Rainbow Arch

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Introduction

A rainbow is an arch of colors that are created naturally by sunlight under specific atmospheric conditions. When sunlight in the atmosphere travels from air into a water droplet, the light slows down and bends as it enters a denser medium. In doing so, the light reflects off the inside of the droplet, separating it into its component wavelengths. Consequently, when light exits the droplet, it creates a spectrum of colors.

Based on Fermat's Principle, light always takes the quickest path when traveling from its source to the observer (Fermat's Principle). In most cases, this path is a straight line. However, when light has to travel through multiple media, such as air and water, it will change speeds. This is because the speed of light varies depending on the medium it is in. As a result, the most direct path is not always the quickest. Light will ultimately travel in a path that is in between the most direct path, a straight line, and the path that includes the least amount of media with a slower speed of light (Fig. 2).

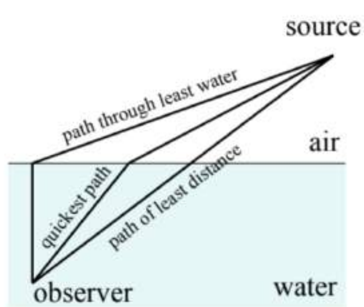


Fig. 1: *Depiction of why light refracts when changing mediums from The Calculus of Rainbows (Rachel W. Hall and Nigel Higson, 1998)*

The speed of light is slower in water than in air. Therefore when light hits the boundary between air and water, it will bend at the entry point creating an angle of refraction. This refraction angle can be computed exactly using the equation:

$$(1) \qquad sin(\alpha) = ksin(\beta);$$

where α is the angle of incidence, the angle at which the light is coming in contact with the boundary surface, β is the angle of refraction, and k is the ratio of the speed of light in the source media over the speed in the observer's media.

When considering a water droplet or mist, the light will enter the drop at an incident angle α. At the entry point, the light is refracted at an angle β, before traveling and hitting the back of the drop at the same angle β. The back of a drop acts as a mirror reflecting the light beam off at the same angle of incidence β. The light will then leave the droplet, refracting again as it transitions back to the air media and travels to the observer (Fig. 2).

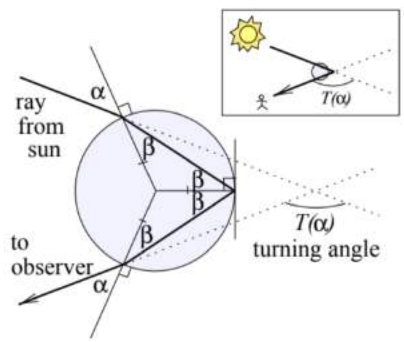


Fig. 2: *Depiction of how light travels through a spherical water droplet from The Calculus of Rainbows (Rachel W. Hall and Nigel Higson, 1998).*

Using this geometry, the total angle the light turns can be found with the equation:

$$(2) \qquad T(a) = 180^{o} + 2\alpha - 2\beta \,;$$

When encountering mist, light is refracted and turned on its path through various angles. To find the angle between the observer and the field of water at which the light creates a rainbow you must find the rate of change in the turning angle ($T(\alpha)$) with respect to α. By differentiating equation (1) and (2) and plug-in you get:

$$(3) \qquad \frac{dT}{d\alpha} = 2 - \frac{4cos(\alpha)}{kcos(\beta)};$$

Using linear approximation, it is possible to calculate a point at which every ray of light entering with a given incidence angle is turned by approximately the same amount. This occurs when $T(\alpha)$ is around 138 degrees, or when the observer is at a 42-degree angle to the light source. At this angle, it is possible to observe the spectrum of rainbow colors because the constant k in the Law of Refraction is different for each color of light. Therefore, when a white light switches media, the colors each refract differently. This separates them and creates the rainbow.

In this project, the objective was to create an artificial rainbow installation. This project takes its inspiration from a fluid art piece presented in class: Olafur Eliasson's *Rainbow Assembly* (2016). Exhibited in a dark room at the Samsung Museum of Art in Seoul, the installation consists of multiple spotlights that illuminate a circular curtain of mist. As the viewer passes through the installation, he is able to observe a rainbow. When discussing his work, Elaisson suggested that, as a member of the audience, you should "feel yourself seeing" the ephemeral, the unstable (Studio Olafur Eliasson). His work echoes our fundamental search for serenity within an environment that is constantly changing, and constantly unstable.

