

FLUID DYNAMICS – AN INVESTIGATION OF ANTIBUBBLES AND THEIR PROPERTIES

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I. **Abstract –**

For our extended lab project, our team chose to investigate the physical properties of antibubbles. By creating a double-filtered, pump-driven formation system we could easily collect reliable data. We analyzed our results through Video Analysis © and found that antibubbles quickly reach a terminal velocity (much like a reverse parachute scenario). We also completed a Newtonian force analysis and calculated the approximate gravitational (-0.00238 N), buoyancy ($4.1 \times 10^{-5}\text{ N}$) and drag (0.00243 N) forces.

II. **Theory –**

For years scientists have studied the properties of bubbles, strange formations of a liquid layer around air. Bubbles form in a variety of substances such as liquids and gases. The properties of these tiny, mysterious spheres have been studied for some time. However, only in recent years have scientists begun to discover another mysterious spherical formation, the anti-bubble. An anti-bubble is the opposite of a conventional bubble; it is a spherical formation of air around a liquid. Usually occurring in soapy solutions, anti-bubbles form beneath the surface of a liquid and have noticeably different properties than their counterpart. The properties that distinguish anti-bubbles and bubbles are relatively unknown in the science world, for people have only recently begun to study these mysterious formations. Our experiment involved the study and analysis of the formation of anti-bubbles, using a variety of dish soap (Dawn © or 29% Sodium Lauryl Sulfate, $\text{C}_{12}\text{H}_{25}\text{NaO}_4\text{S}$) and de-ionized water combinations.

When bubbles form, they ascend rapidly to the top of the liquid and pop almost instantly. This is a result of the density of air being much less than that of the liquid. Less dense objects rise in denser objects. In anti-bubbles, the proportion of liquid to air is reversed. There is only a very thin layer of air encompassing a large amount of the liquid within the liquid. Since the liquid solution inside the anti-bubble is the same as that in the

tank, the anti-bubble should float slowly towards the middle of the tank and remain there until it “pops.” However, since there is still a thin outer layer of air, the sphere will still rise, but at a slower rate. The slow rate of ascension, as well as the surprisingly long times of stability, allow for extensive research potential. Through innovative techniques, we were able to film, extract, and analyze data. By tracking individual frames, we could then calculate the radius and the y-component velocity.

III. Equipment –

- 1 5 Gallon Bucket
- 1 Ring Stand
- 1 10 ft stand vinyl tubing ($\frac{3}{8}$ ” ID)
- 1 Flat glass dish (~4 quarts)
- 1 29% Sodium Lauryl Sulfide ($C_{12}H_{25}NaO_4S$)
- 1 Bottle Dawn © hand soap
- 3 Aluminum shafted squeeze bulbs
- 1 Tablespoon refined salt (NaCl)
- 1 ‘Fram’ type ‘G1’ or ‘G12’ fuel filter
- 3 Cloths
- 1 Aquarium pump (must fit tubing)
- 1 20uF non-polarized film capacitor
- 1 Tube Silicone sealer
- 1 $7\frac{1}{2}$ x $7\frac{1}{2}$ piece of glass
- 2 8 x $11\frac{1}{2}$ piece of glass
- 1 $7\frac{1}{2}$ x $9\frac{1}{4}$ piece of glass
- 1 $7\frac{1}{2}$ x 9 piece of glass
- 1 One way valve (must fit tubing)
- 1 Food dye (optional)
- 1 Clamp
- 1 Roll of duct tape
- 1 20 Inch roll of bare copper wire

5 Beakers (to test feasibility of solution)

IV. Procedure –

Planning

We started off by researching known properties of antibubbles. We came across many interesting sources, such as the first paper on antibubble formation found in the April 1974 of Scientific American. The current ‘guru’ of antibubbles is Terry Fritz, who was a helpful source during our frustrating periods of failure. Because of Terry’s past successes with antibubbles, we chose to incorporate some of his techniques in our own system.

There were a few major dilemmas that needed to be immediately addressed. First, we needed to design a filtered system that would remove dirt and other physical contaminants. Because the shell of air can be ~0.0002 inch, the presence of any extra material would prevent our antibubbles from forming. Next, we needed to make sure there were no voltage discrepancies between the inner and outer fluid; antibubbles will only form if there is less than a 0.3 volt potential difference between them. Finally, we needed to have a clear, organized system that would be easy to analyze.

