**Bling Bling, Lasers aint a G-Thang:**

**By: Amar “Hot” Bhatti &**

**Richard “Wu-Pac Shakur”**

**Introduction**

This is a true scenario…

Your five-year old brother just got home from pre-school. After his milk and cookies, while watching power rangers, someone drops a package out on the front door. You, being upstairs, take it as a regular parcel for one of your family members. As your brother comes back inside with the package, you notice a white substance all over his hands. Unsure of what it is you neglect it, grab the package from him, and carry on with your life. Then it happens…

It’s a week later; you’re sweating profusely, your hands are shaking, you have a fever, you’re coughing, and you’re dizzy and light headed. You go too the doctor with your family. He says it’s “just a common cold.” Twenty-four hours later you’re in the emergency room dying. As you hear the doctors talking, you wonder how all of this could happen, and are you the only one? Smile, you’ve just been a victim of bio-terrorism.

Since the end of World War Two societies have feared weapons of mass destruction such as the atomic bomb and chemical warfare. Complementing these death vectors has been the birth of biochemical agents. Biological agents have always sparked fear in people because of their horrible potential. Recent outbreaks of bio-terrorism through anthrax have demonstrated how essential monitoring equipment for these evils is.

The laser is one of the most fascinating inventions of the twentieth century. Lasers, being an acronym for Light Amplification by Stimulated Emission of Radiation, have many fascinating properties that allows it to be one of the most useful measuring tools available to science. One of the most interesting properties is the theory behind particle scattering. Particle scattering is a sophisticated term that encompasses many elementary ideas behind light – such as diffraction and refraction. Particle scattering, however, also involves the light dispersion phenomenon.

Here’s how particle scattering works. Energy, in the form of light, hits a particle. This particle reacts with the energy by releasing energy of its own. This secondary wave of released energy is what you see when light is diffracted, refracted, or scattered. One of the most basic theorems behind scattering is Mie’s theory. Mie’s theory is an idea that relates shape and size versus intensity. If a particle is small the intensity picked up by a sensor will be relatively high, because all of the waves will be in phase-- meaning there energies will add together. Conversely, if a particle is larger you will have greater variations of waves creating destructive interference—meaning the energies will cancel out. Mie’s theory was the critical component in our experiment.

**What led us to particle scattering:**

Interest in laser applications attracted our attention to this field of science. After learning the many uses of lasers, we contacted the Lawrence Livermore National Laboratory to guide us to a suitable field of study. After we were referred to a scientist at the lab we began our odyssey. Our six--month correspondence with the lab, led us on a wild goose chase that inundated us with many superfluous ideas that hindered our ability to develop a useful experimental design. Much of our frustration corresponded to the deluge of information we were exposed to and our limited time span and our limited resources. At the end of our research expedition, the main areas covered were fluorescence, chemiluminescence, bioluminescence, spectroscopy, diffraction, refraction, and finally particle scattering. What took us from one topic to another was not a spontaneous vision, but an intermittent series of obstacles. The broad spectrum of information, however, allowed us to build on ideas and give us the understanding needed to develop the proper protocol for this experiment.

# **Abstract**

Before starting this project we researched what a laser was and what are some applications. A laser beam is nothing more than a collection of photons as a result of

atom pumping. All laser devices have the same basic set up: a power supply, a pumping device, a lasing medium, and an optical resonant cavity. There are six categories of lasers; crystal, gas, excimer, chemical, semiconductor, and liquid. A laser beams are monochromatic meaning they have one wavelength. All lasers are spatially coherent, meaning they have a consistent frequency, and all lasers are collimated meaning they don’t spread out. Laser, like light, can refract and diffract. These are different types of light bending.