Img. 1: *Rainbow by Olafur Eliasson | Courtesy of Acute Art.*

Above all, we were struck by both the intensity of the work as well as the intimacy of the space. Indeed, viewers can look through and participate in their own unique rainbow experience. It is impossible for two people to view the rainbow from the same angle at the same time; every observer has his own, unique viewing of the phenomena. Aiming to reproduce our own version of the piece on campus, we planned to set up a miniature installation, modifying Eliasson's setup, in which students, staff, and faculty could visit and experience their own unique rainbow spectrum. In the end, we sought to capture the same juxtaposition of individual and collective experiences that Eliasson's work manifests. On the one hand, we invited the campus community to share in this rainbow installation. In that sense, our project was a communal celebration of the end of the semester. Still, as Eliasson aptly explained, the installation also emphasizes the individual experience. The rainbow often is used to represent hope and new beginnings, amidst the chaos of finals season, the work represents a moment of personal reflection as we look forward to the end of the semester. It is a moment for each person to pause and contemplate the moment they're in. A moment to appreciate the beauty of their personal rainbow. The gate also emulates a feeling of running through the sprinklers giving a child-like innocence to the installation.

Methods

This project followed the original proposal to artificially produce the natural phenomenon of a rainbow in a controlled setting. As outlined in the proposal, our objective was to use a mist machine to create a field of water. As the light refracts on the water droplets, our assembly would produce a rainbow large enough for people to walk through. In the process of creating our temporary interactive installation, we iterated through three different designs. Each design is outlined below, as well as an explanation of its corresponding strengths and limitations.

Initial Schematic:

To create the outdoor installation, the initial proposal used a tent to block outside light from the sun. The tent would also allow people to walk under the misters, which would line the tent top. The tent would also serve as a framework to hold the lighting system at an exact angle of 42 degrees (Fig 3).

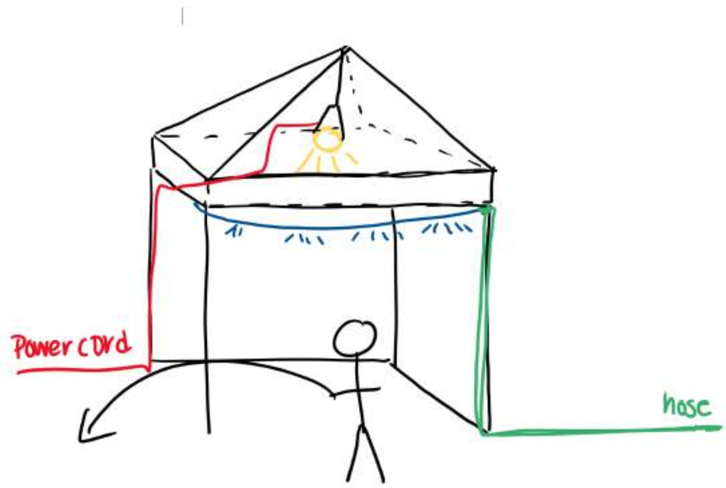
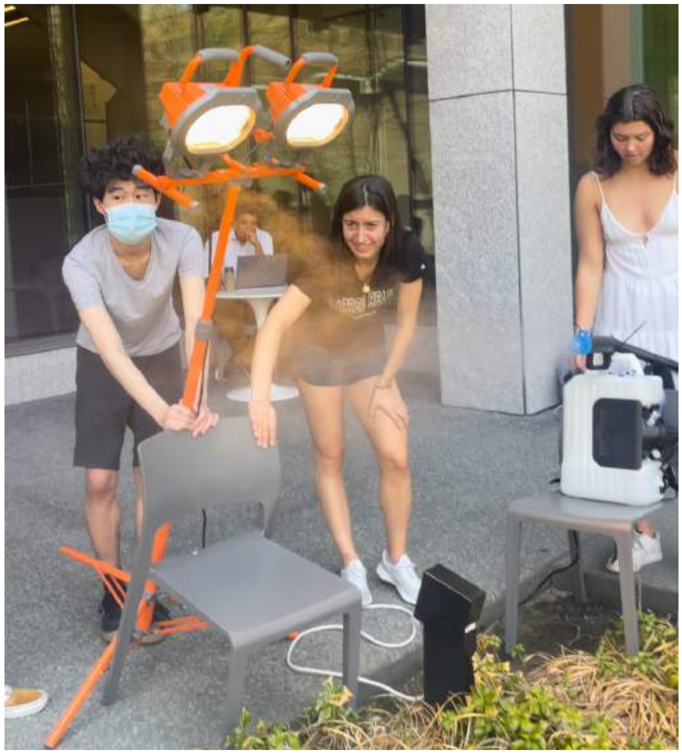


