

Rainbows and Supernumerary Bows

The primary bow

When sunlight strikes a spherical raindrop, light is refracted when it enters the drop, then it is reflected once off the back of the drop and re-emerges having been refracted a second time.

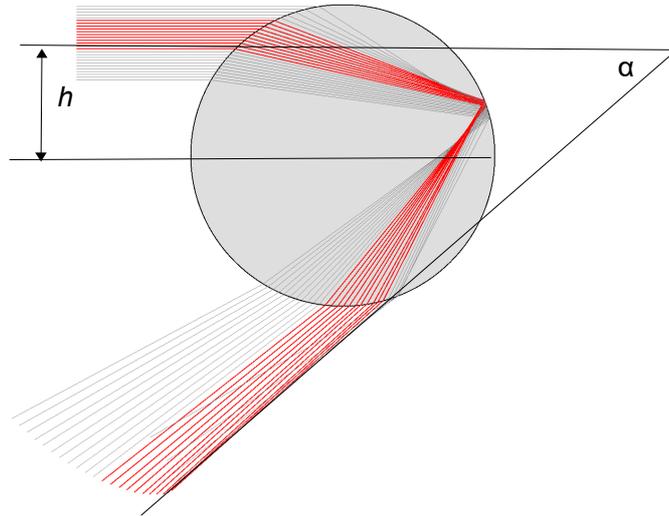
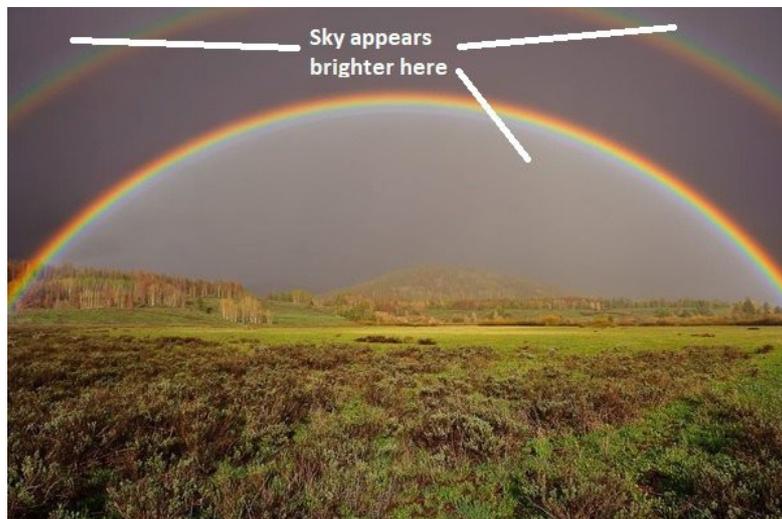


fig 1: Rays passing through a raindrop, reflected once

Depending on where the ray enters the drop, the angle α at which it emerges can vary widely but it turns out that there is a *maximum* angle and that lots of rays which enter the drop in different places (highlighted in red in the image opposite) emerge at close to this maximum angle. For red light this angle is 42.3° while for blue light (which bends more than red light) the angle actually turns out to be a bit *smaller* at 41.1° .

Quite a lot of extra light is reflected from the backs of all the raindrops so the cloud looks quite bright. But beyond 42.3° , no light is reflected and the sky will look darker. The outer edge of the rainbow will be pure red and between 42.3° and 41.1° there will be a mixture of colours, not a pure spectrum, tending to white.



A particularly intense rainbow showing the brighter sky under the bow and also the secondary bow above it

Rainbow colours

The rays of light from the sun are parallel and hit the raindrop at any point across the diameter of the drop. Fig. 1 shows rays hitting the upper half of the drop. The precise relationship between h , the distance between the ray and the axis, and the angle of deviation α is complex and is shown in fig. 2. The figure also shows the difference between red and blue light.

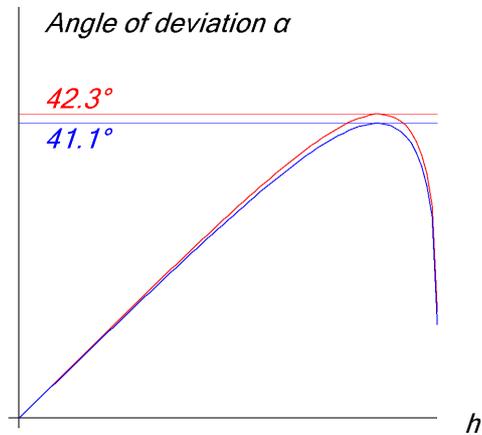


fig 2: The relation between h and α

At the maximum point in red light, there are many rays which emerge at or near this angle so the reflected light is relatively bright. This ensures that the upper edge of the rainbow is a bright pure red. At a smaller angle where the blue light is maximum, there will be some red light mixed in as well so the colour will not be a pure blue. Below that, all colours are reflected more or less equally and the reflected light is white. Fig. 3 is an attempt to approximate the colours of the rainbow.