Construction

We started off by addressing the issue of clarity. Curved glass surfaces, such as beakers and graduated cylinders, bend light and distort the authentic size of the antibubbles. Therefore, we needed to make a large, flat-faces formation tank. We ordered custom glass of the following sizes:

1x 7½ x 7½
2x 8 x 11½
1x 7½ x 9¼
1x 7½ x 9

Notice that one of the two side pieces is $\frac{1}{4}$ of an inch shorter than the other. This allows the solution to uniformly overflow, providing a low-maintenance means of filtration. We spent several days connecting the pieces along the seamed edges with silicone construction gel (See figure 1.1).

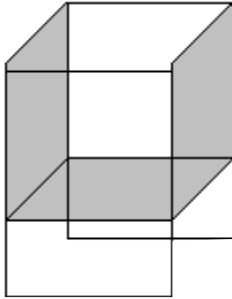


Figure 1.1 – This is what the final formation tank should look like. Notice that the close edge is shorter than the far edge; this allows for clean and efficient filtration. The side and base panels are shaded slight to allow for easier viewing.

The next part was to purchase all the materials necessary for fluid transportation and formation. This system included vinyl tubing, press-fit valves, a one way valve, ring stand, clamp, filter and a 12V pump. Once connected, we supported the system by clamping the valve region into a ring stand (figure 1.2).

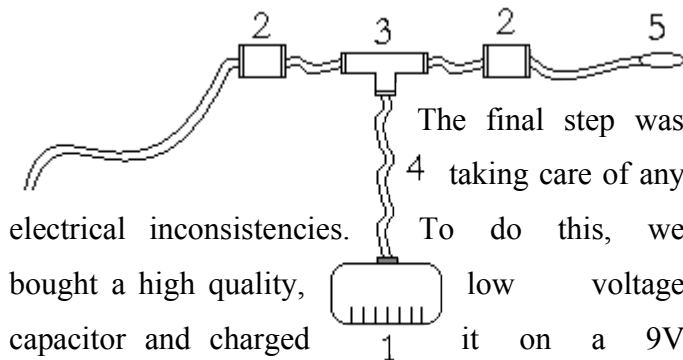


Figure 1.2 – Fluid Transportation

The final step was taking care of any electrical inconsistencies. To do this, we bought a high quality, low voltage capacitor and charged it on a 9V battery.

- 1) Pump
- 2) Press-fit valve
- 3) T-valve (press-fit)
- 4) Vinyl tubing
- 5) One-way valve

Below is a description of the function and application of the capacitor:

Basics

Like a battery, a capacitor has two terminals. Inside the capacitor, the terminals connect to two metal **plates** separated by a **dielectric**. The dielectric can be air, paper, plastic or anything else that does not conduct electricity and keeps the plates from touching each other. When connected to a battery, two things happen:

- The plate on the capacitor that attaches to the negative terminal of the battery accepts electrons that the battery is producing.

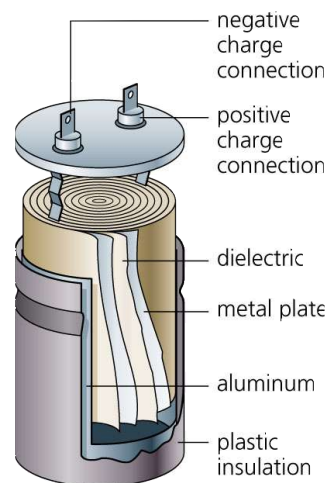
- The plate on the capacitor that attaches to the positive terminal of the battery loses electrons to the battery.

Faradays

The unit of capacitance is a **farad**. A 1-farad capacitor can store one coulomb of charge at 1 volt. A coulomb is 6.25×10^{18} electrons. One **amp** represents a rate of electron flow of 1 coulomb of electrons per second, so a 1-farad capacitor can hold 1 amp-second of electrons at 1 volt.