Fig. 3: *Initial experimental design setup*

Iteration 1: Electric Machine Backpack Sprayer

Before the installation could be made, we tested the proof of concept ensuring that a rainbow could be made from the mist and a light source. In this iteration, we used an electric backpack sprayer as our water source, and a halogen flood lamp as our light source. This allowed us the flexibility to test the setup indoors, without needing to accommodate for weather conditions or to find a water source at our location. Unfortunately, both lamps we tested leaned towards yellow light instead of white light. Since the light was yellow, the setup did not capture the entire spectrum of the rainbow. Instead, we observed a sheet of mist of yellow water (Img 2). There was also an issue with the intensity of the light. In order to get the light to reflect from the mist, the light source had to be inches away from the mist plane. This would create problems if we would want people to be able to walk under the rainbow. We were unsure if the problem of light intensity was due to the strength of the lamp or the amount of ambient light outside. During our next iteration, we aimed to rectify these issues using a new flood lamp with more white light, and a 10 x10 x10 foot tent to block out any ambient light entering the setup.



Img. 2: *Image of electric machine backpack sprayer set up and yellow mist field.*

Iteration 2: Lawn Mister in Tent

Recreating the initial schematic, we set up a dark tent and hung up halogen lamps onto the interior scaffolding. Using garden misters, we tied them to the edges of the tent scaffolding in an arched pattern (Img. 3). Our hope was that the setup in the tent would allow the halogen lamps to produce maximum brightness instead of being interfered with sunlight, as compared to the previous iteration. However, because one side of the tent needed to be kept open to allow the audience to walk through, once again, sunlight interfered with our setup and made the halogen lamps' brightness pale in comparison. This approach also had the downside of being heavy and unwieldy, with the tent taking a significant amount of time to set up.

Img. 3: *Photo of initial tent/mister set up.*

Another issue we found with this setup was, although advertised as a white light, the lights purchased for this setup were also on the yellow side of the spectrum. This, again, made it impossible to create a rainbow using these sources of light. In addition, the weight of the lamps themselves made them difficult to secure at the necessary 42º angle. This, again, complicated the creation of a stable rainbow light spectrum. To find a solution, we decided to test the garden misters by simply turning on the water source and holding the misters up to the sun. From there we were able to capture an image of the rainbows created (Img 4).

Img. 4: *Photo of garden misters refracting the light from the sun and creating a rainbow*

Iteration 3: Mist Trellis

Since we were able to capture the rainbow using the garden misters and the n, the final iteration builds on those aspects. Instead of creating an outdoor environment that blocks out the sunlight, we chose to use the sunlight as our light source forgoing the tent altogether. To create an area that could be interactive and walked through, we used a trellis as the framework and wrapped the mister directly around a trellis frame (Img 3 &4).

Img. 5 & 6: *Photos of the final iteration of the Mist Trellis*

This iteration has the benefit of being lightweight while also providing a larger open area, giving people more space to walk through. This approach offered a more manageable setup that did not require reconstruction efforts. Because of this, the installation was more mobile allowing for multiple places where we could set it up and it can be viewed. The only constraint that remained for installation location was if there was a water source within 25 yards of where we placed the trellis. Although the use of the sun takes away from the control we have over the light source and how the rainbow can be seen, in the end, it creates a more personal experience for the viewer since they all get to experience their own natural rainbow.

