CERN summer studentship report

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Introduction. From July 3rd, 2023, to August 25th, 2023, I had the privilege of collaborating with Julia Woithe as my supervisor. Throughout this tenure, I engaged in two distinct tasks: firstly, the assembly of detectors using LEGO particles, and secondly, an in-depth exploration of the chemical and physical properties of soap bubbles. Our collaborative efforts extended beyond individual tasks, encompassing a series of enriching workshops conducted under her guidance. These workshops were conducted in conjunction with a knowledgeable teacher, fostering an environment of shared learning and growth.

First task: Learning Detectors through LEGO participles

On July 3rd, I visited the office of my supervisor, Julia Woithe, located at room number 3/R-002. I was warmly received by her with a courteous and friendly demeanor. During our meeting, she provided me with a set of LEGO detector components along with a comprehensive handbook. In the subsequent days, I diligently collected the essential components, including CMS, ATLAS, ALICE, LHCb, and the LHC dipole magnet, as instructed.

CMS [1] is a large technologically advanced detector comprising many layers, each designed to perform a specific task. Together these layers allow CMS scientists to identify and precisely measure the energies and momenta of all particles produced in collisions at CERN's Large Hadron Collider (LHC). CMS acts as a giant, high-speed camera, taking 3D "photographs" of particle collisions from all directions up to 40 million times each second. Although most of the particles produced in the collisions are "unstable", they transform rapidly into stable particles that can be detected by CMS. By identifying (nearly) all the stable particles produced in each collision, measuring their momenta and energies, and then piecing together the information of all these particles like putting together the pieces of a puzzle, the detector can recreate an "image" of the collision for further analysis.

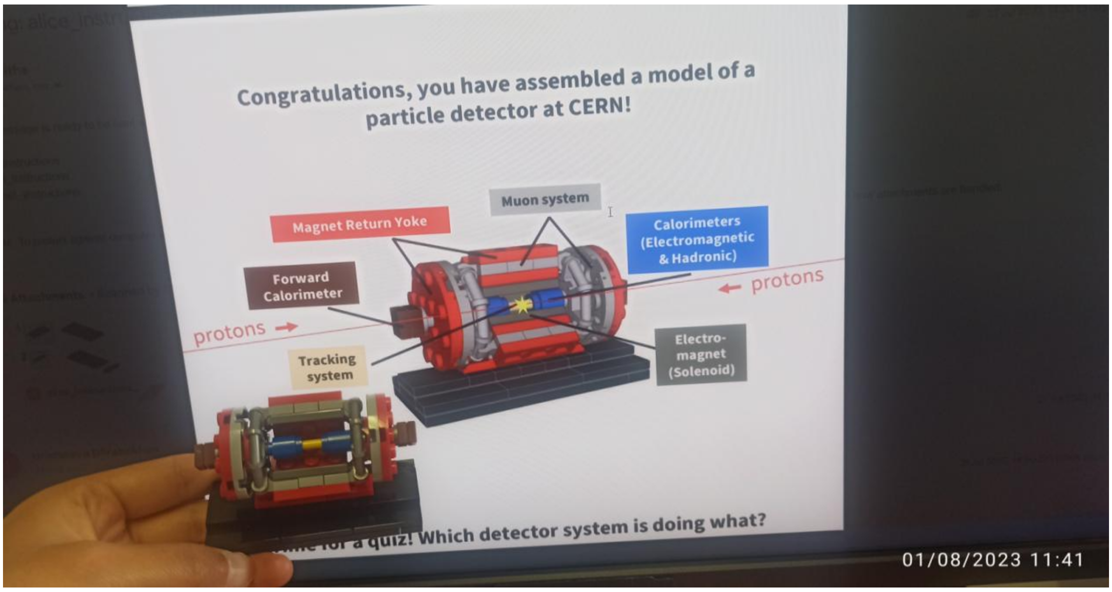

Figure 1 Showing CMS detector through LEGO particles.

