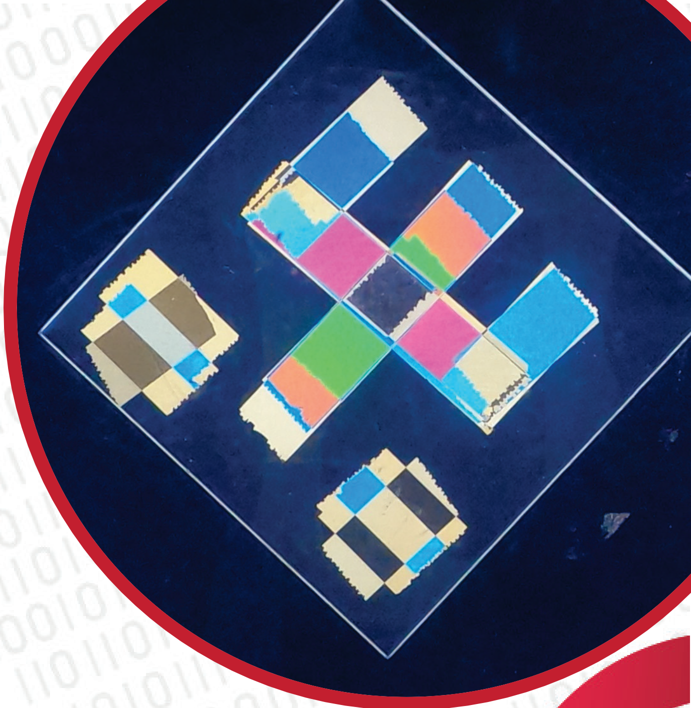

Educator's Guide

POLARIZATION ART

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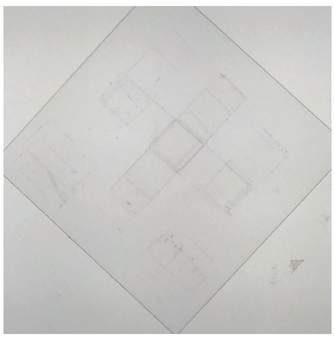
Educator's guide

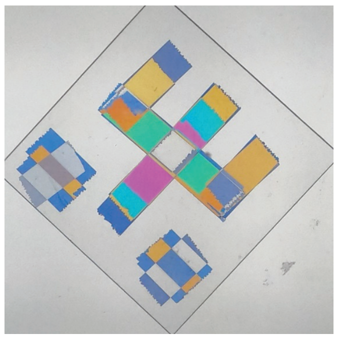
POLARIZATION ART

Light is an electromagnetic field, and the direction of that field is called the polarization. In this hands-on activity, we'll explore polarization and how it behaves in different materials through an art project. We'll connect this behaviour to quantum bits and quantum communication.

ACTIVITY AT A GLANCE

Students will explore the polarization of light through an art activity. By layering plastic materials, students will create patterns that can only be viewed through a polarizing filters.





LEARNING OBJECTIVES

Explore the wave behaviour and colour spectrum of light.

Explore how information is physical and binary digits can be encoded in things like light.

THE BIGGER PICTURE

Polarization can be used to encode information into individual photons. These quantum bits make up technologies like quantum computers and quantum communication.

The polarization art activity is appropriate for **all ages**, from small children to high-school students. Elementary students can engage with the activity purely as an art activity that relies on unexpected phenomena relating to light, and it can be tied into basic facts about light (such as that it carries energy). Middle-school students can engage on a deeper level, and high-school students may be able to perform a formal treatment with vectors.

The brief activity structures are the starting point for all ages. After explaining the activity and the materials needed, this guide will go over a series of questions about and applications of the effect seen, starting at an elementary level and going to topics more appropriate for high-school students.

The hands-on activity can be completed in 10-20 minutes. Further explorations may take up to a full class period or be assigned as an independent-learning project.

ACTIVITY INSTRUCTIONS

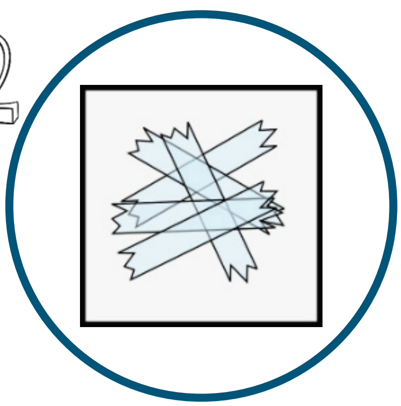
Polarization Art

You will need:

Polarized light source	Transparent plastic sheet
Polarizer for viewing	Clear tape

1. Look at the light source through the viewing polarizer.
   What happens when you rotate the polarizer like a steering wheel?
2. Secure many overlapping strips of tape onto the clear surface.
   Placing many layers and different angles is best.
3. Put the taped object between the light source and the polarizer.
   See what happens when you rotate the object or the polarizer!

2



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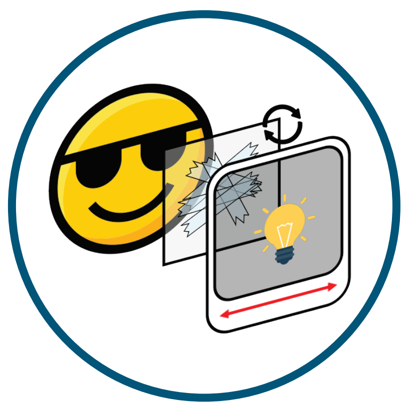


Quantum Connection

The polarization of light can be used to encode binary information or **bits**, 0's and 1's.

