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# The Formation of Rainbows

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## 1.0

## Introduction:

A rainbow is an optical phenomenon caused by refraction, internal reflection and dispersion of light in water droplets resulting in a continuous spectrum of light appearing in the sky.[1] The rainbow takes the form of a multicoloured circular arc.[2] Rainbows caused by sunlight always appear in the section of sky directly opposite the Sun. Rainbows can be caused by many forms of airborne water. These include not only rain, but also mist, spray, and airborne dew.Rainbows can be full circles. However, the observer normally sees only an arc formed by illuminated droplets above the ground,[3] and centered on a line from the Sun to the observer's eye.

## 2.0

## Keywords:

Visibility, Number of colours in a spectrum or a rainbow , Explanation, Variations, scientific history, Experiments, Culture and mythology.

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**3.0**

**Visibility:**

Rainbows can be observed whenever there are water drops in the air and sunlight shining from behind the observer at a low altitude angle. Because of this, rainbows are usually seen in the western sky during the morning and in the eastern sky during the early evening. The most spectacular rainbow displays happen when half the sky is still dark with raining clouds and the observer is at a spot with clear sky in the direction of the Sun. The result is a luminous rainbow that contrasts with the darkened background. During such good visibility conditions, the larger but fainter secondary rainbow is often visible. It appears about 10° outside of the primary rainbow, with inverse order of colours.

The rainbow effect Is also commonly seen near waterfalls or fountains. In addition, the effect can be artificially created by dispersing water droplets into the air during a sunny day. Rarely, a moonbow, lunar rainbow or nighttime rainbow, can be seen on strongly moonlit nights. As human visual perception for colour is poor in low light, moonbows are often perceived to be white.[4]

It is difficult to photograph the complete semicircle of a rainbow in one frame, as this would require an angle of view of 84°. For a 35 mm camera, a wide-angle lens with a focal length of 19 mm or less would be required. Now that software for stitching several images into a panorama is available, images of the entire arc and even secondary arcs can be created fairly easily from a series of overlapping frames.

From above the Earth such as in an areophane, it is sometimes possible to see a rainbow as a full circle. This phenomenon can be confused with the glory phenomenon, but a glory is usually much smaller, covering only 5–20°.

The sky inside a primary rainbow is brighter than the sky outside of the bow. This is because each raindrop is a sphere and it scatters light over an entire circular disc in the sky. The radius of the disc depends on the wavelength of light, with red light being scattered over a larger

angle than blue light. Over most of the disc, scattered light at all wavelengths overlaps, resulting in white light which brightens the sky. At the edge, the wavelength dependence of the scattering gives rise to the rainbow.[5]

The light of a primary rainbow arc is 96% polarised tangential to the arc.[6] The light of the second arc is 90% polarised.

**4.0**

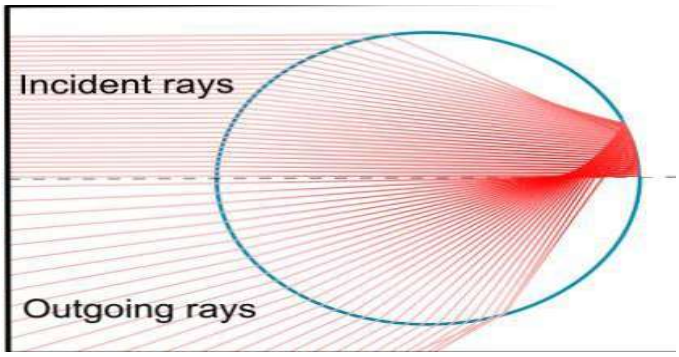
**Number of colours in a spectrum or a rainbow**

For colours seen by the human eye, the most commonly cited and remembered sequence is Isaac Newton's sevenfold red, orange, yellow, green, blue, indigo and violet,[7][a] remembered by the mnemonic Richard Of York Gave Battle In Vain, or as the name of a fictional person (Roy G. Biv). The initialism is sometimes referred to in reverse order, as VIBGYOR. More modernly, the rainbow is often divided into red, orange, yellow, green, cyan, blue and violet.[9] The apparent discreteness of main colours is an artefact of human perception and the exact number of main colours is a somewhat arbitrary choice.

Newton, who admitted his eyes were not very critical in distinguishing colours,[10] originally (1672) divided the spectrum into five main colours: red, yellow, green, blue and violet. Later he included orange and indigo, giving seven main colours by analogy to the number of notes in a musical scale.[7][b][11] Newton chose to divide the visible spectrum into seven colours out of a belief derived from the beliefs of the ancient Greek sophists, who thought there was a connection between the colours, the musical notes, the known objects in the Solar System, and the days of the week.[12][13] Scholars have noted that what Newton regarded at the time as "blue" would today be regarded as cyan, and what Newton called "indigo" would today be considered blue.[8][9][14]