ATLAS [2] has the dimensions of a cylinder, 46m long, 25m in diameter, and sits in a cavern 100 m below ground. The ATLAS detector weighs 7,000 tonnes, similar to the weight of the Eiffel Tower. The detector itself is a many-layered instrument designed to detect some of the tiniest yet most energetic particles ever created on earth. It consists of six different detecting subsystems wrapped concentrically in layers around the collision point to record the trajectory, momentum, and energy of particles, allowing them to be individually identified and measured. A huge magnet system bends the paths of the charged particles so that their momenta can be measured as precisely as possible. Beams of particles travelling at energies up to seven trillion electron-volts, or speeds up to 99.999999% that of light, from the LHC collide at the centre of the ATLAS detector producing collision debris in the form of new particles which fly out in all directions. Over a billion particle interactions take place in the ATLAS detector every second, a data rate equivalent to 20 simultaneous telephone conversations held by every person on the earth. Only one in a million collisions are flagged as potentially interesting and recorded for further study. The detector tracks and identifies particles to investigate a wide range of physics, from the study of the Higgs boson and top quark to the search for extra dimensions and particles that could make up dark matter.

Figure 2 Showing ATLAS detector through LEGO particles.

ALICE (A Large Ion Collider Experiment) [3] is a detector dedicated to heavy-ion physics at the Large Hadron Collider (LHC). It is designed to study the physics of strongly interacting matter at extreme energy densities, where a phase of matter called quark-gluon plasma forms. Universe is made up of atoms. Each atom contains a nucleus composed of protons and neutrons (except hydrogen, which has no neutrons), surrounded by a cloud of electrons. Protons and neutrons are in turn made of quarks bound together by other particles called gluon. No quark has ever been observed in isolation: the quarks, as well as the gluon, seem to be bound permanently together and confined inside composite particles, such as protons and neutrons. This is known as confinement. Collisions in the LHC generate temperatures more than 100 000 times hotter than the centre of the Sun. For part of each year the LHC provides collisions between lead ions, recreating in the laboratory conditions similar to those just after the Big Bang. Under these extreme conditions, protons and neutrons "melt", freeing the quarks from their bonds with the gluon. This is quark-gluon plasma. The existence of such a phase and its properties are key issues in the theory of quantum chromodynamics (QCD), for understanding the phenomenon of confinement, and for a physics problem called chiral-symmetry restoration. The ALICE collaboration studies the quark-gluon plasma as it expands and cools, observing how it progressively gives rise to the particles that constitute the matter of our universe today. The ALICE collaboration uses the 10 000-tonne ALICE detector – 26 m long, 16 m high, and 16 m wide – to study quark-gluon plasma. The detector sits in a vast cavern 56 m below ground close to the village of St Genis-Pouilly in France, receiving beams from the LHC.

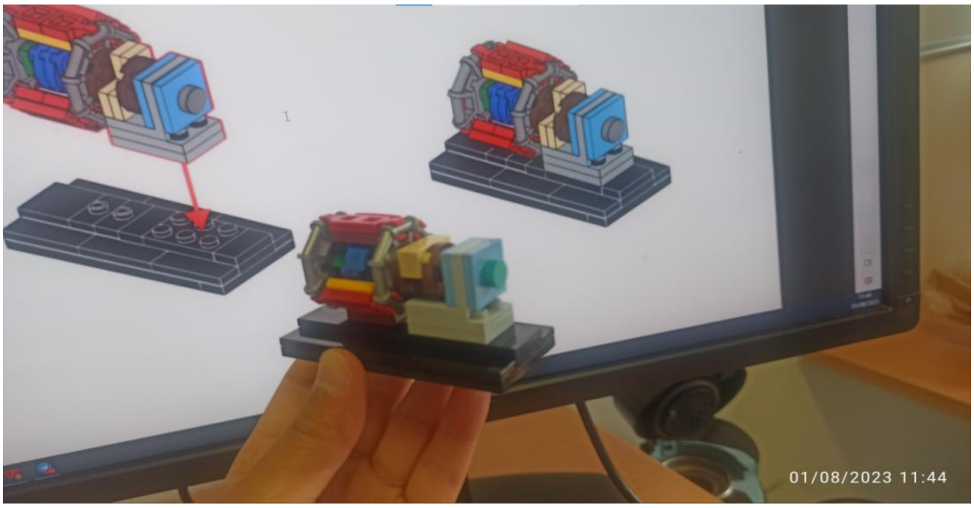

Figure 3 Showing ALICE detector through LEGO particles.