If we encode a bit into the polarization of **one photon**, we can make quantum bits, also called **qubits**, which take advantage of the features of **quantum mechanics**.

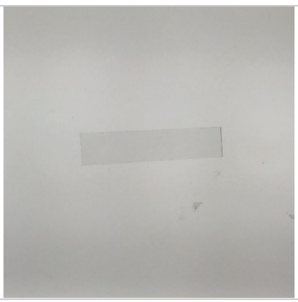
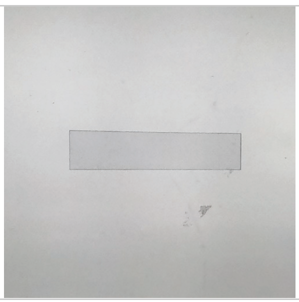
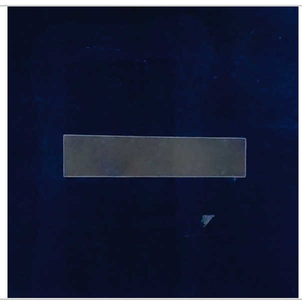
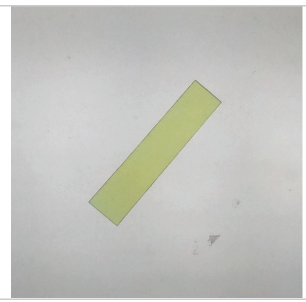
Photon qubits are used to build **quantum computers** and **quantum communication systems**, and can carry information over long distances, even to outer space!

What to expect if it’s working correctly

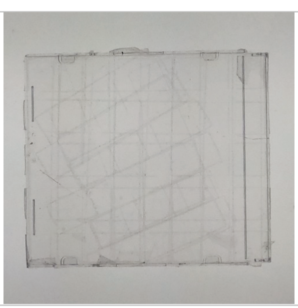
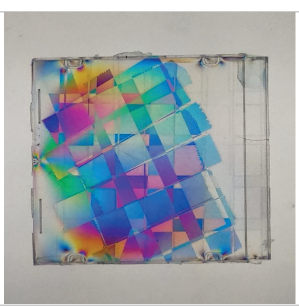
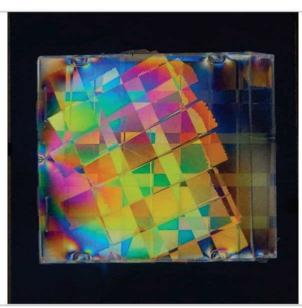
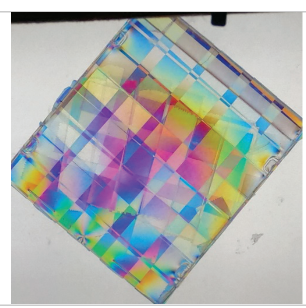
Firstly, participants should observe that the polarized light source appears darker when viewed through the viewing polarizer, but that this depends on the angle it is held at. At a certain angle, the light source will appear completely extinguished; this is the angle where the light source and the polarizer are aligned *perpendicular*. Ninety-degrees from that angle, the light source should appear fully bright, as it is aligned *parallel* to the viewing polarizer.

If participants try to use the polarizer on other light sources, they should see nothing remarkable as they rotate the polarizer. Most light sources are *unpolarized*, meaning that their polarization angle is random. Therefore, the polarizer will simply filter out 50% of the light. Exceptions include TV screens, computer monitors, and phones, as well as reflections off of surfaces.

The taped object should look entirely unremarkable to the naked eye and remain unremarkable when placed on the polarized light source. However, when viewed through the polarizer, participants should see that the tape changes the intensity and colour of the light seen. If the pattern isn’t interesting at first, try rotating both the polarizer and the taped object.

			
Single piece of tape, no polarizer	Single piece of tape, viewing polarizer parallel to the light source	Single piece of tape, viewing polarizer perpendicular to the light source	Single piece of tape rotated 45 degrees

By adding more tape to the surface, ideally at various angles and in a number of layers, more intricate patterns can be formed that are only visible in between the crossed polarizers. It should also be easy to note that the colour seen when viewed through parallel polarizers is opposite to the one seen with perpendicular polarizers (e.g., yellow vs blue), since the mixture of the two must add up to the white light we see with no polarizer.

			
Taped surface, no polarizer	Taped surface, viewing polarizer parallel to the light source	Taped surface, viewing polarizer perpendicular to the light source	Taped surface rotated 45 degrees

This is simply the base activity and key effect for polarization art. This part of the activity is effective for science fairs, festivals, and young learners. The remainder of this guide will explain why we see this effect and provide extensions relevant for more advanced students

Facilitator tips

- Participants will often struggle with the instruction to “rotate the polarizer.” It may help to instruct them to rotate in a specific way, such as “like a steering wheel,” to avoid confusion.

- If all tape is at the same angle, there will be an angle where no polarization rotation effect is visible at all. Be sure to encourage tape be placed in a variety of angles and consider rotating the object relative to the polarizers as well to find the angle where the effect is most prominent.

- This activity works well in well-lit areas, but really stands out in darkened settings or at night.

- Depending on which polarizers you use, you may notice that instead of being completely darkened, the light source appears heavily blue-tinted. Most cheap polarizers work quite well for visible light, but become much less effectively quickly at the blue end of the spectrum.

- Polarizers can appear to block out most visible light, but do not necessarily block infrared or ultraviolet light. If you are performing this activity outdoors, it is important to prevent participants from trying to view dangerous light sources like the sun through two crossed polarizers.

