199	0.180
1.499	1.503	1.500	1.497	1.496	0.175
1.740	1.744	1.741	1.738	1.737	0.170
2.022	2.026	2.023	2.020	2.019	0.165
2.263	2.267	2.264	2.261	2.260	0.160
2.588	2.592	2.589	2.586	2.585	0.155
2.814	2.818	2.815	2.812	2.811	0.150
3.083	3.087	3.084	3.081	3.080	0.145
3.366	3.370	3.366	3.363	3.362	0.140
3.635	3.639	3.636	3.636	3.635	0.135
3.903	3.807	3.904	3.901	3.900	0.130
4.229	4.233	4.230	4.227	4.226	0.125
4.469	4.473	4.470	4.467	4.466	0.120
4.724	4.728	4.725	4.722	4.721	0.115
4.993	4.997	4.994	4.991	4.990	0.110
5.275	5.279	5.276	5.273	5.272	0.105
5.558	5.562	5.559	5.556	5.555	0.100
5.855	5.859	4.856	4.853	4.852	0.095
6.124	6.128	6.125	6.122	6.121	0.090
6.379	6.383	6.380	6.377	6.376	0.085
6.647	6.651	6.648	6.645	6.644	0.080
6.902	6.906	6.903	6.900	6.899	0.075
7.185	7.189	7.186	7.183	7.182	0.070
7.439	7.443	7.440	7.437	7.436	0.065
7.736	7.740	7.737	7.734	7.733	0.060
8.005	8.009	8.006	8.003	8.002	0.055
8.274	8.278	8.275	8.272	8.271	0.050
8.571	8.575	8.572	8.569	8.568	0.045
8.851	8.855	8.852	8.849	8.848	0.040
9.108	8.112	9.109	9.106	9.105	0.035
9.391	9.395	9.392	9.389	9.388	0.030
9.674	9.678	9.675	9.672	9.671	0.025
9.957	9.961	9.958	9.955	9.954	0.020
10.240	10.244	10.241	10.238	10.237	0.015
10.523	10.527	10.524	10.521	10.520	0.010
10.806	10.810	10.807	10.804	10.803	0.005
11.089	11.093	11.090	10.087	10.086	0.000

Table 6: Position vs. Time Raw Data for Dish Soap

Results and Analysis

Calculating Mean Data

I used the arithmetic mean method to find the mean values of the five trials I did for each medium. To calculate the arithmetic mean, all data is summed and divided by the number of data. For example:

3.165	3.170	3.160	3.168	3.162

This row is a set of data from the medium honey for the position 0.195 meter.

1. All the values are summed.

   3.165 + 3.170 + 3.160 + 3.168 + 3.162 = 15.825s

2. The result is divided by the number of the data. I have 5 trials so the number that I divided the result is 5.

   $\frac{15.825}{5} = 3.165\text{s}$

Calculating Uncertainty of the Mean Data

To calculate uncertainty of the mean data, I used $\frac{\max - \min(range)}{2}$ formula.

3.165	3.170	3.160	3.168	3.162

Maximum value: 3.170 Minimum value: 3.160 Range: 3.170 - 3.160 = 0.010

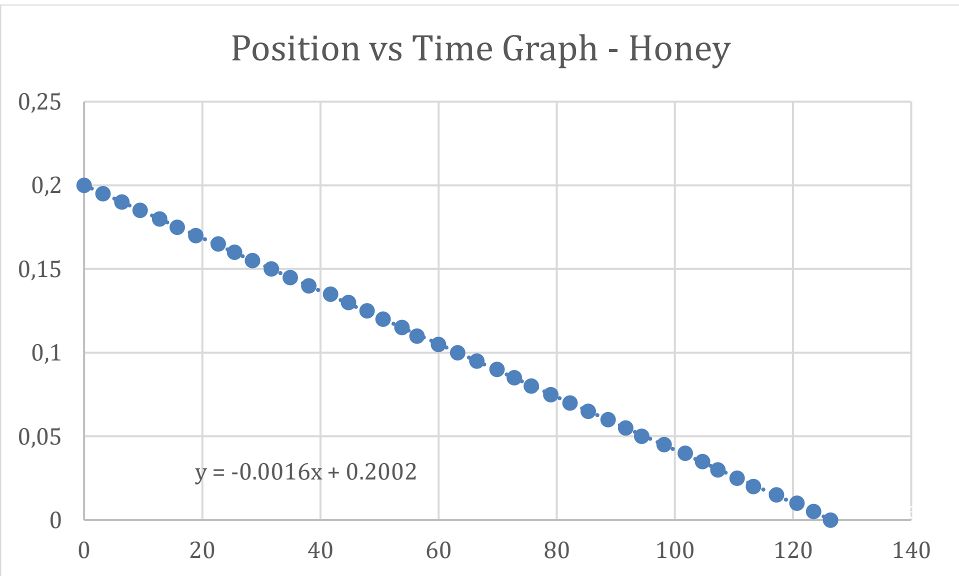
Uncertainty of the mean data: $\frac{0.010}{2}$ = 0.005s