LHCB (The Large Hadron Collider beauty) [4] experiment specializes in investigating the slight differences between matter and antimatter by studying a type of particle called the "beauty quark", or "b quark". Instead of surrounding the entire collision point with an enclosed detector as do ATLAS and CMS, the LHCb experiment uses a series of sub-detectors to detect mainly forward particles – those thrown forwards by the collision in one direction. The first sub-detector is mounted close to the collision point, with the others following one behind the other over a length of 20 metres. An abundance of different quark types are created by the LHC before they decay quickly into other forms. To catch the b quarks, LHCb has developed sophisticated movable tracking detectors close to the path of the beams circling in the LHC. The 5600-tonne LHCb detector is made up of a forward spectrometer and planar detectors. It is 21 metres long, 10 metres high and 13 metres wide, and sits 100 metres below ground near the town of Ferney-Voltaire, France. About 1565 scientists, engineers and technicians from 20 countries make up the LHCb collaboration.

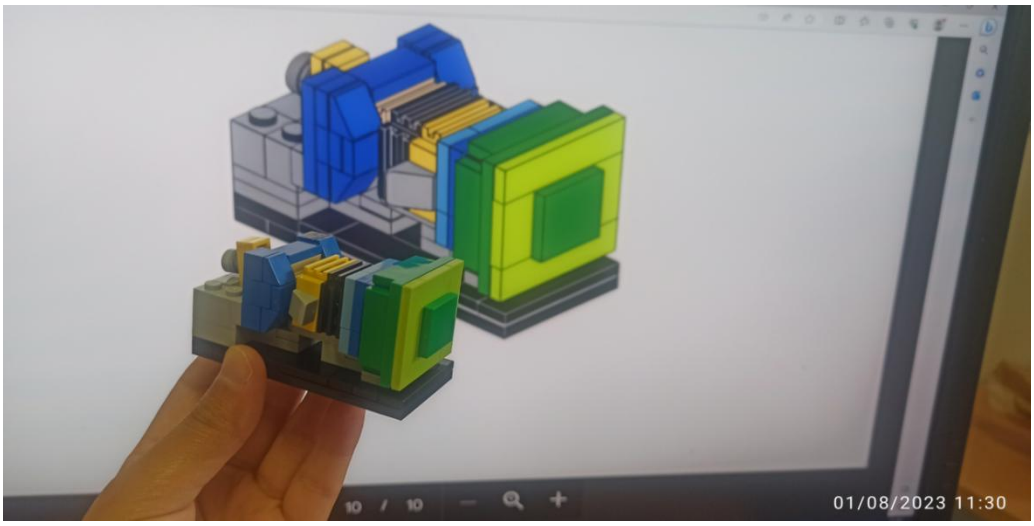

Figure 4 Showing LHCB detector through LEGO particles.

LHC dipole magnet [5]. The main dipoles generate powerful 8.3 tesla magnetic fields – more than 100,000 times more powerful than the Earth's magnetic field. The electromagnets use a current of 11,080 amperes to produce the field, and a superconducting coil allows the high currents to flow without losing any energy to electrical resistance. Dipole magnets, one of the most complex parts of the LHC, are used to bend the paths of the particles. There are 1232 main dipoles, each 15 metres long and weighing in at 35 tonnes. If normal magnets were used in the 27 km-long LHC instead of superconducting magnets, the accelerator would have to be 120 kilometres long to reach the same energy. Powerful magnetic fields generated by the dipole magnets allow the beam to handle tighter turns. When particles are bunched together, they are more likely to collide in greater numbers when they reach the LHC detectors. Quadrupoles help to keep the particles in a tight beam. They have four magnetic poles arranged symmetrically around the beam pipe to squeeze the beam either vertically or horizontally. Dipoles are also equipped with sextuple, octupole magnets, which correct for small imperfections in the magnetic field at the extremities of the dipoles.