MATERIALS AND OPTIONS

In order to see the colourful polarization art effect, you will need to view a birefringent object between two polarizers. It helps to have a polarized source of light to start with and a handheld polarizer to view the effect with.

Note that any links or suggested sources are not endorsed or guaranteed by the University of Waterloo. They are provided as examples accessible in Canada as of the writing of this manual, and many other sources for the materials may exist.

Viewing polarizer

The viewing polarizer is held by the participant to reveal the patterns hidden to the naked eye.

Many sunglasses are polarized, as this helps reduce the glare of the sun off the road and other wet surfaces. Unfortunately, the less expensive the sunglasses are, the less likely they are to be polarized. To test if your sunglasses are polarized, try putting them on and looking at a computer screen. If you tilt your head and the screen gets dimmer (going nearly fully dark at 90-degrees), then the sunglasses are polarizing. If not, you will need to try a different pair.

If you have leftover glasses from a 3D movie, these are also effective polarizers. Note that these glasses polarize in different ways depending on whether you look through them forward or backward, so they will behave differently than regular sunglasses. More details on 3D movies and polarization are found in the next sections.

If it is within budget, the best option is to buy polarizer film. Polarizer film can be purchased in rolls and in slides. Note that you will likely want to avoid adhesive polarizing film.

Sample sources:

- Polarized slides from Rainbow Symphony
- Polarizer film (thick) in rolls from Polarization.com

Polarized light source

A source of polarized light is needed to illuminate the object. Most light we see is not polarized, meaning that it contains components of all polarizations. Since they would all get rotated by the object, viewing the object through a polarizer with no initial source of polarized light will simply result in filtering out half the light with no apparent structure.

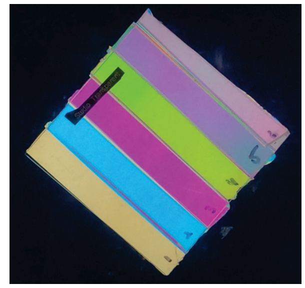
Holding the object between two viewing polarizers and using the room lights as illumination can work, especially in classroom settings. However, we recommend using a source of polarized light when possible. This is especially true for fair-like settings where students will quickly engage with the activity, but also helpful in classrooms to make the ordering of the objects obvious to students.

The easiest source of polarized light is an LCD monitor, like a computer monitor or television. Simply displaying a white screen (such as a blank slideshow) provides an easy-to-use source of diffuse polarized light. More details on why LCD monitors are polarized are found in the next sections.

You may also consider placing a sheet of polarizer under an LED light. Flat rectangular panel lights used for room lighting work well, but a particularly affordable option is a rectangular filling light used for photography and live-streaming. You may consider hacking the light to secure the polarizer inside, but it is important that the polarizer is the last layer of the lamp as any opaque pieces used to diffuse the light will scramble polarization.

Birefringent tape

Transparent pressure-sensitive tape, like Scotch tape or packing tape, is an easy and affordable material for building polarization art. Different brands will have different behaviours, with some producing vivid colours with only a layer or two while others are quite dull unless a great deal of tape is used. In Canada, the Studio-brand transparent tape available at common dollar stores is an excellent option.

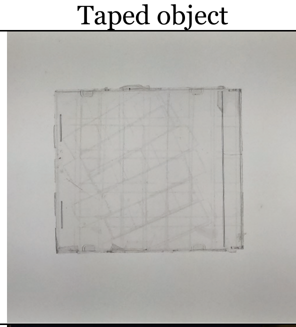
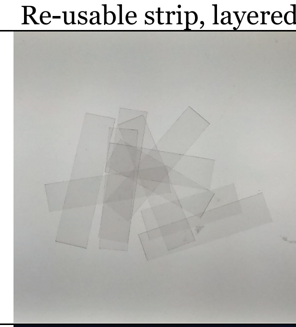
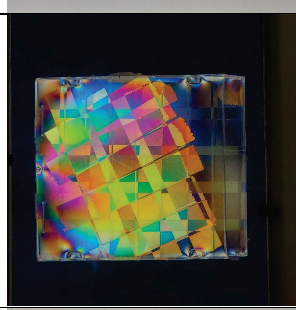
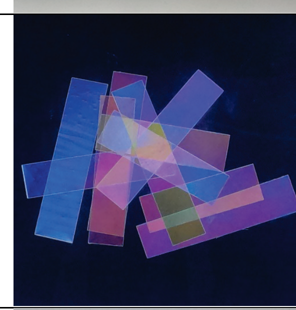
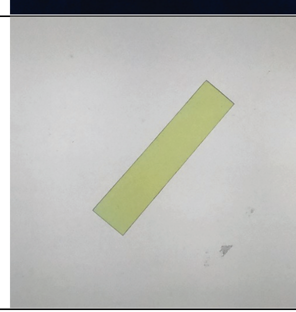
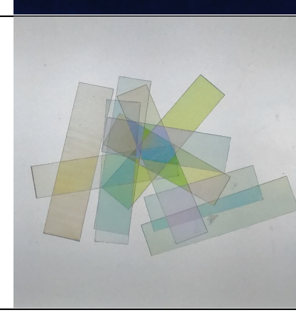


Studio-brand transparent tape under crossed polarizers. The number of layers increases from one at the bottom-left to six at the top-right.

Note that it is important to get transparent tape. Some tape is marketed as “invisible”, which is opaque to the eye but blends into the paper when applied. This tape scrambles polarization and cannot be used in this activity. Any tape that is effective will be near-completely transparent before it is applied to the surface.