Applications

- Capacitors can also **eliminate ripples**. If a line carrying DC voltage has ripples or spikes in it, a big capacitor can even out the voltage by absorbing the peaks and filling in the valleys.
- A capacitor can **block DC voltage**. If you hook a small capacitor to a battery, then no current will flow between the poles of the battery once the capacitor charges (which is instantaneous if the capacitor is small). However, any alternating current (AC) signal flows through a capacitor unimpeded. That's because the capacitor will charge and discharge as the alternating current fluctuates, making it appear that the alternating current is flowing.
- In our case, we used the capacitor to evenly polarize the surrounding solution as well as the pumped solution used to make the antibubbles. Using the capacitor, we had about a 90% success rate while forming antibubbles.



Once charged, we wrapped wire around either the tubing or an eye dropper, and then connected one end of the capacitor to the wire and the other into the solution. This provided us with a safely equilibrated system. To amplify the effect of the capacitor, we added a little bit of salt to our solution. Adding an ionic compound such as NaCl helps the flow of electricity. After tweaking our setup, we finally came to a point where we could consistently create antibubbles. It was now time to record and analyze some data.

Analysis

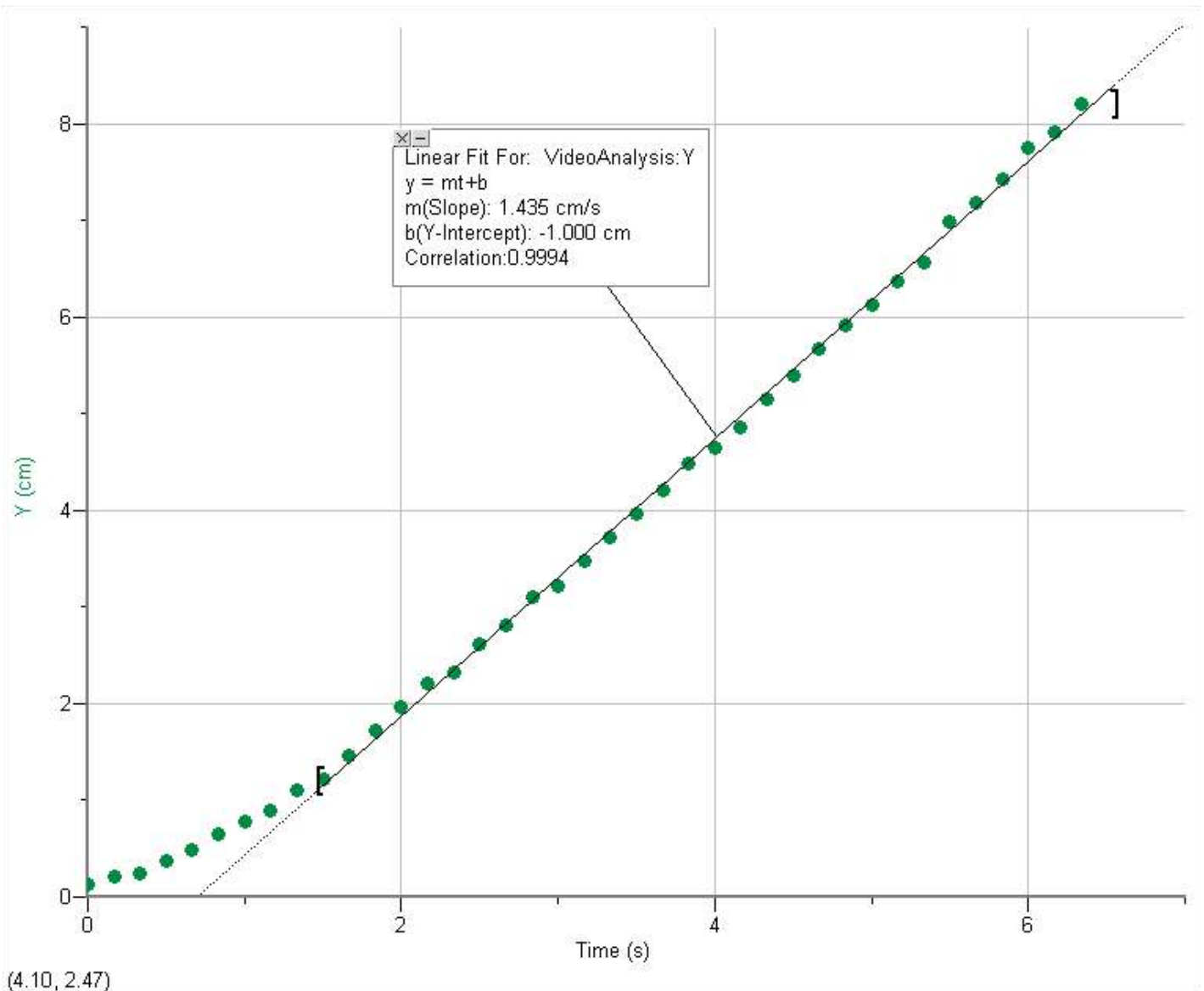
We used a method of Video Analysis to collect data on our antibubbles. First we recorded our experiments on a digital video camera. We were sure to mark the side of the tank so that we would have a known measurement to scale distances by. The angle of the camera had to be level and perfectly perpendicular to the face of the tank so that as little distortion as possible would occur. For the same reason, we had to produce the antibubbles as close to that face of the tank so that the scale on the plane of the bubble was as close to the scale on the plane that holds the face of the tank as well. After the experimenting phase was done, and they have been properly recorded, we digitized the footage onto the computer. The footage was then converted from .mpg to .mov with a lower frame rate (6 fps rather than 30 fps) for reasons that will show up in a bit. The long footage was trimmed down in to shorter clips for the ascension of each individual antibubble; we ended up with fourteen different movie clips. We then imported the clips in to Logger pro (graphical analysis software with video analysis capabilities). In Logger pro we located the bubble in each frame; this is why we lowered the frame rate. The clips were on average about five seconds long, at 30 fps that is 150 frames, at 6 fps that's 30 frames. So, although not quite as accurate, it saves a huge amount of time, and the loss of accuracy is not that significant. The clip is then scaled using the markings on the side of the tank. Logger pro collected the time and position coordinates and from there position and velocity (among many other) graphs can be extracted.