Diffraction and refraction are elementary versions of particle scattering. Particle scattering shows a relationship between a size and shape versus amount of light scattered. Smaller particles are isotropic, meaning they scatter light evenly in all directions. Larger particles will have greater forward scatter than a backscatter. Fluorescence is a property of atoms where an atom becomes excited by an outside energy source and releases a photon. Bioluminescence is a special type of chemiluminescence that occurs in a living organism. Luminescence works the same way as fluorescence does.

## **Question**

Can particle scattering allow us to differentiate between bacteria?

# **Hypothesis**

We believe that particle scattering is a building block that can lead us to differentiating between different substrates (particle scattering itself cannot allow us to separate living and nonliving things, but it is a stepping stone into that direction. Further addition in areas such as bioluminescence for example, can perhaps lead to a discovery of identifying pathogenic materials that may be around us.)

**Prediction**

If particle scattering can differentiate particle shapes and sizes of inanimate objects, then it should be a practical method in differentiating living organisms.

**Materials**

**1) Light Sensor**- A hardware component of our software program Logger Pro. It allowed us to pick up the illumination that was given off by the laser once it had refracted off the tube.

**2) Syringe-** The syringe was our suction device that picked up the substances that we used.

**3) Taigon Tubing-** Our transport of fluid that was connected to the syringe in our setup.

**4) Beakers-** Each substance was placed in a 140 ml beaker for constant measurements and precise analysis.

**5) Helium Neon (class II laser)-** The crux of our experiment this laser was the main device that allowed us to test particle scattering in our experiment. This class II laser was an exception from the other lasers in its class due to the fact that it was harmless to us during our experimentation.

**6) Gram Scale Weights-** We used two 200g weights and one 50g weight taped one ontop of the other to set a force to push down the plunger of the syringe.

**7) Ringstand-** The light sensor was clamped to a clamp from a ring that held the light sensor at the right height.

**8) Molding Clay-** Molding clay allowed us to keep the light sensor flat on the board reading the energy given off up the particles from the laser. It also allowed us to keep the board in one spot so that we would not have to set the board at the right angle after every run.

**9) Two flat wooden boards-** Were placed under our wooden apparatus making sure that the tube was exactly at 0 degrees with the laser.

**10) Cable Anchors-** Were used to keep the taigon tubing firm allowing constant flow from the syringe through the tubing and into the beaker.

**11) Metal Bracket-** Held the syringe upright allowing constantly also keeping the flow constant.

**12) Cork Board-** Kept the bracket attached and was nailed into the board.

**13) Wooden Board-** Was the base for all the things placed ontop.e. taigon tubing, syringe, bracket)

**14) Chewing Gum-** Wrigley Double mint, used as an adhesive, was eventually an essential part in keeping the light sensor in place.

### **15) Titanium 0.5 Mechanical Pencil & Bic Pen-** Pencil was attached to gum to wedge the sensor on one side, while the pen was wedged in between the sensor and the piece of cork board holding the bracket/syringe.

### **16) Sony Labtop-** Used to support Logger Pro (graphing software). Was attached to light interface system for readings from the light sensor.

### **17) Logger Pro 2.1-** Graphing program that read light intensity (luminance) that was coming from the laser through the tube picked by the light sensor.

**18) Light Interface System-** Hardware box that was connecting the light sensor to the lab-top. Transferred all data and ran along with logger 2.1.