Mean Value of Honey Medium Trials

Second ± 0.005s	Meter ± 0.005 m
0.000	0.200
3.165	0.195
6.348	0.190
9.481	0.185
12.762	0.180
15.772	0.175
18.886	0.170
22.658	0.165
25.446	0.160
28.486	0.155
31.658	0.150
34.881	0.145
38.022	0.140
41.699	0.135
44.754	0.130
47.883	0.125
50.561	0.120
53.763	0.115
56.341	0.110
59.945	0.105
3.211	0.100
66.473	0.095
69.851	0.090
72.767	0.085
75.658	0.080
78.996	0.075
82.213	0.070
85.322	0.065
88.641	0.060
91.622	0.055
94.338	0.050
98.155	0.045
101.712	0.040
104.645	0.035
107.229	0.030
110.484	0.025
113.281	0.020
117.141	0.015
120.648	0.010
123.428	0.005
126.331	0.000

Table 7: Mean Value of Honey Medium Trials

Mean Data Table for Honey



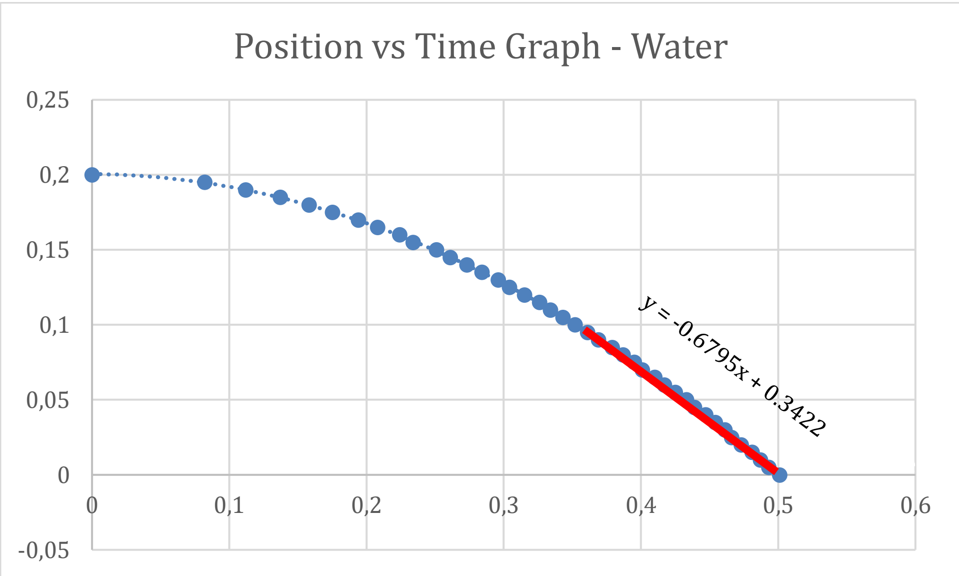
Graph 2: Position vs Time Graph – Honey (created with excel)

Mean Value of Water Medium Trials

Second ± 0.002s	Meter ± 0.005 m
0.000	0.200
0.082	0.195
0.112	0.190
0.137	0.185
0.158	0.180
0.175	0.175
0.194	0.170
0.208	0.165
0.224	0.160
0.234	0.155
0.251	0.150
0.261	0.145
0.273	0.140
0.284	0.135
0.296	0.130
0.304	0.125
0.315	0.120
0.326	0.115
0.334	0.110
0.343	0.105
0.352	0.100
0.361	0.095
0.369	0.090
0.379	0.085
0.387	0.080
0.395	0.075
0.401	0.070
0.410	0.065
0.417	0.060
0.425	0.055
0.433	0.050
0.439	0.045
0.447	0.040
0.454	0.035
0.461	0.030
0.466	0.025
0.473	0.020
0.481	0.015
0.487	0.010
0.493	0.005
0.501	0.000

