

10). However, he is incorrect when he states that the dark zone (known as Alexander's dark belt) between the rainbows is due to interference.

The dark belt can be understood from geometrical optics. The primary (lower) rainbow represents an extreme value of the angle at which light rays are scattered after being internally reflected once by a raindrop. If a viewer on the ground looks at the top of the primary rainbow, and then lifts her head a little higher, she sees a dark sky because no light rays emerge from water droplets at angles steeper than the rainbow angle. The sky is not completely dark in the belt because of scattering due to more than one internal reflection and to light from the sky and the landscape.¹

One rainbow phenomenon that must be explained by interference is the presence of supernumerary bows beneath the primary rainbow. A partial explanation of that phenomenon was given in 1838 by George Airy.² If you look carefully, you can see one supernumerary bow (the narrow white band) underneath the primary one in Saccocio's photo. As with many topics related to rainbows, the supernumerary bow is still actively researched.³

References

1. See, for example, M. G. J. Minnaert, *Light and Color in the Outdoors*, Springer-Verlag, New York (1993), p. 197.
2. G. B. Airy, *Trans. Camb. Phil. Soc.* **6**, 397 (1838).
3. See, for example, C. L. Adler, J. A. Lock, D. Phipps, K. Saunders, J. Nash, *Appl. Opt.* **40**, 2535 (2001).

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The text accompanying E. Blaise Saccocio's double rainbow picture should have pointed out the existence of supernumerary rainbows clearly visible inside the primary rainbow. Although the primary and secondary rainbows are explainable in terms of geometric optics, the supernumerary rainbows are not, because they are a manifestation of light interference within a raindrop. In fact, it was an observation of supernumerary rainbows that prompted Thomas Young to perform the famous double-slit experiment in 1801, which confirmed the wave nature of light and led to his explanation of these rainbows in 1803. For more information and pictures, see references 1 and 2.

References

1. Raymond L. Lee Jr, Alistair B. Fraser, *The Rainbow Bridge: Rainbows in Art, Myth, and Science*, Pennsylvania State U. Press, University Park, PA (2001); see especially chap. 8, available at http://www.usna.edu/Users/oceano/raylee/RainbowBridge/Chapter_8.html.
2. M. Sawicki, P. Sawicki, *Phys. Teach.* **38**, 19 (2000). Available at <http://www.jal.cc.il.us/~mikalajsawicki/rainbows.htm>.

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Saccocio replies: For 20-odd years, having read Jearl Walker's paper and a number of its references,¹ I have attributed the rainbow's dark zone to optical interference. A closer reading more clearly reveals that the mechanism is refractive, just as Chuck Adler and Mikolaj Sawicki point out. Both their understandings are supported by Walker;² my earlier reading likely did not focus on that part of his discussion. Walker's paper is highly detailed and describes what is and is not observable both in nature and in laboratory rainbow-simulation conditions. My thanks to Adler and Sawicki.

References

1. J. D. Walker, *Am. J. Phys.* **44**, 421 (1976).
2. Reference 1, p. 424.

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Causes and Correlations of Master's Degree Statistics

The article in the June 2003 issue of PHYSICS TODAY (page 32) on master's degree recipients in physics states:

People who added a master's to their resumé rated their undergraduate education as more useful preparation than those who stopped after the bachelor's. This rating shows the important role of physics departments, says report coauthor Rachel Ivie. "People who had a better undergraduate environment—better advising, better relationships with professors and other students—are more likely to complete graduate degrees."

Those statements are an example of the well-known fallacy of confusing correlation with causality. An equally

plausible explanation, one of many possibilities, for why master's degree recipients gave a high rating of their undergraduate education is that students skilled in physics tend to enjoy their undergraduate education and also tend to obtain higher degrees. The study's authors are not necessarily wrong, but they certainly do not have the data to prove their point.

It is disappointing, but all too common, to see scientists abandon their logical skills in discussions of policy and other nonscientific matters.

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Ivie replies: Many skilled physics bachelors choose not to obtain graduate degrees for various reasons. And 60% of the physics bachelors who earned master's degrees did so in fields other than physics.

I suggest that Laurette Tuckerman read the full report, available at <http://www.aip.org/statistics/trends/reports/masters.pdf>. It details our multiple measures of physics bachelors' evaluations of their undergraduate experiences. As the report shows, those with graduate degrees

in any field are more satisfied with undergraduate advising, supportiveness of professors, and working relationships with professors and students than are those without graduate degrees. However, those who earned master's degrees and work in scientific fields actually rate their undergraduate physics preparation lower than those who did not earn graduate degrees and who work in scientific fields. So at least retrospectively, physics bachelors without graduate degrees felt more prepared in physics than those who earned master's degrees in any field.

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An Observation on Hofstadter's Butterfly

Joseph Avron, Daniel Osadchy, and Ruedi Seiler have nicely highlighted the relevance of topological invariants, or Chern numbers, to the integer quantum Hall effect and to the conductance of a Hofstadter model when the Fermi en-