Results

In our final interaction, we had great success in generating and capturing rainbows in photos. Visualizing the rainbow was initially challenging since we were standing at eye level with the mist. This resulted in the arch of the rainbow spectrum being on the ground. Once we elevated the height at which we took the photos, we could visualize the spectrum at body height. We found that the rainbow could be seen more vividly on a dark backdrop, so we held up a black nylon tarp behind to capture some of the photos.

Img. 7 & 8: *Looking Forward*

Img. 9 & 10: *Reminiscing*

Img. 11: *Walking on Water*

Overall, we found that we found that we did not produce several rainbows from the multiple misting heads but only a single one when we directed all the misters in a similar plane. Although this was a different result from what we initially expected to see from the misting heads pointed at different angles, we were able to visualize a large singular rainbow spectrum that was easier to photograph.

Discussion, Conclusions, and Recommendations

The most important takeaway from the iterations and testing of the experiment are that under limited time and resources, it is sometimes difficult to start from scratch. We wanted to – almost literally – recreate the sun and ultimately had to utilize it anyway.

Although we are proud of our ambitious plan to create a miniature Eliasson, we quickly realized that we had vastly different resources and constraints that eventually led us to our final –

and best – iteration. In the future, we would recommend finding an indoor location to set up the rainbow. One of our biggest concerns was the ambient light conflicting with the incident light of the lamp, which impacted the light spectrum. If we could have found an indoor space that allowed water and hoses, we would have been able to easily control the light input and produce more intense incident light.

References

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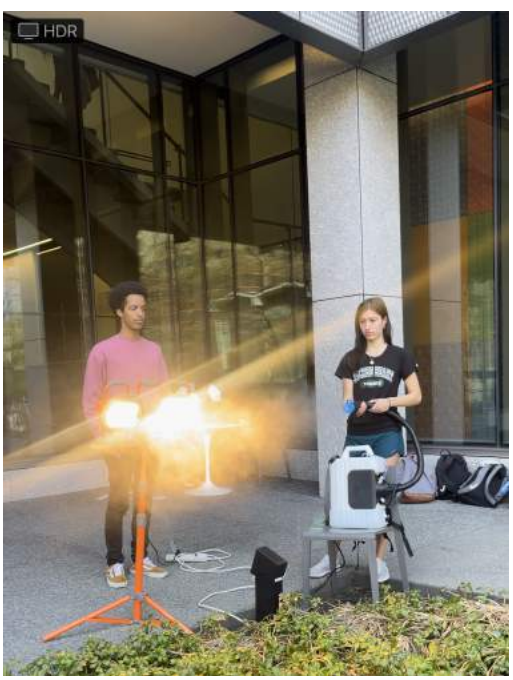
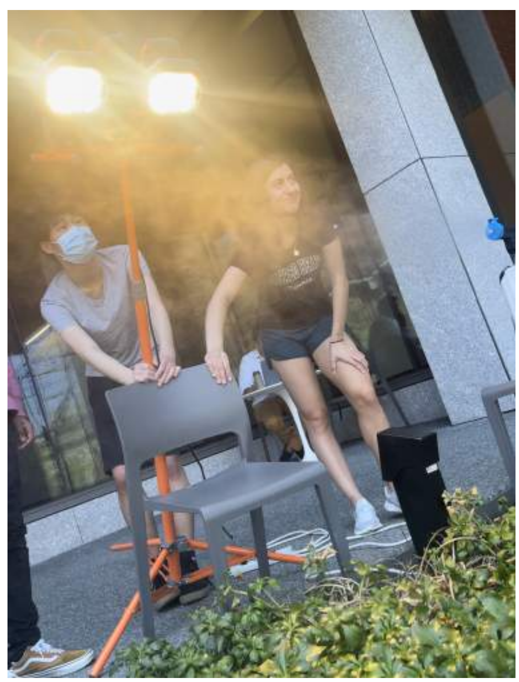
Appendix

A1: Final Product Images

A2: Construction and Set Up Images

A3: Extra Images of Iteration 1





A4: Extra Images of Iteration 2

A5: Extra Images of Iteration 3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