Table 8: Mean Value of Water Medium Trials

Mean Data Table for Water



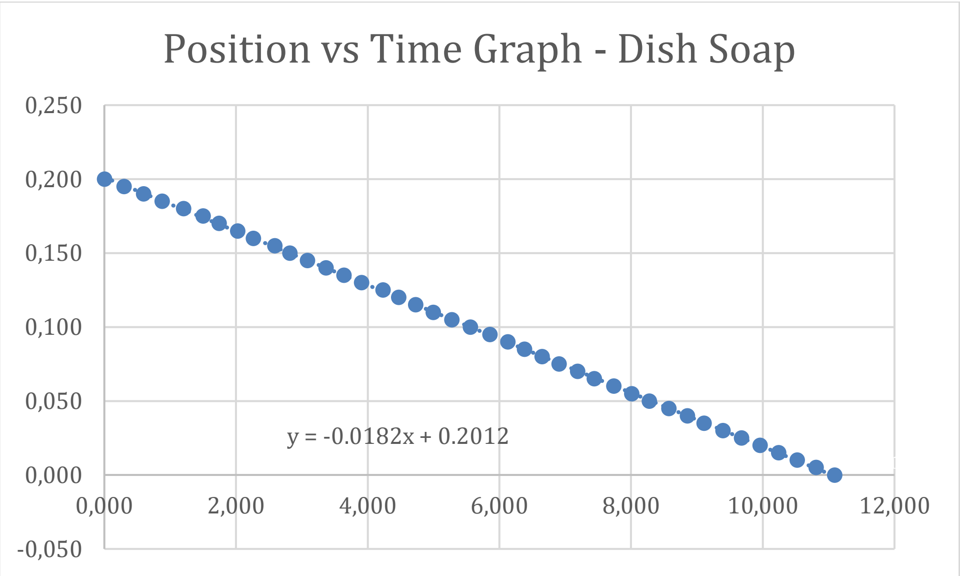
Graph 3: Position vs Time Graph – Water (created with excel)

Mean Value of Dish Soap Medium Trials

Second ± 0.0035s	Meter ± 0.005 m		
0.000	0.200	6.379	0.085
0.297	0.195	6.647	0.080
0.594	0.190	6.902	0.075
0.877	0.185	7.185	0.070
1.202	0.180	7.439	0.065
1.499	0.175	7.736	0.060
1.740	0.170	8.005	0.055
2.022	0.165	8.274	0.050
2.263	0.160	8.571	0.045
2.588	0.155	8.851	0.040
2.814	0.150	9.108	0.035
3.083	0.145	9.391	0.030
3.366	0.140	9.674	0.025
3.635	0.135	9.957	0.020
3.903	0.130	10.240	0.015
4.229	0.125	10.523	0.010
4.469	0.120	10.806	0.005
4.724	0.115	11.089	0.000
4.993	0.110		
5.275	0.105		
5.558	0.100		
5.855	0.095		
6.124	0.090		

Table 9: Mean Value of Dish Soap Medium

Mean Data Table for Dish Soap



Graph 4: Position vs Time Graph – Dish Soap (created with excel)

The graphs above were created in excel program. To find the terminal velocity in these graphs, it is necessary to find the interval in which the neodymium ball moves at the terminal velocity. As I mentioned on page 5, in velocity graph (linear drag), while the object is moving, it approaches the terminal velocity over time, that is, as the acceleration of the object approaches 0, its velocity increases towards a constant value during this time. Because as the speed of the object increases, the drag that adversely affects the motion of the object also increases. This event is observed as a straight horizontal line on the velocity-time graph because there is no change in the velocity of the object at the terminal velocity. In the position-time graphs on pages 13, 14 and 15, this event is observed as a linear line. But since the object continues to move, this line is not horizontal. As can be seen in the graphs, a linear progression is seen in honey and dish soap. In fact, graphs of honey and liquid soap also have a curve at first, but since this is so small, lines can be observed as linear. The reason of this is, because of they are much more viscous that water, the drag force acting on the object is much more powerful. So, in honey and dish soap the object reached its terminal velocity in a shorter time interval. When the graph of the water is examined, it is understood that it is slightly different from others. First, a curvilinear behavior is observed in the graph, and then it turns into a linear progression like the others. I found the equation of these lines by drawing the best fit lines of the graphs I obtained through the Excel program. For the equation of water, I only used the part that seems linear. According to these procedures