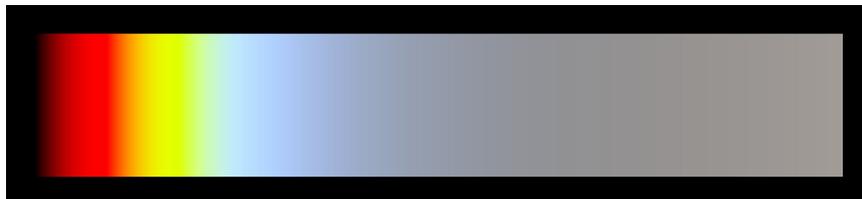
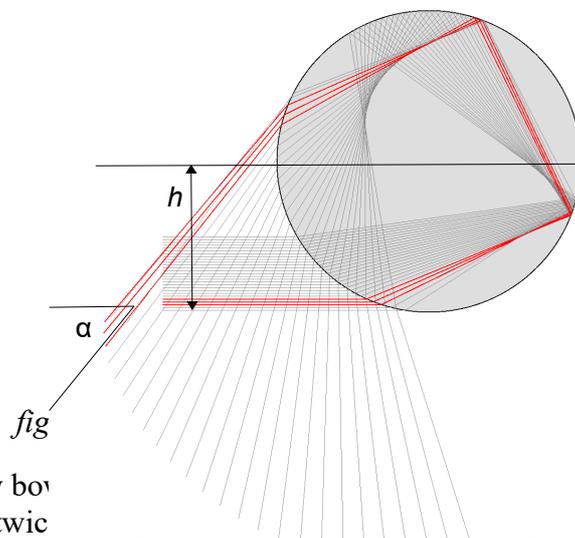


fig 3: The colours of the rainbow (approximate)

The secondary bow



The secondary bow light which bounce twice rays which return at a *minimum* angle of about 50° . What this means is that the red colour is on the

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inside the drop. Most rays of re lost but there is a cluster of

inside of the arc and that there is a dark area between the two arcs of about 8°

The secondary bow is much fainter than the primary bow partly because it undergoes two partial reflections but mostly because the relation between h and α has a much sharper peak. This means that there are fewer rays which reflect at or near the turning point.

The supernumerary bows

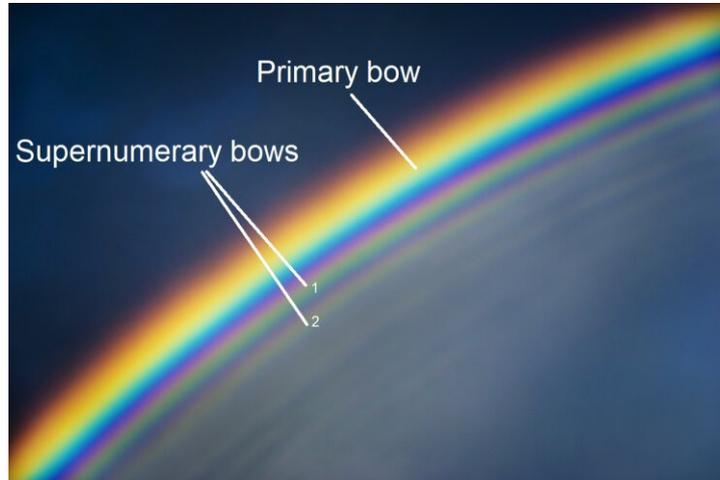


fig 5: Supernumerary bows

Sometimes a number of extra rainbows can be seen inside the primary bow as seen in fig. 5. These are caused by interference. If you look at fig. 2, where the blue reflected light is maximum you will see that there are two red rays which emerge at exactly the same angle. Now these two rays take different paths through the raindrop and therefore will have different path lengths. If the path difference is exactly a whole number of wavelengths the two rays will interfere constructively and there will be a certain amount of red mixed with the blue; if the path difference has an extra half wavelength, however, the two rays will interfere destructively and there will be no red. At smaller angles there are always two rays of any given colour which return at the same angle and interference will occur making the reflected rays vary in colour in a complex way. The colours are, in fact, similar to those seen in thin films of varying thickness such as those seen in a soap bubble or an oil slick.

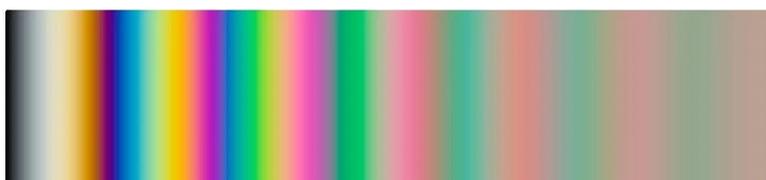


fig 6: Colours in a soap film

In order for these effects to be seen, all the raindrops must be the same size. If the cloud consists of drops of different sizes that makes no difference to the angles of reflection but it messes up the interference effects. The larger the drops, the greater the path difference between the two interfering rays and the closer the supernumerary bows will be. The optimum size is probably about half a millimetre in diameter.