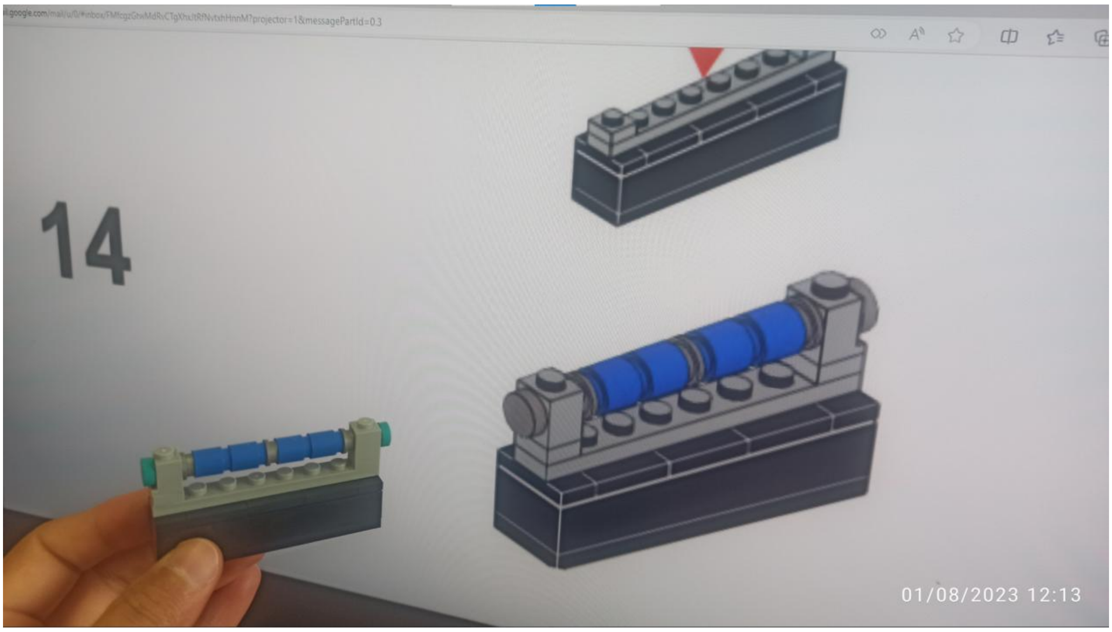

Figure 5 Showing LHC dipole magnet through LEGO particles.

About workshop and the main opinion this event

Between July 10th and August 14th, we engaged in a series of dynamic LEGO Workshops, welcoming teachers from various corners of the world. The central goal of these workshops was to foster a collaborative space for the exchange of fresh ideas and constructive feedback. This collaborative endeavour aimed to enhance the LEGO instruction process and offer comprehensive insights into the realm of detectors. Throughout these engaging workshops, we seized a multitude of innovative concepts and valuable feedback that surfaced organically during the interactive sessions. The attending teachers also received a wealth of new knowledge regarding detectors, which further enriched their understanding of this intricate field. The workshops were not only informative but also injected a sense of delight and enjoyment into the learning experience. Guiding these enlightening sessions, Julia Woithe, my supervisor, assumed the role of an invaluable source of information. Her comprehensive insights into detectors, coupled with her elucidation of their underlying purpose, added immense value to the proceedings. I am convinced that the participating teachers not only gained insights into particle physics but also enriched their tool-kit for their future endeavour. As these educators embark on sharing their new-found knowledge with their students, I anticipate a surge of interest in the realm of physics among their students.

Throughout the workshop, the educators were actively involved in the assembly of detectors using LEGO components and the accompanying handbook. Their constructive suggestions on refining the LEGO instruction manual greatly enriched the learning process. In the aftermath of the workshop, I meticulously compiled all the handbooks and feedback received, amalgamating them into a comprehensive single resource.

On July 12th, we convened to deliberate upon the amassed feedback, collectively exploring ways to integrate these insights. As a result of these discussions, we made meaningful refinements to the handbook, ensuring that it is a testament to the collaborative efforts and insights gained during this enriching period.

Figure 6 Instruction LEGO detectors

Second task: Learning soap bubbles through scientific way.

Creating soap bubbles is undeniably enjoyable, yet delving into this activity through a scientific lens imparts a deeper understanding. Acknowledging this, my supervisor, Julia Woithe, entrusted me with the task of comprehending the intricate mechanics underlying the formation of these captivating spheres. The objective was to unravel the diverse tools and techniques that influence these processes while discerning the fundamental physical principles at play.