You will need a surface for the students to place the tape onto, which must also be transparent and not scramble polarization. Transparency papers used for overhead projectors work well, though if you layer them you will find that they eventually scramble polarization. Old CD cases are an option as well. In a pinch, a plastic baggie will work too.

This activity can create a great deal of waste if students each create their own artwork, which will certainly end up in the trash immediately. One option is to pre-tape a hard piece of transparent plastic [like PET] which can be cut into strips. By stacking the strips, students can make their own art piece without creating waste.

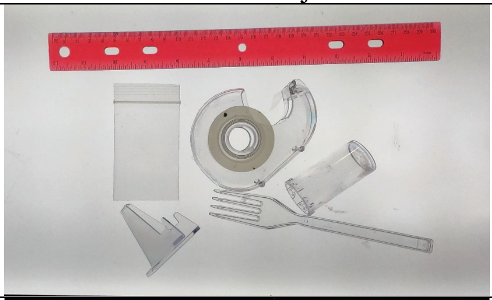
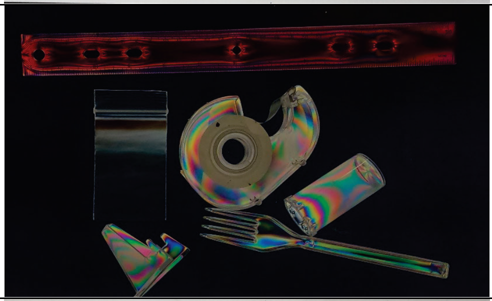
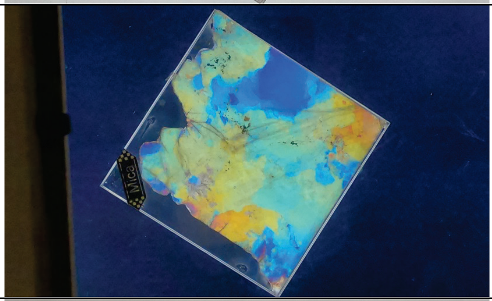
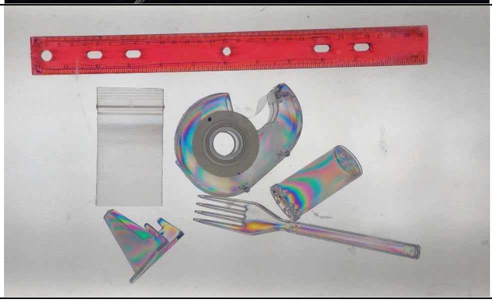
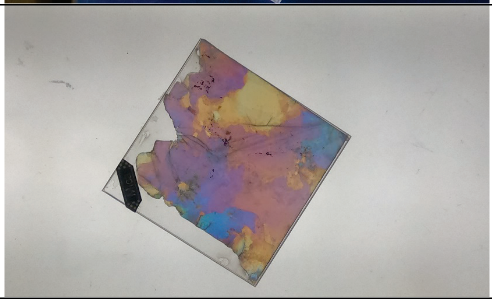
	Taped object	Re-usable strip, single	Re-usable strip, layered
No polarizer			
Crossed polarizers			
Parallel polarizers			

Other birefringent objects

Having a selection of other birefringent objects to show students can extend this activity.

Most transparent plastic materials are birefringent and can be quickly checked by examining them between polarizers. Options include (but are not limited to) plastic utensils, CD cases, baggies, tape dispensers, and rulers. The effect is particularly noticeable in regions of the material that have undergone stress.

Other birefringent materials exist in nature. For example, mica is a mineral that naturally cleaves into thin sheets that are mostly transparent. This mineral rotates polarization through birefringence, which can be analyzed using the cross polarizers and is used to make custom polarization rotators for scientific applications. Mica can be acquired from [Educational Innovations Inc](), for example.

	Household objects	Mica
No polarizer		
Crossed polarizers		
Parallel polarizers		

UNDERSTANDING POLARIZATION ART

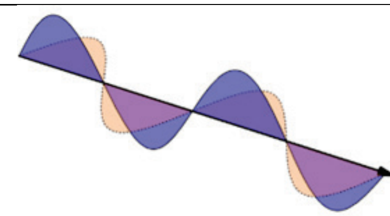
Why was the tape colourful when viewed through the polarizers? Polarization art provides a strong opportunity to explore the science of light with students of all levels, since the explanation can be readily simplified but may also be expanded upon for more advanced students.

To help explain the effect to students, we've phrased the explanation below as a series of questions. The first few parts of the explanation are appropriate for elementary-aged students, while the later questions approach an undergraduate level of understanding.

Extinguishing light with polarizers

Why can we make the light go dark with the polarizer?

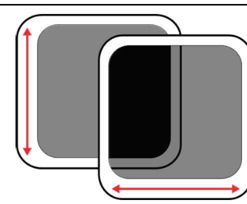
Light carries energy as a wave, which can wave side-to-side (horizontally) or up-and-down (vertically). The direction of the wave is called the *polarization*.



Waves can oscillate horizontal (side-to-side) or vertical (up-and-down).

Polarizers are filters that absorb light depending on its polarization. If the light's polarization lines up to the polarizer, it transmits through just fine. If the light's polarization is perpendicular to the polarizer, it will be absorbed.

If we hold two polarizers in a row at the same angle, the light that makes it through the first will make it through the second. If one is opposite to the other, the light that makes it through the first polarizer will be absorbed by the second, blocking the light completely.