V. **Results/Data Analysis –**

After successfully extracting all the data from the Video Analysis software, we copied the information into columns. These data columns, when graphed, yielded a fairly linear correlation (*Note – all data files are located in the “workspace” section on the schools server. These files are open to anyone interested in further investigating our finds. However, it is in both the best interest of the group and reader that only a few charts are analyzed). Below are three charts, the first two of position vs. time and the second with a velocity curve as well.

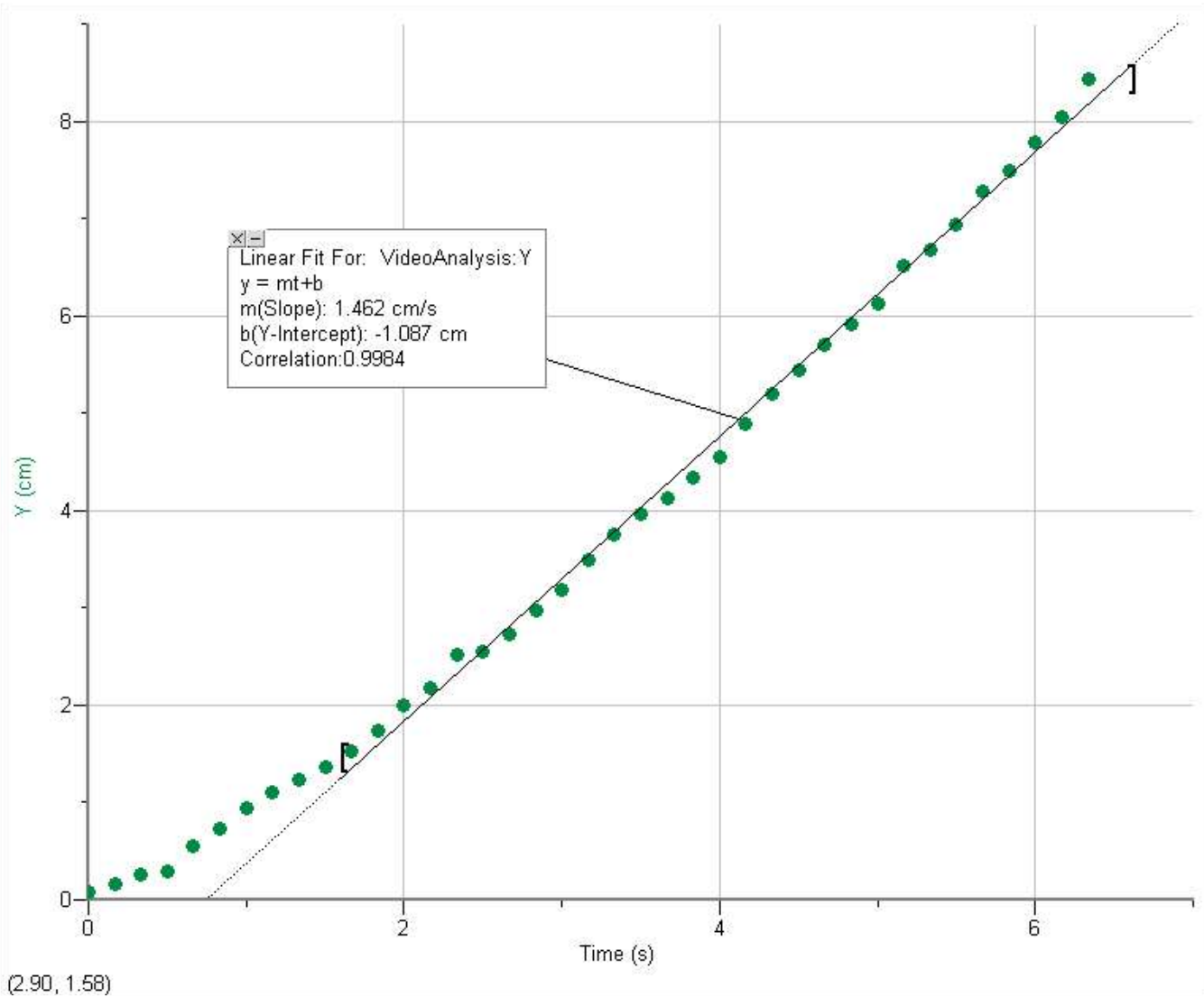
VERTICAL POSITION VS TIME

CHART ONE



VERTICAL POSITION VS TIME

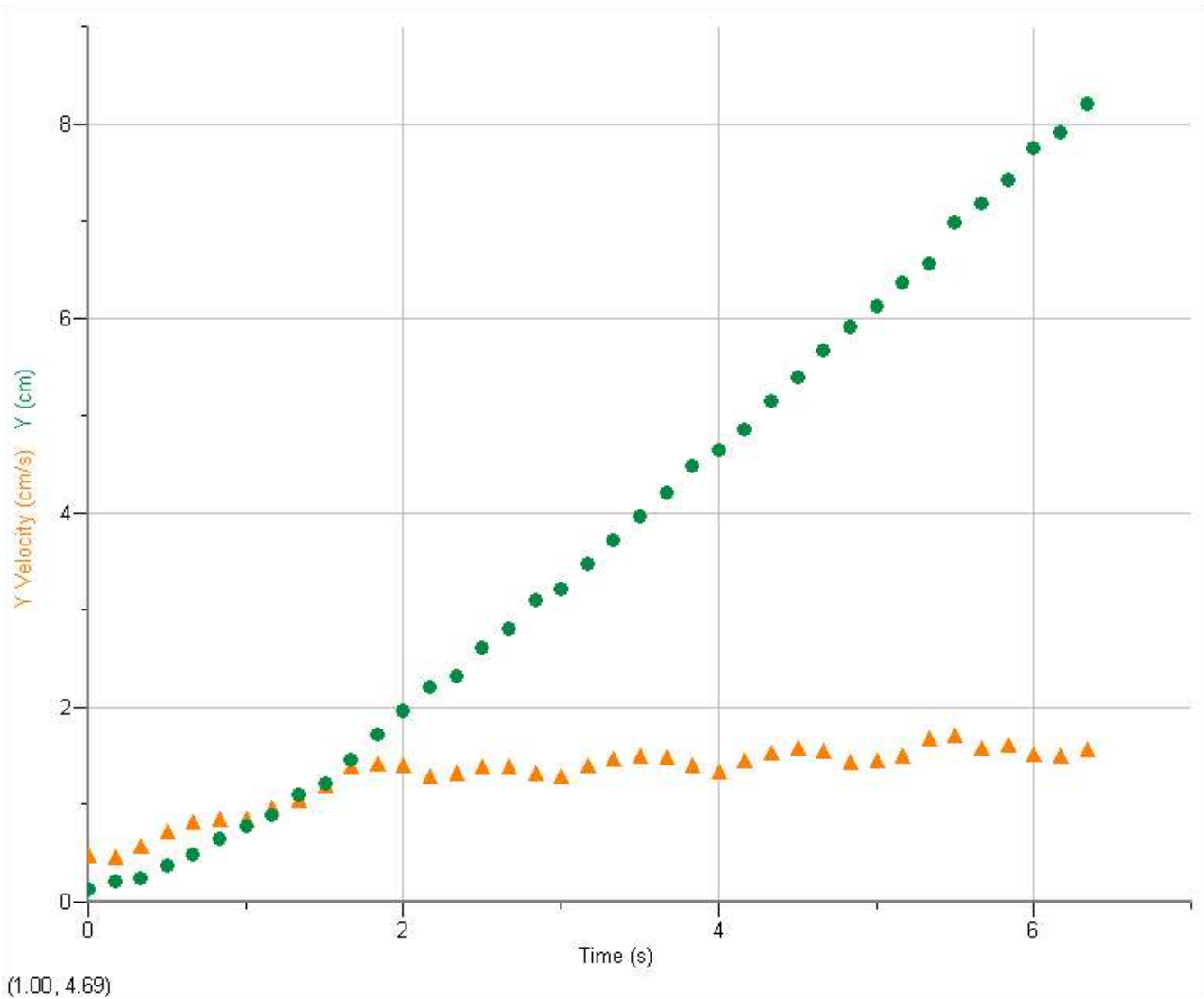
CHART TWO