On the 23rd of July, our exploration took on a structured scientific approach as we engaged in a comprehensive discussion. In the lead-up to this enlightening exchange, I immersed myself in the realm of bubbles, amassing a wealth of information that shed light on their behaviour and properties. Some of the key insights I gathered are as follows:

1.What is a bubble?

A bubble is a thin film of soapy water [6]. Most of the bubbles that you see are filled with air, but you can make a bubble using other gasses, such as carbon dioxide. The film that makes the bubble has three layers. A thin layer of water is sandwiched between two layers of soap molecules. Each soap molecule is oriented so that its polar (hydrophilic) head faces the water, while its hydrophobic hydrocarbon tail extends away from the water layer. No matter what shape a bubble has initially, it will try to become a sphere. The sphere is the shape that minimizes the surface area of the structure, which makes it the shape that requires the least energy to achieve. In dry air, the water evaporates quickly, meaning that the dry air will soak up the water inside the bubble and the skin will gradually grow thinner and thinner and eventually pop!

2.Ingredients in Bubble Solutions:

On July 20, 2015, Gary Pearlman Gary Pearlman and his team studied the properties of soap films and how they change when polymers of different kinds are added [7]. The results provide a unique insight into the science of bubble formation and the atmospheric conditions most favourable for world-record attempts. The consensus is that the best bubble mixtures contain water, a detergent in the form of dish-washing liquid (Dawn Pro seems to be the favourite), and a mix of polymers, long chain-like molecules that increase the viscosity of the fluid. The favoured polymers are polyethylene oxide (also called polyethylene glycol), often used in skin creams, and guard gum, a common food thickener extracted from guard beans.

3. But why is it round? Why not a square or a triangle?

Bubbles that are free and not attached to anything are always round because there are forces pushing on the bubble from the inside and the outside in equal directions. This causes the surface to be completely smooth and uniform, without any corners and edges. Spheres are the strongest and most efficient shape in nature, which is the basic reason why bubbles form like that. A bubble will always try to hold the least amount of surface area inside of it! Out of all the geometric shapes, a sphere takes up the least amount of space! Soap films always adopt the shape which minimizes their elastic energy, and therefore their area. Basically, as they follow a minimization principle, they always try to fit into the lowest energy state possible. For a soap bubble, the lowest energy state is directly correlated with the lowest surface area. This is why free-floating bubbles form spheres at it occupies the least surface area.

Conclusion from experiments

On August 2nd, I conducted a series of experiments involving soap bubbles, and what transpired during these experiments left me utterly astonished. The unfolding events were nothing short of remarkable.

First experiment with strings:

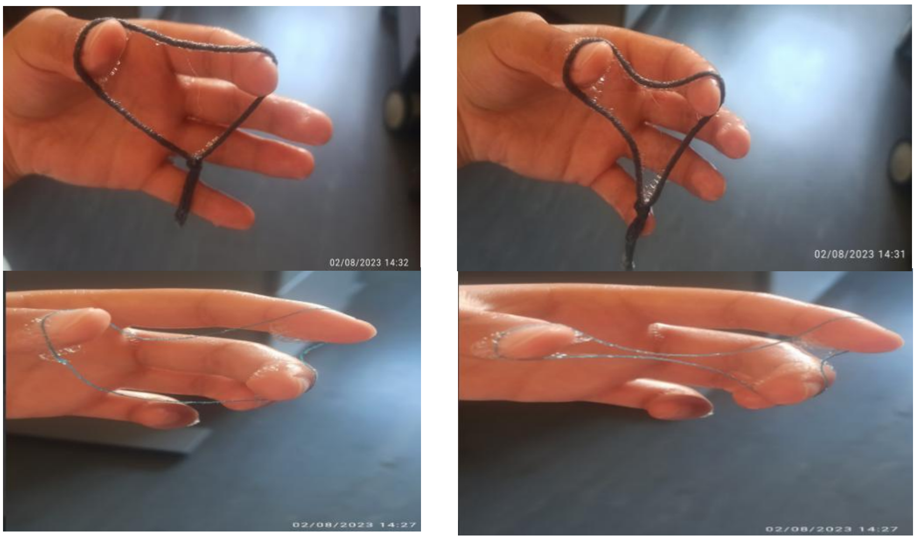

Figure 7 Testing interaction forces between molecules

I conducted a series of diverse experiments involving various materials, each yielding distinct outcomes. For instance, I utilized both thick and thin strings, and the results were notably dissimilar. Despite the common factor of interactions occurring between the strings and the molecules of the bubbles, as well as between the individual molecules within the bubbles themselves, the curvature exhibited by these strings deviated significantly. Interestingly, the thick string exhibited a lesser degree of curvature compared to the thin string. This divergence in curvature led me to hypothesize that while the forces of interaction between the strings and the molecules of the bubbles were comparable, the varying masses of the strings played a pivotal role. Specifically, the slender string displayed a more pronounced curvature due to its lighter mass. Consequently, the stability of the bubbles connected to the thin string endured for an extended duration, a contrast to the relatively quicker dynamics observed with the thick string.

Second experiment with different shape of magnets:

Figure 8 Experiment with magnet tools

During my experimentation involving bubbles and magnetic tools, I observed a notable extension in the stability of the bubbles when compared to other conditions. This phenomenon led me to hypothesize that the introduction of magnetic tools initiated the emission of a magnetic field in their proximity, subsequently giving rise to magnetic forces. In this intricate system, the forces at play became twofold: the inherent interacting forces and the newly introduced magnetic forces. This synergy of forces culminated in a heightened stability for the soap bubbles. The magnetic component introduced an additional layer of influence, enhancing the cohesive properties of the bubbles and prolonging their structural integrity.

Third experiment with two type of cubes:

Figure 9 Experiment with different size cubes

I procured two cubes for my experiment, both with side lengths of 8 cm, except that the second cube was precisely half the size of the first. Intriguingly, during the course of my experiment, the 4 cm-cube demonstrated a remarkable degree of stability. The bubbles formed around this smaller cube exhibited a prolonged duration of stability when contrasted with those formed around the larger 8 cm-cube. This phenomenon led me to conjecture that the relationship between material size and bubble stability is inversely proportional. In simpler terms, as the material size diminishes, the stability of the resulting bubbles tends to increase. This concept is underscored by the observation that when utilizing smaller materials, such as the 4 cm-cube, the bubbles tend to maintain their structural integrity for a more extended period, suggesting a correlation between material dimensions and bubble stability.

Fourth experiment with plastic straws and magnet tools.

I utilized plastic straws to fashion two distinct shapes: a triangular form, and an equivalently sized triangle constructed using magnet tools. Subsequently, I immersed both triangles in soap bubbles and closely monitored their behaviour. The resulting observations led me to record the following measurements.

N	Plastic straws (seconds)	Magnet tools (seconds)
1	1.26	1.45
2	1.35	1.56
3	1.30	1.55
4	1.38	2.05
5	1.48	2.35

Table 1 Experiment with plastic and magnet tools

The average stabilization time for soap bubbles using magnet tools was approximately 1.78 seconds, while for plastic straws, it was around 1.4 seconds. This signifies that the stability of soap bubbles created with magnet tools exceeded that of those formed around plastic straws by approximately 1.3 times. This discernible contrast strongly suggests the influence of magnetic forces at play.

Figure 10 Experiment with plastic and magnet tools

A catenary curve shape with soap bubbles

Figure 11 A catenoid

Minimal surfaces *are the surfaces that* follow the principle of least action to acquire a shape that minimizes their surface area with respect to a specific volume [8]. Soap bubbles are known to follow the minimization principle 5 to formulate exotic minimal surfaces similar to the one that will be used in this exploration which will be justified through extensive mathematical concepts ranging from basic differentiation to integration by substitution and surface area of

