BLOSSOM MODULE

THE SECRETS OF SOAP BUBBLES #2
By Paola Rebusco

Hello. Some soap bubbles we are used to typically aren't blue. They are rainbow colored, and they can be more or less transparent.

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In the previous Blossom module about soap bubbles, we were investigating the basic nature of soap bubbles and their shapes. Today we will find out everything—or as much as we can—about the color of soap bubbles. Also, did you know that soap bubbles and telescopes have something in common? We will understand what this is. Moreover, we will see that blue bubbles actually exist, and we will try to understand the difference in color between the blue and the usual bubbles. Finally, if you watch a soap bubble for a certain amount of time, you may notice that the colors and the patterns on the surface change over time. This can have something to do with the large-scale motion on the atmosphere of the earth and other planets.

In order to understand the colors, we first must make the connection with light and waves. So let's start making some waves.

Here I have a salad spinner filled up with plain water. If I poke my finger in the center, you can see one ripple, one pulse that is moving outward and then coming back because it reflects on the wall. I can do it many times, at a periodic rhythm, and you can see waves on the water on the salad spinner. Now, it may be a little bit difficult to see the waves for you, because there is a camera in a difficult position. However, you should try to do this in the classroom. If you look from the right position, you will be able to see the ripples and the waves moving in different directions. You can also try to create waves using a very long rope or a string.

So stop the video now and I'll see you soon.

Welcome back! Now that we know how to create some waves, we want to look at their anatomy.

What is a wave? A wave is a perturbation that travels in time and space. A transverse wave is a wave that is oscillating in one direction and is traveling in a perpendicular direction. So here, for example, I have string, and I can perturb it in this way. The perturbation in this direction is creating a pulse that is traveling in the perpendicular direction. If you look at the black tape in the center, you will notice that it's just moving back and forth; it's not actually moving with the wave itself.

[spinning noise]

Let's look at this in a drawing. Here we have the displacement in function of the distance from the origin, the distance from the place where the perturbation is taking place. We call amplitude the maximum displacement of the wave, while the crests and troughs are the highest and lowest points reached by the wave. The wave length is the distance over which a wave repeats itself. For instance, it is the distance between two crests, or between two troughs.

You may have noticed when you were trying to create waves in the classroom that when you increased the frequency of oscillation then the wavelength, the distance between crests, was decreasing, and vice versa.

Why are we talking about waves? Well, light is an electromagnetic wave. Other electromagnetic waves includes microwaves, radio waves, and x-rays, for example. Electromagnetic waves originate from the oscillation of the electric and magnetic fields. We cannot see this field oscillating, but we can see the resulting light.

So, now you will try to create a rainbow in your classroom. You can do this by using a light, or flashlight and a bowl full of water. And you need a lot of dark.

So please switch off the video and the lights and see you soon.

Well done! You decomposed light.

Indeed, white light—what we usually call the normal light—is composed of all the different colors. But what makes these colors, these waves, different? This is the wave length. Indeed, the wave length of the red light is larger than the wave length of the violet light. And the other colors have wave lengths in between. So here, from red to violet, we have decreasing wave lengths, which means increasing frequency. This distance, in reality, is really really tiny. It's on the order of one-hundredth of a billionth of a meter. A billionth of a meter is called a nano-meter.

Now, when you were shining the light through the water, what happened was that the different colors, the different wave lengths, were bent—in scientific terms we say "refracted"—at different angles. This is one way to decompose light. But we can do it also in another way. For example, let's use a black mug, or a film can, and dip it in a soapy solution. We want to create a film here, and we want to look – now the film exploded, so I'm going to do it again.

You can notice two things. First of all, you can notice that there are many different colors. Second, you see there is the reflection of the ceiling, in this case.

Try to do this in the classroom, and take careful note of what you see, what are the patterns, and what are the colors.

Welcome back! I hope you had fun playing with the thin film in a black mug, and that you observed the horizontal bands of colors and how they change in time.

Here we have a nice photo of a thin film, where you can see all the colors. But where do they really originate? We said that colors are light, and light is an electromagnetic wave. Waves travel in time and space. They can bounce off some obstacles. If they go through a different medium they get bent, they refract.