Through point-by-point video analysis we were able to extrapolate position data sets of our antibubbles. The antibubbles approach what seems to be a linear trend very shortly after starting their ascension. All of the data sets start at the end of the descent and the start of their ascent. There were fourteen trials. In all fourteen the graph comes to a linear trend, and when fitted has a correlation of at least .995. This linear trend in the position means a constant velocity, which then means no acceleration. This section of constant velocity is said to be the antibubble's terminal velocity. Zero acceleration also means that the net Force is zero. All of which is talked about in the Force Analysis.

VERTICAL POSITION & VELOCITY VS TIME

CHART THREE



Even though we have established that the velocity is constant, the graph does not show up constant. This is caused by the method of data collection. Point by point video analysis basically collects a series of times and coordinates, which makes it perfect for collecting position data. However, it does not calculate velocity that well. This is because what it does is it takes the Δy and Δt , between each frame, the limited frame rate makes this process less accurate and further from the desired instantaneous value of dy and dt .

Since we now know that antibubbles rapidly reach their terminal velocity, we can analyze the forces acting on them during their period of constant ascension velocity. While the antibubble travels upward, it is acted upon by three forces: Gravity, Buoyancy and Drag. The free body diagram below (figure 1.3) shows their respective vector directions:

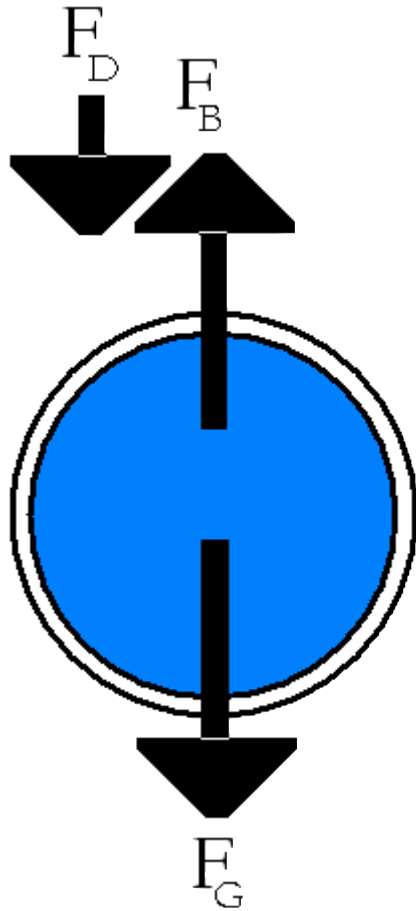


Figure 1.3 – Free Body Diagram of an Antibubble in Solution. *Note¹ that this diagram applies during the antibubble’s travel upward. *Note² – magnitudes are not to scale)