**5.0**

**Explanation**



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When sunlight encounters a raindrop, part of the light is reflected and the rest enters the raindrop. The light is refracted at the surface of the raindrop. When this light hits the back of the raindrop, some of it is reflected off the back. When the internally reflected light reaches the surface again, once more some is internally reflected and some is refracted as it exits the drop. (The light that reflects off the drop, exits from the back, or continues to bounce around inside the drop after the second encounter with the surface, is not relevant to the formation of the primary rainbow.) The overall effect is that part of the incoming light is reflected back over the range of 0° to 42°, with the most intense light at 42°.[20] This angle is independent of the size of the drop, but does depend on its refractive index. Seawater has a higher refractive index than rain water, so the radius of a "rainbow" in sea spray is smaller than that of a true rainbow. This is visible to the naked eye by a misalignment of these bows.[21]

**6.0**

**Variations:**

- **Double Rainbow**

A secondary rainbow, at a greater angle than the primary rainbow, is often visible. The term double rainbow is used when both the primary and secondary rainbows are visible. In theory, all rainbows are double rainbows, but since the secondary bow is always fainter than the primary, it may be too weak to spot in practice. Secondary rainbows are caused by a double reflection of sunlight inside the water droplets.

- **Twinned rainbow**

  Unlike a double rainbow that consists of two separate and concentric rainbow arcs, the very rare twinned rainbow appears as two rainbow arcs that split from a single base. The colours in the second bow, rather than reversing as in a secondary rainbow, appear in the

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same order as the primary rainbow. A "normal" secondary rainbow may be present as well. Twinned rainbows can look similar to, but should not be confused with supernumerary bands. The two phenomena may be told apart by their difference in colour profile: supernumerary bands consist of subdued pastel hues (mainly pink, purple and green), while the twinned rainbow shows the same spectrum as a regular rainbow. The cause of a twinned rainbow is believed to be the combination of different sizes of water drops falling from the sky. Due to air resistance, raindrops flatten as they fall, and flattening is more prominent in larger water drops. When two rain showers with different-sized raindrops combine, they each produce slightly different rainbows which may combine and form a twinned rainbow. A numerical ray tracing study showed that a twinned rainbow on a photo could be explained by a mixture of 0.40 and 0.45 mm droplets. That small difference in droplet size resulted in a small difference in flattening of the droplet shape, and a large difference in flattening of the rainbow top.

❖ **Full circle rainbow**

In theory, every rainbow is a circle, but from the ground, usually only its upper half can be

seen. Since the rainbow's centre is diametrically opposed to the Sun's position in the sky, more of the circle comes into view as the sun approaches the horizon, meaning that the largest section of the circle normally seen is about 50% during sunset or sunrise. Viewing the rainbow's lower half requires the presence of water droplets below the observer's

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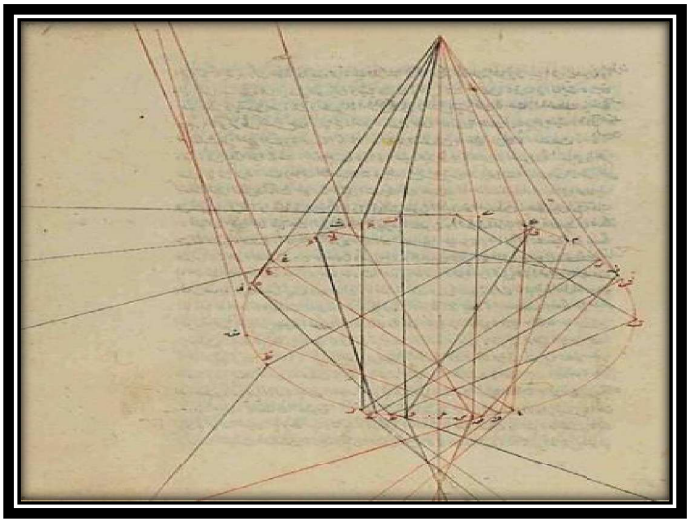
horizon, as well as sunlight that is able to reach them. These requirements are not usually met when the viewer is at ground level, either because droplets are absent in the required position, or because the sunlight is obstructed by the landscape behind the observer. From a high viewpoint such as a high building or an aircraft, however, the requirements can be met and the full-circle rainbow can be seen.

**7.0**

**Scientific History**

The classical Greek scholar Aristotle (384–322 BC) was first to devote serious attention to the rainbow. According to Raymond L. Lee and Alistair B. Fraser, "Despite its many flaws and its appeal to Pythagorean numerology, Aristotle's qualitative explanation showed an inventiveness and relative consistency that was unmatched for centuries. After Aristotle's death, much rainbow theory consisted of reaction to his work, although not all of this was uncritical."