If they meet at the same position, they can interfere. Interference is at the origin of the colors in soap bubbles. For example, we can have constructive interference. When we have constructive interference, the crests of two different waves match, and the troughs match the troughs of the other wave. The resulting wave will be reinforced; we have an amplitude that is higher than the two incoming waves.

Destructive interference occurs when two waves meet at the same position, but they are out of phase. So the maximum meets with the minimum, and vice versa. If it has the same amplitude, well the resulting wave will be nothing, they cancel out. This is a very weird phenomenon, because we have light that meets other light, and the result is something dark. [drawing on the board as she talks]

Now, in this drawing, there are two extreme situations. In reality, there will be all the situations in between. If we look at a soap bubble, what is happening? We said that a soap bubble can be thought of as a sandwich of water in between two slices of soap. So when we have an incoming wave – let's say purple light – it will reflect on the first external surface and then part of it will be transmitted through the water onto the second surface where it will be reflected again. And here, of course, there is a little part that is still transmitted.

So the two reflected waves will meet at the surface and they will interfere. The interference can be constructive, and so we will see the colors more intense; or it can be destructive.

When we consider a soap bubble, we look at it, and we look from different angles. Moreover, the thickness is not the same everywhere. So what happens is the different waves, the different colors, work through different paths. So when they interfere, the difference between the wave lengths and how they compare to the thickness of the soap film, will originate different colors. This is where all the swirling colors of soap bubbles take place.

Now, in the classroom, you will investigate interference using sound. I also want you to go back to the math experiment and observe carefully what happens at the top of the film after some time.

So, now we have two pieces of information. First of all, we observed that the film at the top, after some time, becomes black. This means that there is some destructive interference, because we saw that light plus light gives something dark when we have destructive interference. And the second piece of information is that the film at the top becomes thinner. This is due to the fact of gravity. The liquid in the soap film will go downwards, so the top of the film becomes thinner and thinner over time.

Are these two clues really in agreement? Hmmmmm…. Let's try to find out.

Here we have the thin soap film. It is very thin, and an incoming wave. The wave length is much larger than the thickness of the film itself. When the wave hits the soap film, part of it is refracted on the first surface, while part of it goes through the water and the soap and gets refracted on the second soapy surface. Here it is. Then these two outgoing waves will interfere.

However, here there seems to be something wrong, because these waves are interfering constructively. We have the maximum in correspondence with the maximum, and the minimum in correspondence with the minimum. This is not what we observed. We must not be seeing something.

And here is what we are missing. When we have the incoming wave, the part that is reflected at the first surface is changing phase. This means that the maximum becomes minimum, and vice versa. This happens at the surface between air and water. The rest of the wave, which goes through and is refracted here between water and air, when it's refracting it doesn't change phase.

So now we have two outgoing waves, but they are out of phase. So we will have a destructive interference, something black. This is now our problem is solved.

Here we can see an example. This represents the first surface. Here we have an incoming wave, and when it is reflected at the first surface, it changes phase.

We can look at this also when we are considering a pulse that is transmitted on a string or a long rope. If the end is free to move, then when the pulse is coming and then gets reflected, it doesn't change phase. The incoming and outgoing pulse have the same phase. We can see here an animation. However, if the end of the rope is fixed, then when the pulse is refracted, it changes phase. The reflected pulse has exactly the opposite phase. This is somehow what happens at the interface between the air and the water. We're going from a fast-moving medium to a slower-moving medium. It is as if the wave was hitting against this brick wall and so when the wave is coming back, it has the opposite phase.

So, I told you at the beginning that soap bubbles have something in common with telescopes. Let's see what it is. First of all, if you consider the most common and the biggest optical telescopes, then they have in common with soap bubbles that reflection plays an important role in both cases. We won't go into the details of how optical telescopes work, but you can see here that they have mirrors. And indeed, they are composed of different curved mirrors, the light is reflected and finally an image is formed.

If we consider not just one single telescope but an array of different telescopes, or radio antennae, then there is another aspect in common, which is interference. Here in this image, there is a project that is in the phase of construction. It's called Alma, it is an international collaboration, and it will be composed of 66 antennae.