**19) Stirring Rod-** Used to mix solution in beaker for homogenous flow.

**20) Vortex Machine-** Allowed us to have a complete mixture of substances once in water.

**21) Gram Scale-** Allowed us to measure 3 grams of each substrate that we used.

**22) Mortar & Pestel-** Allowed us to crush substrates into powder (some of the substrates that is).

**23) Ultra Carbon Powder-** A substrate

**24) Corn Starch Powder-** A subtrate

**25) Diatomaceous Earth (a.k.a Chalk)-** A substrate

**26)Saccharomyces-Cerevisiae (a.k.a Bakers Fleischmenn Yeast)-** A substrate

**27) Air-** You need, so did we

**28) Distilled Water-** Used for mixture and as a constant

**29) The wire-** Used to hold the syringe against the cork board

**30) Light Microscope-** Used to look at particles of each substrate

**31) Digital Lens Camera-** Hooked up to a microscope to capture image of particles onto computer screen

**32) Adobe Photoshop-** Allows us to look at images from digital camera

**33) Chemical Journal Magazine-** Placed under flat boards to raise the height of apparatus.

#### **Literature Review**

Lasers, the final frontier. Not really, but they are one of the most interesting and useful inventions of the twentieth century. They have numerous applications in industry and science. Curiosity in lasers led us to broaden the usefulness, of these fascinating devices.

Two pieces of information were vital to finding a project relating to lasers: what is a laser and what are some current applications? Laser is an acronym standing for Light Amplification by Stimulated Emission of Radiation. It gets this name through atomic properties. Photons are released when atoms change from a ground state meaning its natural state, to an excited state (also known as pumping) and back. The release of photons in the natural world is called spontaneous emission. When one induces a chain reaction with photons, causing photons to hit other atoms releasing more photons stimulated emission of radiation has occurred-this action will continue until the energy source is terminated. A laser is a thin, intense light beam that is highly directional. The non-dispersal property of lasers is what separates it from other forms of light..

All lasers are composed of the same basic components. First, they all require a power supply. Lasers use an electrical power supply that delivers up to 10,000 volts and several hundred amps. Second, they all need a pumping device- a high voltage power supply. Third, they all require a lasing medium- a material that generates laser light such as solid, gas, or a liquid. Lastly, they all need an optical resonant cavity, which is just something that holds the other components and has mirrors inside to focus the light. There are six classes of lasers: crystal or solid, gas, excimer, chemical, semiconductor, and liquid. A ruby laser is an example of a crystal laser. The original ruby laser was the Maiman Contraception. It works through a fascinating through a fascinating system of pumping and focusing. First, a power supply sends short pulses of electricity to a lamp, which baths the ruby in white light. The chromium atoms from the ruby absorb only the blue and green colors of light. Absorbing the light raises the energy level of atoms. When they drop back they release photons, which bounce of mirrors and are focused into a thing beam. Another type of laser is the Nd:YAG laser which uses a crystal made of aluminum, yttrium, oxygen, and neodymium. A laser is formed through the same method as the ruby laser. This laser emits light in the infrared region. Gas lasers are the biggest group of lasers and are relatively inexpensive. The most common gas compounds of lasers are helium-neon, helium-cadmium, argon, carbon dioxide, and krypton. Argon and krypton lasers produce multiple wavelengths of light usually in the blue or green range. They generate a large amount of energy. Excimer lasers are special types of gas lasers. When a molecule is excited and stays in an excited state it is called an excimer. When it emits its photon it breaks into different atoms rather than falling back on ground level. Chemical lasers are high powered and favored by the military. Most chemical lasers have a hydrogen-fluorine compound as a lasing medium. This compound is pressurized and ignited into a flame to become a laser. Semiconductor lasers use a semiconductor as the medium. The semiconductor has a space called the positive/negative junction or PN. When current runs through the junction a glow of light is produced, mirrors fill this space and amplify the light. Liquid or dye lasers use an organic due as the lasing medium. The dye is run through a cavity pumped by a source. These lasers are special because you can adjust their wavelength.

Lasers are nothing more than focused light, therefore, it is important to understand certain basic principles of light and its wavelengths before learning the principles of lasers. A photon will oscillate in a sine wave pattern. The distance between the crests of these bobs is one wavelength. A smaller wavelength equals a higher energy or frequency. The frequency is measured in hertz. The special aspect of a laser’s wavelength is that it exists at only one wavelength making it monochromatic (one colored). All lasers are said to be spatially coherent which means that the distance between crests never change. Lasers are all temporarily coherent meaning that the waves from lasers are emitted in evenly spaced intervals.