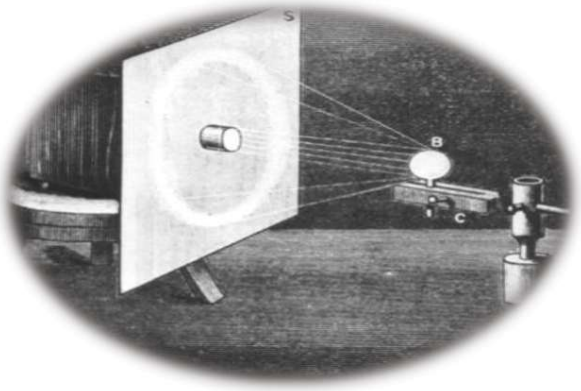
In Book I of Naturales Questioners (c. 65 AD), the Roman philosopher Seneca the Younger discusses various theories of the formation of rainbows extensively, including those of Aristotle. He notices that rainbows appear always opposite to the Sun, that they appear in water sprayed by a rower, in the water spat by a fuller on clothes stretched on pegs or by water sprayed through a small hole in a burst pipe. He even speaks of rainbows produced by small rods (virgulae) of glass, anticipating Newton's experiences with prisms. He takes into account two theories: one, that the rainbow is produced by the Sun reflecting in each water drop, the other, that it is produced by the Sun reflected in a cloud shaped like a concave mirror; he favours the latter. He also discusses other phenomena related to rainbows: the mysterious "virgae" (rods), halos and parhelia.According to Nader El-Bizri, the Persian astronomer, Qutb al-Din al-Shirazi (1236–1311), gave a fairly

accurate explanation for the rainbow phenomenon. This was elaborated on by his student, Kamal al-Dīn ale-Fārisī (1267–1319), who gave a more mathematically satisfactory explanation of the rainbow. He "proposed a model where the ray of light from the sun was refracted twice by a water droplet, one or more reflections occurring between the two refractions." An experiment with a water-filled glass sphere was conducted and al-Farisi showed the additional refractions due to the glass could be ignored in his model. As he noted in his Kitab Tanqih al-ManazAccording to Nader El-Bizri, the Persian astronomer ,Qutb al-Din al-Shirazi (1236–1311), gave a fairly accurate explanation for the rainbow phenomenon. This was elaborated on by his student, Kamal al-Dīn al-Fārisī (1267–1319), who gave a more mathematically satisfactory explanation of the rainbow. He "proposed a model where the ray of light from the sun was refracted twice by a water droplet, one or more reflections occurring between the two refractions." An experiment with a water-filled glass sphere was conducted and al-Farisi showed the additional refractions due to the glass could be ignored in his model. As he noted in his *Kitab Tanqih al-Manazir* (*The Revision of the Optics*), al-Farsi used a large clear vessel of glass in the shape of a sphere, which was filled with water, in order to have an experimental large-scale model of a rain drop. He then placed this model within a camera obscura that has a controlled aperture for the introduction of light. He projected light unto the sphere and ultimately deduced through several trials and detailed observations of reflections and refractions of light that the colours of the rainbow are phenomena of the decomposition of light composition of light.

**8.0**

**Experiments**

Experiments on the rainbow phenomenon using artificial raindrops, i.e. water-filled spherical flasks, go back at least to Theodoric of Freiberg in the 14th century. Later, also Descartes studied the phenomenon using a Florence flask. A flask experiment known as



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Florence's rainbow is still often used today as an imposing and intuitively accessible demonstration experiment of the rainbow phenomenon. It consists in illuminating (with parallel white light) a water-filled spherical flask through a hole in a screen. A rainbow will then appear thrown back / projected on the screen, provided the screen is large enough. Due to the finite wall thickness and the macroscopic character of the artificial raindrop, several subtle differences exist as compared to the natural phenomenon, including slightly changed rainbow angles and a splitting of the rainbow orders.

**9.0**

**Culture and mythology**

Rainbows occur frequently in mythology, and have been used in the arts. The first literary occurrence of a rainbow is in the Book of Genesis chapter 9, as part of the flood story of

Noah, where it is a sign of God's covenant to never destroy all life on Earth with a global flood again. In Norse mythology, the rainbow bridge Bifröst connects the world of men (Midgard) and the realm of the gods (Asgard). Cuchavira was the god of the rainbow for the Muisca in present-day Colombia and when the regular rains on the Bogotá savanna were over the people thanked him, offering gold, snails and small emeralds. Some forms of Tibetan Buddhism or Dzogchen reference a rainbow body. The Irish leprechaun's secret hiding place for his pot of gold is usually said to be at the end of the rainbow. This place is appropriately impossible to reach, because the rainbow is an optical effect which cannot be approached. In Greek mythology, the goddess Iris is the personification of the rainbow, a messenger goddess who, like the rainbow, connects the mortal world with the gods through messages. In Albanian folk beliefs the rainbow is regarded as the belt of the goddess Prende, and oral legend has it that anyone who jumps over the rainbow changes their sex.

**10.0**

**Conclusion:**

In conclusion, the formation of a rainbow is a breathtaking display of optics and atmospheric science. When sunlight enters the Earth's atmosphere, it encounters tiny water droplets in the air, which refract and disperse the light into its individual colors. As the light passes through the droplets at a precise angle, it creates the vibrant arc of colors we know as a rainbow. With its stunning beauty and intricate scientific explanation, the rainbow is a natural wonder that continues to inspire and fascinate people around the world.

**11.0**

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**12.0**

**Footnotes:**

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