Buoyancy is the tendency of a body to float or to rise when submerged in a fluid. The magnitude of the buoyancy force on an antibubble was one area we chose to investigate. The free body diagram to the left shows that the only force opposing gravity (F_G) is a buoyancy force (F_B). The drag force, analogous to friction, slows the upward movement of the antibubble. Therefore, the $F_{NET Y}$ equation would be:

$$F_{\text{NET Y}} = F_B - F_D - F_G$$

The antibubble quickly reaches its terminal velocity, at which point the acceleration is zero. Since $F_{\text{NET Y}} = m \cdot a$, and a is zero, $F_{\text{NET Y}} = 0$. We calculated the density of our solution to be 0.998 grams per mL, which we can use to calculate the weight (F_G). The average diameter on our bubbles was roughly 2 cm (.02 m), which we will use to calculate the buoyancy force (*note ζ = density):

$$F_B = m_f \cdot g = \zeta_{\text{fluid}} \cdot \pi \cdot (D^3/6) \cdot g = 4.1 \times 10^{-5} \text{ N}$$

$$F_G = \pi \cdot (D^3/6) \cdot \zeta_{\text{sphere}} \cdot g$$

*Note - ζ_{fluid} and ζ_{sphere} are the same, but the shell of air must be included.

We know the viscosity of water at 25°C to be 0.89 centipoise, so the addition of SLS would increase the viscosity to approximately 0.91 centipoise. Using this as the viscosity and the common velocity as 1.42 cm/s, we can calculate the drag force:

$$F_D = 3 \cdot \zeta_{\text{fluid}} \cdot \pi \cdot \text{viscosity} \cdot \text{Velocity} \cdot D = 0.00243 \text{ N}$$

$$F_G = F_B - F_D = -0.00238 \text{ N}$$

At last, we have the final magnitude values for F_D , F_B and F_G . Because $F_D > F_G$, the antibubbles travels upward. However, we can see how if a denser solution is used inside (ζ_{fluid} is larger) then $F_D < F_G$ and the balloon would continue to sink (or remain still).

VI. Conclusion –

Through weeks of brainstorming, testing, failures and retesting, we eventually achieved success. Our goal was to study the physical properties of a fluid phenomenon, and in the end we even surpassed our expectations. Thanks to our successful systematic approach to creating antibubbles, we had no problem filming the products of our toils. Video Analysis © allowed us to calculate position and velocity in an extremely precise

manner, a lot more effective and accurate than the primitive means we had planned on using. Our knowledge on Newtonian forces greatly helped when calculating the approximate magnitudes of gravity, buoyancy and drag.

In this particular case, $\zeta_{\text{sphere}} = \zeta_{\text{fluid}}$. This may not always hold true, as in the case where a solution containing NaCl is pumped into a salt-free environment. After grinding through the numbers, we concluded that:

<u>Force</u>	<u>Magnitude</u>
Gravity	-0.00238 N
Drag	0.00243 N
Buoyancy	4.1×10^{-5} N

In the scenario where $\zeta_{\text{sphere}} = \zeta_{\text{fluid}}$, we found that the antibubble rapidly reached its terminal velocity. If we had more time, we may have investigated whether or not varying densities yield V_T similar to that of equal densities. It would also have been interesting to do a refraction/spectrophotometric investigation of the Sodium Lauryl Sulfide, exploring the chemical properties of the solution. Finally, we would have liked to use an oscilloscope to trace the charge discrepancies between the solution and the forming antibubble.

Acknowledgements

Thanks to The Hun School of Princeton for fulfilling our financial requests and providing us with this research opportunity.

Thanks to Terry Fritz for his essential aid on the concepts and logistics of this undertaking. Also, thanks for supplying us with the capacitor. We will submit this paper to your website in hopes of sparking new interest in the field.

Special thanks to Mr. Bernard Gilroy for all his support over the years. You have impacted our lives in so many ways, and we are very fortunate to have had both a teacher and friend of your ability.