Equation of Honey: y = -0.0016x + 0.2002

Equation of Water: y = -0.6795x + 0.3422

Equation of Dish Soap: y = -0.0182x + 0.2012

With the help of these equations, the terminal velocities of the neodymium ball can be found separately for each medium. For this step $\frac{\Delta position}{\Delta time} = velocity$ [10] formula could be used. Since the x axis of the graph shows position and the y axis shows time, if the slopes of these graphs are calculated, terminal velocity can be found for each environment. Equations of the graphs were found as they are linear. For this reason $y = mx + c$ [11] formula can be used to calculate slope of the graph. According to this formula the coefficient of x (m) gives slope.

Terminal Velocity for Honey Medium: -0.0016 meter per second

Terminal Velocity for Water Medium: -0.6795 meter per second

Terminal Velocity of Dish Soap Medium: -0.0182 meter per second

The reason these values are negative is because the position of the neodymium ball is determined by its height from the bottom of the container. As time passes, the neodymium ball falls down, the height decreases, so their position also decreases. In order to make a real comparison, these values need to be examined in terms of magnitude, that is, a scalar approach should be taken.

Maximum Speed in Honey: 0.0016 meter per second

Maximum Speed in Water: 0.6795 meter per second

Maximum Speed in Dish Soap: 0.0182 meter per second

$V_{terminal}$: Water > Dish Soap > Honey

Time required to reach $V_{terminal}$: Water > Dish Soap > Honey

Accordingly, the following conclusions can be drawn. Terminal velocity is directly proportional to the time required to reach this velocity. In honey and dishwashing liquid, it reached terminal velocity in a much shorter time than water, but the terminal velocity of water was the fastest. The reason for this can be deduced from stokes law.

$F_d = 6\pi\mu Rv$ [12]

- F_d is the frictional force – known as **Stokes' drag** – acting on the interface between the fluid and the particle
- μ is the dynamic viscosity (some authors use the symbol η)
- R is the radius of the spherical object
- v is the flow velocity relative to the object.

Stokes' law makes the following assumptions for the behavior of a particle in a fluid:

- Laminar flow
- Spherical particles
- Homogeneous (uniform in composition) material
- Smooth surfaces
- Particles do not interfere with each other.

According to the stokes law:

$\mu \propto F_d \rightarrow$ As the viscosity increases, drag force increases.

Viscosity relationship between mediums:

Honey [13] (100 poise) > Dish Soap [14] (0.68 poise) > Water [15] (0.01 poise)

As a result of this investigation:

Neodymium ball reached terminal velocity in honey in a very short time to be observed compared to the others. The main reason for this is that the viscosity of honey is very high. This increases drag. For this reason, the resistance force opposite to the motion in honey is much higher than the others. In water, it reached terminal velocity in the longest time. Because the viscosity of the water is much lower than the others, the drag opposite to the movement of the neodymium ball in the water is much lower and showed its effect in a much longer time than the others. Density and viscosity of detergent were between the values of honey and water. Therefore, neodymium ball reached terminal velocity longer than honey and shorter than water.

EVALUATION

Strengths	**Reason it's believed to be a strength**
Professional Camera	It increased the accuracy of my results by providing access to quality images. Also played an important role in proving my hypothesis correct.
Video Program	By using a video program, I had the opportunity to watch the recordings again and again by zooming in slow motion. In this way, even though I obtained data with my eyes, I reduced the margin of error considerably.
Neodymium Magnet Ball	I never had to drain the liquid to get the ball for my graduated cylinder repeatedly in trials. At the end of each experiment, I brought another magnet to the bottom of the container and dragged it from the bottom of the container to the surface, so I took the neodymium ball inside for the next experiment. In this way, I did not waste material and saved time.

Table 10: Table of Strengths

Limitations	**Effect of Limitation on the result of investigation**	**Suggested improvement and why it will improve the investigation.**
Lack of an instrument that measures instantaneous speed.	I entered the data with respect to my own eyes. Therefore, a margin of error arose from human reflexes.	If I could find an instrument like an instantaneous speedometer, there would be no margin for error from human reflexes.

Table 11: Table of Limitations

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