Lasers have many applications. Their monodirectional behavior makes them ideal for communications. They have become particularly useful in long-range communications, which advances in optics (a branch of physics). In industry they are useful as cutting utensils, drills, and welding tools. In medicine doctors can use lasers in surgery to remove diseased tissue. In the military lasers are used to navigate planes. They are used in monitoring tectonic shifts, separation of isotopes, and measuring.

Lasers have many interesting properties. Two are these properties include diffraction and refraction. Refraction is nothing more than the bending of light from one medium to another. When two different mediums have two different indexes of refraction, light will change its speed contributing to the bending affect. This bending can be measured using Snell’s Law which is simply N1\*sin (x1)= N2\*sin (x2) where N is the index of refraction and X is your angle. The index of refraction can be calculated by the speed of light divided by the speed of light through your substance.

Diffraction is light’s ability to bend around obstacles. When light passes through very thin slits, instead of seeing two straight lines one sees a series of lines. This was first seen in Thomas Young’s double slit experiment. The multi-line pattern is due to a phenomenon known as wave interference. The series of lines are known as an interference pattern. The areas if bright lines are a product of constructive interference. The shadowy areas are a product of destructive interference. Constructive interference means that two waves travel along the same wavelength which means they are in phase. Destructive interference means that two waves travel at different wavelengths and are said to be out of phase. The position of lines seen is affected by the size of slit- as the slit gets smaller the angle of the light’s path will increase. The equation for diffraction is d \* sin (x) = mw where d stands for distance between slits, x is your angle, m is the order of interference meaning which light your describing and w stands for wavelength.

Understanding refraction and diffraction are essential to our project because they are both elementary aspects of a sophisticated idea known as particle scattering. The basic properties of scattering are rather complicated. First of all, all matter is made up of particles called electrons and protons. When any part of matter is hit by light the electrons and protons will oscillate through the energy input of incident light wave. This secondary radiation is the scatter we see (a.k.a. reflection, refraction, diffraction, etc). Sometimes this newly absorbed energy is converted to other forms of energy (heat, kinetic energy, etc). This is called absorption. Absorption and scattering often go hand in hand.

It is important to realize that everything scatters light. Solids, liquids, and gases are all said to be optically dense. This means the wavelength of the incident light beam is bigger than the separation of molecules. The closeness of all molecules means that when a beam of light hits matter a molecule reacts to both the incident radiation and the secondary radiation of its surrounding molecules. The scattering of light is the result of dense fluctuations. A density fluctuation is a term that says that the number of molecules in a specific location at a specific moment in time changes constantly.

The most important property of scattering, which was vital to our experiment, is how the intensity will change due to the scattering affect. To understand this we must know that scattering is both size and shape specific. Different sizes and shapes will produce different light intensities. If a particle, on the other hand, will crate more peaks and valleys of a scattering pattern—meaning that more light will be scattered in one direction. Therefore, the intensity of light of a larger particle will be greater or smaller than a smaller particle depending on where you place your sensor.

Before using particle scattering as the buttress of our experiment, we pursued a far different route, which was also far more complicated. Our original idea involved fluorescence. Fluorescence is a widely known phenomenon of chemistry; when a particle is excited by energy, in our case light, the light beam will excite the particle to releasing a photon or some other form of energy. Often times this energy will result in a color. A major problem with this idea is that not everything will fluoresce.

Originally our experiment was supposed to be coupled with a bioluminescent reagent. A major advantage of pairing scattering with luminescence is that one can

definitively discover whether something is alive, making the identifying process more specific.

Bioluminescence is simply light from life. The patterns of emission between species involve four main groups: the manner and location of light emission, the continuity and control of the light, the intensity of light, and the color of light. Most bioluminescence is intracellular and intermittent. In nature, species illuminate themselves as a response to stimuli. The intensity and color of emitted light falls into a large range.