Polarizers can be aligned horizontally or vertically to absorb light with a specific direction.

Why doesn't the polarizer do anything to most light in the room? What's special about the light source we used in the activity?

Most light around us is *unpolarized*. This means it doesn't have a particular polarization direction. Another way to think about it is that the light is randomly polarized, and half the light makes it through no matter what angle we hold our polarizer at. Some light sources that are polarized include computer monitors, TVs, and reflections.

Are there other directions other than up-and-down or side-to-side?

Yes, the light could also be waving diagonally or at any other angle we can think of. Holding the polarizer at different angles lets different amounts of light through, with the most coming through when the polarizer is aligned the same way (parallel) as the light source and the least coming through when it is opposite (perpendicular) to the light source. Putting it halfway between (at a diagonal angle) will let through half of the light.

What's actually waving in light? *[intermediate]*

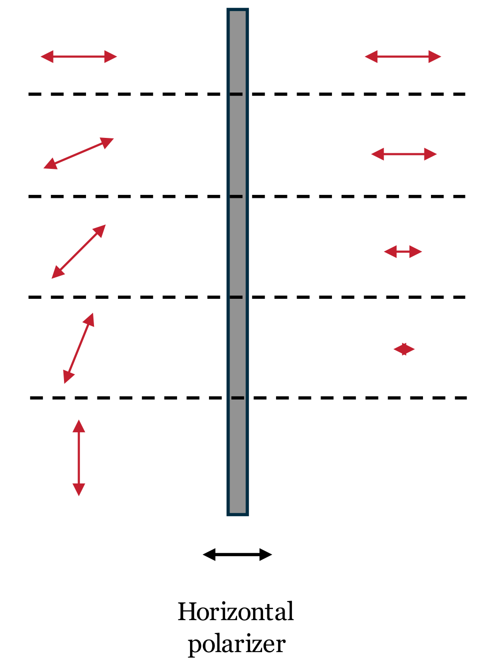
Specifically, light is an *electromagnetic wave*. The property that is "waving" is the electric field, which is how light interacts with matter like atoms and electrons.

The electric field in visible light oscillates very quickly, nearly one quadrillion (a million billion) times per second. Since light travels approximately 300 million metres per second, the spacing between the high and low of the wave (called the *wavelength*) is a few hundred billionths of a metre, or *nanometres*. Other electromagnetic waves, like microwaves and x-rays, have different oscillation frequencies and wavelengths, but are still ultimate waving electric fields.

What determines how much light passes through? *[advanced]*

The amount of polarized light that makes it through a polarizer depends on the difference between the angle of the light's polarization and the angle of the polarizer. The exact relationship is given by *Malus' Law*, which relates the amount of light that transmits to the cosine of the angle difference.

So why does diagonally polarized light partially transmit through a horizontal polarizer? One way to think about it is to consider that diagonally polarized light has a significant horizontal *component*. We can break the diagonal polarization up as being partially horizontal and partially vertical. The vertical component would be absorbed by the horizontal polarizer, while the horizontal component would transmit through.

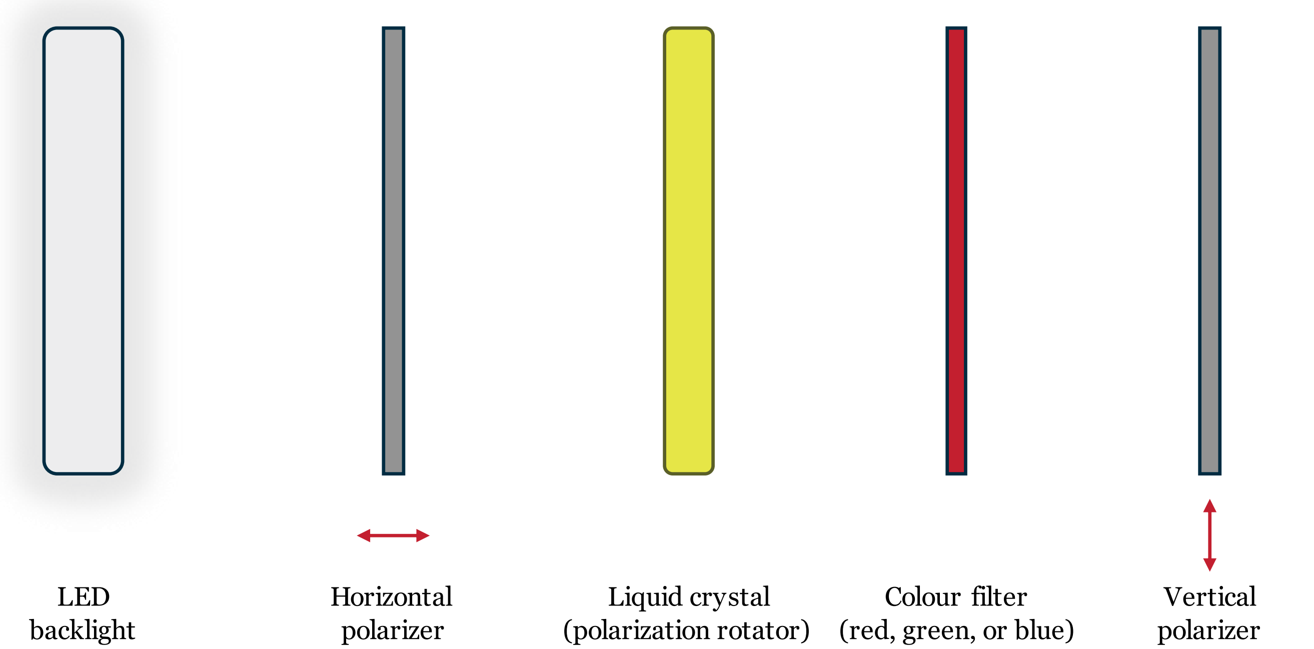


Various polarizations encounter a horizontal polarizer. The horizontally polarized light fully transmits. As the polarization gets further from horizontal, less and less transmits. For vertical polarization, zero light makes it through. While reduced in intensity, the output light is always horizontally polarized.