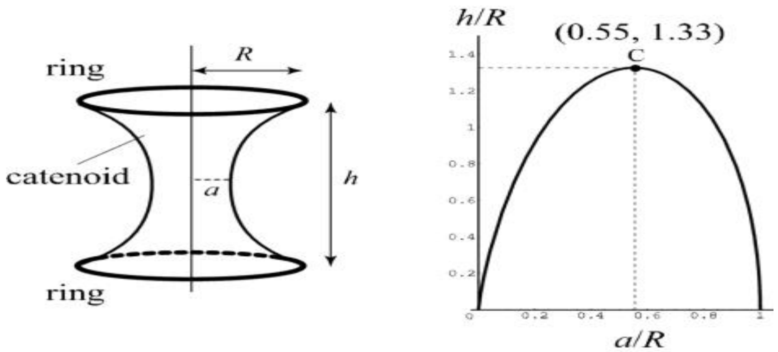

Figure 12 Showing a catenoid that is a minimum surface which follows the principle of least action for the relation shown on the right between height h versus inner radius a

revolution formulas through integration. Generally, soap films act like the aforementioned as they try to acquire the least surface tension hence the least surface area to achieve a behaviour of least action in accordance with the principle of least action where the kinetic energy stays minimal in terms of potential energy. Soap films always adopt the shape which minimizes their elastic energy, and therefore their area. Basically, as they follow a minimization principle, they always try to fit into the lowest energy state possible. For a soap bubble, the lowest energy state is directly correlated with the lowest surface area. This is why free-floating bubbles form spheres at it occupies the least surface area.

Surface area of the shape In order to calculate the surface area, we would have to use the equation of catenary and formulate an equation

$$y=a\cosh\{\frac{x}{a}\} \quad \textit{a=a set parameter}$$

using integration to formulate for the area under the curve. The following is the equation of catenary:

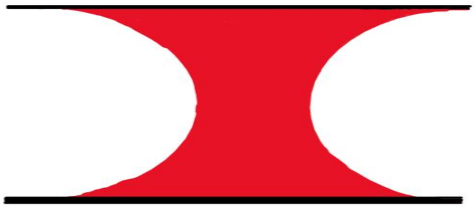

Figure 13 Shaded region showing the surface area of the shape

x = value on the x-axis y = value on the y-axis

Now we integrate the equation on both sides:

$$\int f(x)dx = \int a\, cosh\{\frac{x}{a}\} \tag{1}$$

Before proceeding further, we recall

$$cosh\{\frac{x}{a}\} = \frac{e^{\frac{x}{a}}+e^{-\frac{x}{a}}}{2} \tag{2}$$

So now equating the right side of the equation (1) with right side of (2) we get:

$$a\int\ cosh\{\frac{x}{a}\} = a\int\frac{e^{\frac{x}{a}}+e^{-\frac{x}{a}}}{2}dx \tag{3}$$

Now continuing with the right side of equation (3), we integrate the following expression:

$$= a\int\frac{e^{\frac{x}{a}}+e^{-\frac{x}{a}}}{2}dx$$

If we notice there are two things, we need to integrate here so we divide the expression into two separate components;

$$a\left[\frac{1}{2}\int e^{\frac{x}{a}}dx + \frac{1}{2}\int e^{-\frac{x}{a}}dx\right] \tag{4}$$

Using u substitution, we first integrate the first part, so for

$$\int e^{\frac{x}{a}} dx$$

$$\mathrm{u} = \frac{\mathrm{x}}{\mathrm{a}}, \mathrm{du} = \frac{\mathrm{dx}}{\mathrm{a}}, \mathrm{dx} = \mathrm{du} \times \mathrm{a} \tag{5}$$

Substituting for $\frac{x}{a}$ and dx, we get the following by bringing the constant parameter a out of the integral;

$$\int e^u du \times a = a \int e^u du = a \times e^{\frac{x}{a}} + \mathrm{C} \tag{6}$$

Now for the second part;

$$\int e^{-\frac{x}{a}} dx$$

Here we do the same thing using;

$$\mathrm{u} = -\frac{\mathrm{x}}{\mathrm{a}}, \mathrm{du} = \frac{-\mathrm{dx}}{\mathrm{a}}, \mathrm{dx} = -\mathrm{du} \times \mathrm{a} \tag{7}$$

Hence, we get:

$$\int e^u (-du \times a) = -a \int e^u du = -a \times e^{-\frac{x}{a}} + \mathrm{C} \tag{8}$$