Categorizing bioluminescence still doesn’t tell us one thing; what is bioluminescence? Bioluminescence is a subcategory of chemiluminescence. Chemiluminescence is a specific type of fluorescence. When organic compounds are stimulated the “excited” molecules release energy as the excitement subsides and drops to normal or ground levels. When the excitation diminishes, it is the dropping back action that emits a controlled amount of energy, in the form of photons. How many photons released is regulated by the molecular structure of your compound. Bioluminescent systems radiate within the visible spectrum. The specific aspect of bioluminescence that we were interested in was ATP-Bioluminescence. Currently ATP-Bioluminescence is used to test for the presence of a microbial load in milk.

Lasers already have so many applications and the properties behind them can blow one’s mind.

##### **Procedure**

In an experiment like this, every little detail can amplify into a big problem. Our procedure was very consistent, specific, and almost fully efficient.

###### **Procedural Steps:**

1. **Getting into Logger Pro with your lab-top-** Install Logger Pro into your computer. Once you have gotten into the program click on open and open the 600 lux graph (hidden in probes and sensors folder). Once you have opened it you should see an empty table of values and a graph with seconds as your “X”, and illuminate (lux).
2. **Setting the Apparatus-** Much of the work is done with the board preset. We placed two same sized boards next to each other underneath the board to set a fixed height. This latter board keeps our laser set at 0 degrees and is placed 8 cm from the edge of the flat boards underneath.
3. **Setting the laser and light sensor-** Once the board is fixed, the laser is placed 18 cm from the edge of the underlying board hitting the tubing at 0 degrees. The light sensor is placed directly across from the laser on the other side of the tube catching the light coming through the tube once hitting the particles.
4. **Clamping the laser right on the board-** The light sensor is clamped and hooked on to a ring stand 12 cm from the edge of the board. Modeling clay is added to keep the sensor in place.
5. **Place a wedge to keep the sensor in place-** Further support is needed to keep the sensor in place. Once pen is wedged in between the board that held the bracket and the sensor. On the other side we used a mechanical pencil, which was held down by adhesive chewing gum.
6. **Measuring out the substrate-** Each mixture contained 140 ml of water and 3 grams of material.
7. **Getting a homogenous mixture-** In order to have a homogenous mixture for each substrate, each mixture was placed on top of a vortex machine for 25 seconds. After 25 seconds we stir the mixture with a glass rod until it seems that the mixture has an even concentration of material seems.
8. **Keeping the tube clean**- Before we used any substance we made sure that the taigon tube was completely clean, this was done by using a beaker of distilled water and beaker for waste. Taking in water and then pushing it out about 3-4 times was enough to push any extra particles from previous substrates.
9. **Last Check on Constants**-Before taking in liquid, make a trial run to see if you are getting the correct air constant for that day. If you are not getting the right value then either your laser your light sensor or both are off angle.
10. **Clean Tube start taking in liquid**- If the tube is completely clean place the beaker underneath the end of the tube and have one person on the other side ready to pull the syringe (one person can do both if necessary, but they must

make sure that the tube is in the mixture when they pull the syringe and that it does not move out).

1. **No flaws while filling the syringe-** A critical part of this process is that you do not get air bubbles when you are pulling the plunger (inability to have tube in the mixture may lead to that). If you have an air bubble while sucking the fluid, flush all mixture out and try again.
2. **Placing the weight-** Once you have pulled the plunger all the way up with the mixture in the taigon tubing, place the 450g weights on top of the plunger. The 450g weight is composed of two 200g weights and one 50g weight. Do not actually let go of the weight once you have placed it on top of the plunger of the syringe until you are ready to collect data.
3. **Having the perfect dark environment-** Once you have the graph ready on logger pro and the mixture in the tube with the weight ready to push on it, shut all lights. Once it is dark you should be able to see a fairly large red line on the wall behind the laser. The red line on the wall is the backscatter from the laser hitting the particle releasing it into a higher energy level and reflecting off the tube.
4. **Begin Collecting-** One person should be at the lab-top ready to hit the collect button, while the other person should have the weight balanced on top the plunger, but they should have not let it push on the syringe. Make sure that the beaker catching the waste is underneath the tube.
5. **Collection-** To begin the collection of data the person that is going to let go of the weight should tell the person on the computer to begin collecting once they have let go of the weight. A good estimate of time for a decent collection of values is about 10 seconds.
6. **Cycle the procedure-** Once done collecting for that run, save the graph turn the lights back on, and flush any extra liquid. Use distilled water to rinse the tube as mentioned in step 8. Once clean repeat steps 1-15 for next run.