Application: LCD (liquid crystal display) monitors

Modern computer monitors and televisions use polarization to quickly and efficiently display high-resolution and colourful images. Behind the screen is a bright white backlight, usually made of LEDs, followed by a pair of crossed polarizers. In between the polarizer is a grid of liquid crystals, which act very much like the tape in the polarization art experiment but can be controlled with electric fields. If no electric field is applied on a pixel, the polarization is not changed, meaning no light will pass through the second polarizer. If an electric field is applied, the polarization rotates by ninety degrees and passes through the polarizer. The electric field can be controlled for each pixel in the grid, and by placing different colour filters behind each one, colour images can be created.

If you have an old monitor that would otherwise go in the garbage, you can try to take it apart and peel off the outer polarizer, which is usually a sticker underneath a protective plastic layer. The monitor will appear as a plain white screen, but if viewed through a handheld polarizer or sunglasses, the image will re-appear.



Application: Polarized sunglasses and photography

Many sunglasses and filters for photography are polarized. This is to reduce the effect of reflections (glare) off of surfaces. Even though sunlight is essentially unpolarized, the amount of light reflected from a surface strongly depends on its polarization, a phenomenon called the *Brewster effect*. By wearing polarized sunglasses, most light is reduced by half but glare from bright surfaces like wet roads can be reduced even more. Polarized camera filters can be used to reduce glare as well, for example to reduce reflections from the surface of water.

Sunglasses are often polarized. This can be tested by looking at a computer monitor and rotating them to see if light is blocked.

The surface of a pond as seen without a polarizing filter (left) and with a polarizing filter (right), demonstrating that the reflections can be significantly reduced. (Image: Amithshs)

Application: 3D movies

RealD polarized glasses for 3D movies.

Why do we need two eyes? Each eye sees a slightly different image, which our brain stitches together for us. The slight difference is significant for objects close to us and minimal for objects far away from us. This is how we have our sense of *depth perception*.

We can trick our eyes into perceiving depth when there is none by showing each eye a very slightly different image. This is the idea behind 3D-movies, which actually project two images on the screen: one for the left eye and one for the right. If you look at the screen, you'll see that the image is very blurry. But if you were the 3D-movie glasses, suddenly you'll see the illusion of objects coming out of the screen.

Most modern 3D-movies use polarization to trick our eyes. Your glasses have opposite polarizers in each lens. The left-eye image is projected onto the screen with the left-eye polarization, and the right-eye image with the right-eye polarization. The glasses filter out the "wrong" image from each eye, ensuring each eye sees a different image.

Twisting the polarization with tape

Why do we see something different with the tape in the middle?

Two crossed polarizers don't let any light through, but objects like the tape seem to let light pass through. The objects affect polarized light, but instead of absorbing it, they *rotate* the light's polarization. After the rotation, the polarization is no longer perpendicular to the other polarizer, so it will (at least partially) transmit through.

What makes the tape special? *[intermediate]*

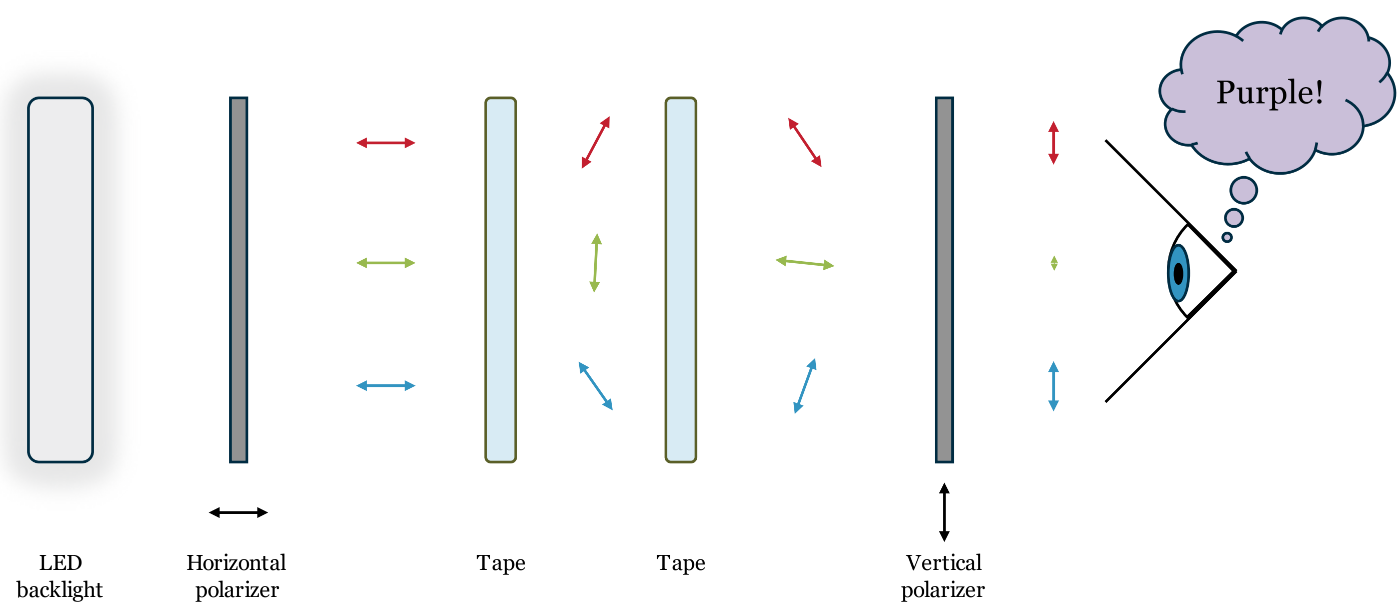
The tape and many other plastics and crystals have a property called *birefringence*. This means that light travels at different speeds in the material depending on its polarization. Since the polarization components travel at different speeds, the way they add together changes as they travel through the material, effectively twisting and rotating the polarization of the light.