So, when you are using telescopes or antennae as interferometers, what happens is that we have them observing the same celestial object, for example the same star. Then the light coming from the different telescopes or the different antennae is combined. This allows to have deeper and more precise observations. It's like using many smaller telescopes as one single, much larger telescope.

In order to understand in detail how this works, we need a little bit of physics – more than what you know right now. So I will leave this for the future. For now, you should just keep in mind that this is possible, thanks to interference – the same phenomenon that occurs on the surface of soap bubbles.

Now, I will leave you for a couple of minutes so you can play in the classroom, trying to create pulses with a rope so they reflect changing, or not changing, phase.

Welcome back! Let's go back to soap bubbles. At the beginning we were talking about blue bubbles, and I was trying to make them. I was trying to do it by mixing a normal soapy solution with some food coloring, in this case blue. However, you can see here what happens.

Hmmmm… the bubble remains transparent, and all the dye goes to the bottom. This happens because the molecules of food coloring are heavier than the molecules of soap and water, so they just go to the bottom.

However, I found out that there are some toy producers who invested a lot of time and money looking for colored bubbles, and finally they found the right recipe. These bubbles are called Zubbles, and you can see here one example. They use a dye that does not stain.

How does this work? Well, this is a dye that sticks to the soap molecules at the surface. Here the tadpoles represent the soap molecules, and you have this blue dot that represents the dye. This dye has also the right weight, so it is diffused homogeneously in the sandwich of water. As a result, when we have some light coming in on the surface of the bubble, the dye molecules are absorbing this white light, and then they are re-emitting preferentially one color – in this case blue. So there is still interference and reflection going on, but the blue color has a different origin. It originates from the dye. It is exactly in the same way as you see my sweater, turquoise. My sweater is absorbing the white light, all the different colors, and then it is re-emitting preferentially one color, the one you see. So in this case, the interference is not involved.

We will finish now with one last experiment. We take again the black mug and the soapy solution. However, this time we try to make a semi-sphere. I want you to look closely at the patterns.

Now, in this way, I'm creating some vortices on the surface of the bubble. And unfortunately, you cannot see them right here, but you can see them in the classroom once you try to do it yourself. You will see that these vortices are very similar to, for examples, cyclones on earth or cyclones on Mars. This indeed inspired a group of physicists who were using soap bubbles as models of cyclones on planets. Here we have this beautiful image that was published in Physical Review letters, where this vortex is created just by heating the equator of soap bubbles at different temperatures. Heating the crater would create convective motions, and this is the origin of this beautiful vortex. The colors keep trace of the thickness of the disk.

This is it for today. It's your turn to play in the classroom.

See you next time.

Ciao!

END OF MODULE

TEACHER'S MODULE

Hello Teacher. The purpose of this Blossoms module is to investigate and understand some properties of waves and colors. We are using soap bubbles to do that. Soap bubbles are easy to make, and they are fun for us and the students. But they have one problem – they are very delicate. So sometimes it can be a little tricky to have a stable solution.

I suggested a recipe, however you may need to change it because you have a different soap, the water is different, the weather is different. It could also happen that one solution that works one day doesn't work the day after, or after a few hours. You just have to be patient, and then it's really worth doing it because you will see that these demonstrations are really beautiful.

Going through the list of activities.

In the first activity, we were creating a home-made ripple tank. I was using a salad spinner to do that. You can use any transparent container. If it's larger, it is better, so that the reflections are a little bit reduced. And you do not need to fill it up with water. It can be pretty shallow.

In the activity where you are creating the rainbow, it may be a little bit tricky to put the rainbow in focus. To do that you will have to change the distance between the light and the container of water, and between the container and the wall on which you are creating the rainbow itself.

For the activities with the black mug and soap film, I strongly recommend having one mug or one film can for each student, because if you do it as a demonstration it is really difficult for everyone to look at the different effects of the different light. If every student or couple of students have an experimental set, then they can really put hands on and see the light color patterns and they can create the perturbations and have a sense of what's going on.

This is it for today. Have fun teaching soap bubbles.