**Conclusion**

The data supports our hypothesis that Laser Scattering can be used to differentiate between living particles. The most convincing evidence is the fact that each particle tested had a different intensity and the living cell we used, yeast, was no exception. Our goal, however, of incorporating Mie’s theory failed, because of our experimental design. To further substantiate our hypothesis we should of either collected intensities off multiple locations or used different concentrations. According to Mie’s theory water should have given off the highest intensity since its basically going through air. Taking data at two locations would have made our information further validated our claim because we would have been able to compare the ratios of the backscatter and the forward scatter. By comparing these two ratios we would have been able to definitively state which particle was larger or smaller and or which particle was smoother or rougher.

There were many other areas of experimental error, which make our results suspicious. First of all, the particles we used were not homogenous. The particles all fell within a range of sizes. Having heterogeneous particle sizes means there is no accurate way of comparing ratios of sizes. Therefore, the intensity you pick up in the data will incorporate many different sizes making it difficult to see a trend. A second source of error was the presence of electronic interference. Electronic interference affected the pattern you saw on the graphs. For example, the graphic data we collected and placed in a graph showed a sinusoidal pattern with a certain frequency, which suggested that the

sensor was picking up the electronic interference’s intensity rather than the particle scattering intensity. A third source of error was the sensor. Although we set the maximum range on our sensor to pick up 600 lux, data which gives concrete evidence that 600-lux was not the maximum intensity it picked up. The maximum was less than that, around 434.7- lux. A fourth source of error was the position of the sensor. By having the sensor 180 degrees from the laser we could not differentiate between scatter and absorption (the release of converted energy). Differentiating between the two is significant because they behave differently. Although our data suggests that our hypothesis is correct, a more proper experimental design is required to validate that claim. The presence of multiple sources of error affects the data we collected too much to be negligible.

# **Biases**

No experiment is perfect. There will always be certain factors that contribute to errors within a system. Our experimental design had many flaws that did not give us completely accurate results, however, the differences in intensity between materials were so great that any error would be negligible with respect to our ultimate goal. There are many ways to improve this experiment (and thus give more conclusive results). First of all the plunger in the syringe was frequently contaminated. Often times the plunger got sticky and stuck to the sides of the syringe affecting the velocity the plunger fell (which was supposed to be constant). Also, at the bottom of the syringe, which was connected to the taigon tubing, there were large deposits of wastes from the previous samples that often clogged the syringe. At times the taigon tubing had some contamination and was difficult to flush out. To solve this required many rounds of flushing—even then it was difficult to ascertain whether the tube was completely sterile.

The rate the plunger fell was a recurring problem in our experiment. Vasoline was applied to make the tube a little slicker, however we added too much making the plunger fall much faster than the desired velocity. Keeping a constant speed is critical in collecting data, and for the syringe to not move at one point, then suddenly move too fast displayed the lack of control we really had over that variable.

Keeping a constant angle of the light sensor was a second factor that contributed to experimental error. To minimize the error, we raised the board the system with magazines and used clay to keep the sensor at a fixed position. Writing utensils were also used as wedges to keep the sensor in a steady position.