Separating the colours of light from each other

Why do we see different colours emerge? *[intermediate]*

The light source used in the experiment is white light, which contains all colours of the rainbow. In other experiments that use tools like prisms or diffraction gratings, you may have seen that you can separate white light into an entire rainbow of colours. The birefringent material does something similar, with a bit of a twist.

Birefringent materials have different speeds-of-light depending on the polarization, but this also usually depends on the colour of light as well, with red light travelling at a different speed than blue light, for example. How strong that speed depends on polarization can also depend on the colour, so red light might rotate by a very different amount than blue light. Since different colours rotate by different amounts, some will happen to line up with the final polarizer and others won't, resulting in not just a change in polarization but a chance in colour when the birefringent material is introduced to the experiment.



Want to check to be sure? Try rotating the final polarizer by ninety degrees and you should see the opposite colour of what you previously saw. For example, if it was blue for a horizontal polarizer, it may be yellow for vertical. This is because the two colours combined must add up to the white light we see without the polarizer.

Binary information

What is binary code?

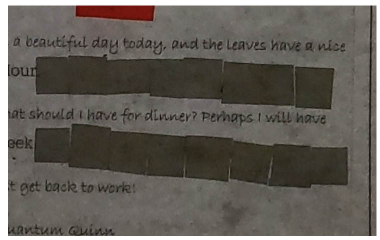
Binary is a way to represent numbers and information in a series of 0's and 1's. Each unit of the code, called a *bit*, can be either a 0 or a 1. We can think about the 0 and 1 as ON or OFF, YES or NO, and TRUE or FALSE. One bit is the smallest possible amount of information.

Most information technology, like computers, operate on binary information at the deepest level, usually in the form of currents in a circuit. While we provide input in ways we can understand, it is translated to binary using codes such as ASCII, which assigns an 8-bit code to each letter of the alphabet (for example, Q = 1010001).

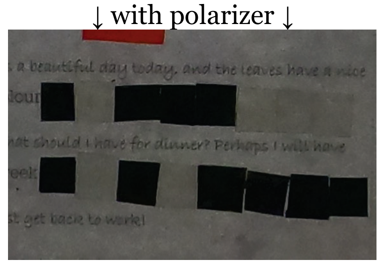
While we usually think about binary as codes and mathematics, each bit must be encoded into something real and physical. This could be the circuits inside our computers, but could also be any other thing with two distinct values we can imagine. For example, we could use a light bulb that is ON or OFF, or a coin that is HEADS or TAILS.

Can we use polarized light to communicate?

If we measure a horizontally polarized beam of light with a horizontal polarizer, it will fully transmit. If we measure a vertically polarized beam of light with the horizontal polarizer, it will be fully absorbed. If we build a bit out of light and say that horizontal is "0" and vertical is "1", we can measure the value of the bit using a polarizer. In this way, polarized light is a natural way to encode bits and send them over long distances.



↓ with polarizer ↓



Sample activity hiding binary messages with polarization. Each square is a polarizer oriented in a certain direction. When viewed through another polarizer, an ASCII-coded message can be read out as "0" = dark and "1" = bright, in this case 01000111 (G) and 01010000 (P).

Photons and quantum physics

What is light at the smallest scale?

We usually think of light as something that can go from very bright to completely off and anywhere in between. In other words, we think about light as *continuous*. If we study light at the very small scale, we find that it is *discrete*, meaning that it is emitted in countable units that we call *photons*. You can think about this in analogy to the way we understand water: in our day-to-day life, the water level in a cup can change by any amount large or small, but at the fundamental level, we know that an H_2O molecule is the smallest possible amount of water.

We don't usually see the effects of photons directly, since the light that we usually interact with is made of so many photons that they are essentially continuous. For example, a 60-W light source emits approximately one-hundred-million-trillion (10^{20}) photons per second. But at the scale of atoms and electrons, this discrete nature matters. When an atom gains or loses energy, it must absorb or emit exactly one photon of light. These behaviours are studied in the field of *quantum physics*.

How can a photon be polarized? *[advanced]*

A photon is often described as a "particle of light", which can lead to the misinterpretation that there's nothing there to "wave". To be a bit more accurate, we can describe a photon as the smallest possible unit of light. In other words, a photon is the smallest possible amount of an electromagnetic wave that can exist. The photon still has an oscillating electric and magnetic field, which still have a direction like all electric and magnetic fields do. This direction is still the polarization of the photon.