Now substituting (6) and (8) into (4), we get:

$$\mathrm{a}\left[\frac{1}{2}(a \times e^{\frac{x}{a}}) + \frac{1}{2}(-a \times e^{-\frac{x}{a}})\right] + \mathrm{C} \tag{9}$$

So, we get:

$$a^2 \times \frac{e^{\frac{x}{a}} - e^{-\frac{x}{a}}}{2} + \mathrm{C} \tag{10}$$

This gives us the following final equation which can also be found using the basic rule for integration we know that integral of $\cosh(t)$ becomes positive $\sinh(t)$, and as we know that we divide the value by the integral value to get:

$$\int f(x) = a^2 sinh\{\frac{x}{a}\} + \mathrm{C} \tag{11}$$

Now this gives us the surface area for half of the shape that is the image on the left. Now, in order to get the surface area of the complete shape, the above equation will be multiplied by 2. Here we are assuming that the shape has a line of symmetry at x=2cm that cuts the shape into two equal and congruent segments. Hence, we get the following equation

$S = a^2 sinh\{\frac{x}{a}\}$+C Where S= Surface area of the shape (12)

Formulation of the shape. After amalgamating all this secondary research, it was found out that in order to construct a focused analysis onto the three dimensions represented by the aforementioned hyperbolic equations, it becomes difficult to do that. Hence Just a chunk of the two-dimensional catenoid film was taken that could be represented in two dimensions. So, I used two equal lengths of plastic straws and connected them with two thin and thick strings to make something similar to the following figure. Using the equation of catenary, the visual representation of this shape will be given after the derivation of the equation for this shape. After making this stencil, it was dipped in a soap film solution and then taken out for qualitative observations. The surface tension in the soap films and their ability to make minimal surfaces made the strings to taut inwards to gain the least surface area with reference to the height. Hence the following shape was acquired which was completely novel and based upon personal innovation stitched through the secondary research conducted. Now, using the aforementioned shapes, I used the equation of catenary to mould how the surface area transitioned with a deviation in height. on the tendency of soap films to behave as minimal surfaces that is validates the transition in the 2-dimensional shape to change with the principle of least action.

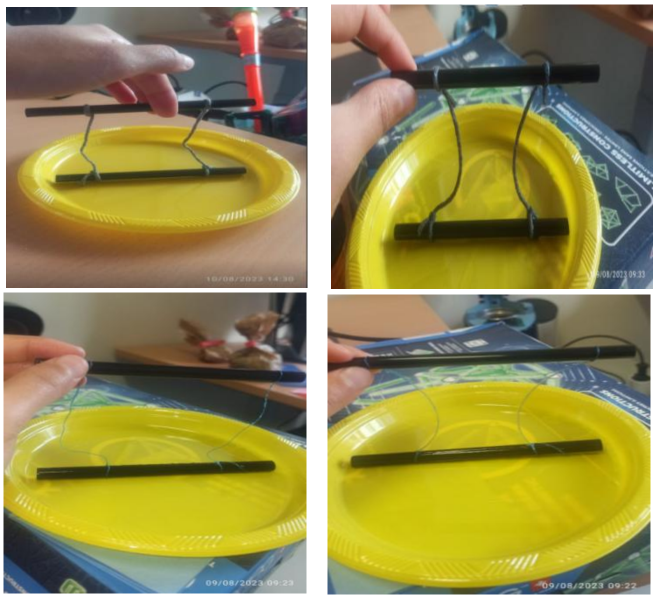

Figure 13 experiment with thin and thick strings

I did soap bubbles and recipe is [9]:

1. Measure 6 cups of water into your container, then pour 1 cup of dish soap into the water.
2. Slowly stir until the soap is mixed in, being careful to not let foam or bubbles form.
3. Measure 1 tablespoon of glycerine and add it to your container.
4. Stir the solution until it is well mixed. For best results, let your solution sit overnight. (Note: if you used “Ultra” dish soap, double the amount of glycerine or corn syrup).
5. Add 2 tablespoon sugar to boiled 1/2 cup boiled water.
6. Dip your bubble wand into the mixture, wait a few seconds, then blow.

References

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