A third factor was the laser itself. When we began the experiment we used a gyroscope to adjust its angle; later we raised the board, which solved both the light sensor problem and the laser problem. The main obstacle was if the table was bumped the laser moved. A steady table would of helped in keeping the laser at a constant angle.

Another factor was the constants, which we were comparing the substrates to, often changed. Air was the main constant in our experiment. Everyday the air scatter constant changed from 435 lumens to 434 lumens. The fact that the constants changed suggests that a constant room temperature and humidity must be kept throughout the experimental process. Since the constants change it is reasonable to assume that out substrate’s scatter was also affected. This did not totally throw off our results, however, and the expected outcome occurred.

Using a mortar and pestle to ground the materials was another bias because we were not entirely sure if all the particles were the same size. As mentioned in the introduction, size and shape affects the scatter of light. Therefore, different sizes of the same particle will give us different results of scatter.

In addition, another deficiency was that we were not entirely sure if the material we put into the water was evenly displaced throughout the liquid. If there were different concentrations at different locations in the solution, that change in concentration could have affected the particle scatter of lasers.

The final bias was the environment in which we had conducted our experiment. Collecting data from the light sensor we were expecting only readings from the laser. However, with light detectors such as the one we used, these sensors are so sensitive that they will pick up electrical rays from surrounding things. Thus in our case, our apparatus was next to a digital weather station suggesting that perhaps our data could be inaccurate to what should be expected with a perfect environment. To solve this we need a setting that will cut off any electrical source other than our collection devices, and a complete dark area.

Having many uncontrollable variables affected our results. With the resources available to us, our system was fit accordingly to its maximum potential. Access to better equipment could minimize these variables and thereby giving very precise results that could better support our hypothesis and ultimately lead to further discoveries.

**Improvements**

Besides conducting the experiment properly, understanding your flaw’s and how to improve them is very critical towards your experiment. Hence in our experiment, doing something that hasn’t really been tested before we were expecting to encounter difficulties along the way. Even though these difficulties at times delayed our experiment we eventually overcame them, and have kept a record on what needs to be improved.

First off, one major factor that can definitely make this experiment more valid is trying different concentrations of each substrate at different angles. Increasing this data should validate our theory extensively, and possibly allow us to discover some other key concepts. By adjusting the angle, we can be able to compare different particle sizes at various positions, which can give us an all around better idea rather than one view of the particle. Perhaps a gyroscope mounted on a tripod could be the next step towards that idea. With that gyrating laser, you may want to place more than one sensor at different spots around the tube to really capture every angle the scatter will come off of.

Another factor that if corrected can be of immense value towards our experiment is keeping our constants **CONSTANT!** Much of our experiment was devoted to finding a consistent position at which light intensity of the laser and pickup of the sensor was the greatest. Having a hard clamp on the board, laser, and sensor would be of great significance in collecting correct data quickly, instead of fixing everything when you accidentally nudge the table. In addition, due to the uncontrollable temperature in our room, our air constant always changed everyday. For an experiment such as this one to work, a constant room temperature and humidity would be needed for accurate results. Differentiating between particles may be easy to get with or without constant temperature, but like anything to narrow something down when you’ve got already a limited source is very hard to do unless you have something that can get that specific.

Using a weight gave us a constant free fall motion to work with however relying on the balance of a weight on a syringe top isn’t the greatest idea. Perhaps a support device can be used to hold the weight in place, throwing out all the balancing effort. By doing that you should not need to worry about constant water flow no matter how much weight is used. Furthermore, sterilization of not only the syringe, but of the tubing is extremely important. After our experiment with graphite, many of the particles were left at the bottom of the syringe, where it is impossible to make clean. Getting rid of that extra dried out particles would surely guarantee a legitimate result for all your readings.

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Over the past six months, our experiment has had its highs and lows. At points where we were quite confused and frustrated, to times where our perseverance turned into success, much of our achievement comes from the people who stuck with us the whole way.

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