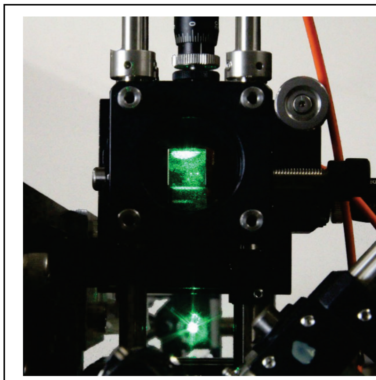
Application: Quantum computing and quantum communication

The rules of quantum physics are different in many ways than the rules of physics that we encounter in our everyday life. When we think about bits used in computers, we usually think about circuits, which can be described completely using the traditional rules of physics. If we build bits out of objects that obey the rules of quantum physics, perhaps they can use the different physics to solve different types of problems?

This is the idea behind quantum information science and technology, which includes ideas like quantum computing and quantum communication. All of these encode information into systems that obey the rules of quantum physics, with the polarization of a photon being a common example.

Quantum computers process information encoded in quantum systems. Some problems that are very difficult for today's computers can potentially be solved much more efficiently with quantum computers. Some problems that people hope quantum computers can be useful for include factoring large numbers and simulating the behaviour of molecules, with applications in cryptography, materials science, and more. Quantum computers are being developed in research labs around the world, and it is a significant challenge to build a computer out of elements like photons that can out-perform today's computers.

Quantum communication uses single-photon signals to allow two or more people to talk to each other. There is a significant challenge in sending photons over long distances, but this has advantages in networking a variety of quantum devices and keeping information secure. Experiments have demonstrated that single-photon signals can be exchanged from Earth to satellites in outer space.



A polarization analyser used in a quantum communication experiment.

GLOSSARY

ASCII (American Standard Code for Information Interchange): A character encoding standard for electronic communication, representing text in computers and other devices using binary code.

Birefringence: A property of a material that causes polarized light to be rotated based on its colour, resulting in the appearance of different colours when viewed through a polarizer.

Electromagnetic wave: A wave consisting of oscillating perpendicular electric and magnetic fields. Examples include visible light, microwaves, radio waves, and x-rays.

LCD: Liquid-crystal display technology, which works by quickly rotating the polarization of the light emitted from each pixel in a screen.

Malus' Law: The algebraic relationship between the angle of polarization, the angle of the polarizer, and the amount of light that makes it through the polarizer, given as $I = I_0 \cos^2 \theta$, where I is the output intensity, I_0 is the input intensity, and θ is the relative angle between the polarizer and the light's polarization.

Photon: The smallest possible unit of light energy.

Polarization: The direction of the electric field of a light wave.

Polarizer: A filter that allows light waves of a specific polarization to pass through and blocks others.

Quantum physics or **quantum mechanics**: The field of study pertaining to how the world behaves at the scale of atoms, photons, electrons, and other sub-microscopic particles.

Qubit: A quantum bit is the smallest unit of quantum information. It can be built by controlling a system that obeys quantum mechanics and can exist in one of two states, labelled "0" and "1" traditionally. The polarization of a single photon is a useful example of a qubit, though others like electrons, atoms, and superconductors are possible.

Quantum information science and technology (QIST): The field of research related to encoding and processing information in systems that obey the rules of quantum physics instead of traditional physics.

Stress Points: Areas within a material that experience high levels of mechanical stress, which can be visualized using techniques like birefringence.

Wavelength (λ): The distance between successive peaks of a wave, typically measured in nanometres (nm) for visible lights.

Wave-particle duality: A statement describing a somewhat counter-intuitive feature of quantum mechanics. The behaviour of light, electrons, and other objects at the quantum scale is reminiscent of wave physics in some ways (such as interference) and particle mechanics in other ways (such as discretization).

POTENTIAL CURRICULUM CONNECTIONS

Curricula vary between locations, but possible connections include:

- Elementary-school science
  - Light sources and energy
  - Colours of light
- High-school physics
  - Optics, light rays, the wave nature of light
  - Vectors

CONNECTIONS TO QIS KEY CONCEPTS

	Concept	Fundamental	Activity Connection
2	Quantum state	A quantum state is a mathematical representation of a physical system, such as an atom, and provides the basis for processing quantum information.	Drawing the polarization of a photon as an arrow is a way of representing its quantum state.
3	Measurement	Quantum applications are designed to carefully manipulate fragile quantum systems without observation to increase the probability that the final measurement will provide the intended result.	A polarizer measures the polarization state of a photon. If we think of it as a quantum bit, it reads out the “0” or “1”.
4	Quantum bits	The quantum bit, or qubit, is the fundamental unit of quantum information, and is encoded in a physical system, such as polarization states of light, energy states of an atom, or spin states of an electron.	The polarization state of light is a common way to encode qubits. Students can create or decipher messages in binary using the polarization art setup.
8	Quantum communication	Quantum communication uses entanglement or a transmission channel, such as optical fibre, to transfer quantum information between different locations.	Communication with polarized photons is a very common way to realize quantum communication. By using polarizers at different angles, the idea of measurement disturbance can be demonstrated in this setup.

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About IQC
The Institute for Quantum Computing (IQC) is a world-leading research centre in quantum information science and technology at the University of Waterloo. IQC’s mission is to develop and advance quantum information science and technology through interdisciplinary collaboration at the highest international level. Enabled by IQC’s unique infrastructure, the world’s top experimentalists and theorists are making powerful new advances in fields spanning quantum computing, communications, sensors and materials. IQC’s award-winning outreach opportunities foster scientific curiosity and discovery among students, teachers and the community.

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