Chromatic effects near a white-light vortex

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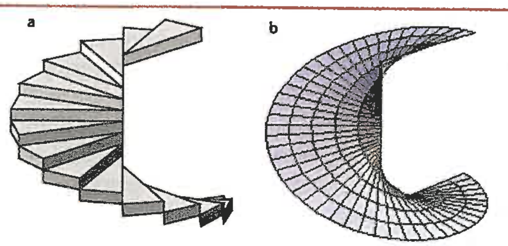
Phase singularities are common throughout optical physics [1-3]. They occur at points or regions of undefined phase, the consequence of which is that the light field has zero intensity. Phase singularities in white-light sources have been modelled and studied experimentally, producing dramatic chromatic effects [4-9]. Recently, these chromatic effects were predicted to exist in the case of beams containing optical vortices [10,11]. We have experimentally observed these distinctive effects by looking closely at the centre of such beams, produced by a spatially coherent white-light source and a computer generated hologram [12].

A simple example of a singularity is that of a spiral staircase. However, it is not possible to accurately describe the center height, leading to a singularity at the center of the staircase.

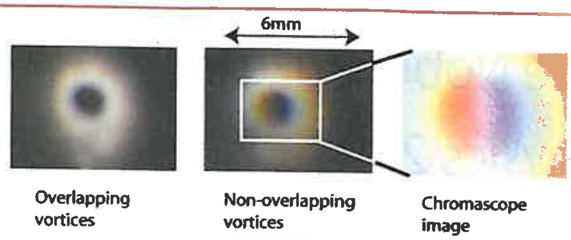
The example of a spiral staircase is particularly illustrative when considering beams that contain optical vortices. The steps that spiral around the center of the staircase are equivalent to surfaces of constant phase around the beam's axis. This helical phase structure means the phase on the beam's axis is undefined resulting in a phase singularity. The corresponding intensity zero produces a characteristic ring or "doughnut" intensity profile of the beam.

In our case, we are interested in phase singularities of not monochromatic light but of white-light, for example a tungsten halogen bulb. In order to get helical phase fronts, we produced a spatial coherent white-light beam by passing light from the bulb through an optical fiber and collimating the output. The helical phase structure was then added to the beam by reflecting it off a computer-generated hologram. The design of the hologram resembled that of a diffraction pattern but with an additional fork dislocation on the beam's axis. The first order diffracted beam has the desired helical phase structure. After the hologram, each spectral component of the source was recombined and made co-axial with a low dispersion prism. The relative direction of the components and thus spectral spread of the source could then be controlled by the computer-generated hologram.

As the chromatic effects occur in the center of the beam where there is very little light, they are very hard to observe. The effects are subtle and can only be revealed by amplifying the colours. The technique used is referred to as a "chromascope". This is a colour correction such that at every pixel in the image, the RGB values are



▲ Fig. 1: Examples of singularities. a). A spiral staircase where the height in the middle is undefined. b). The helical phase fronts of a beam with an optical vortex.

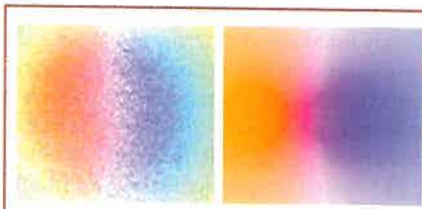


▲ Fig. 2: Experimental results.

increased to make the largest of them fully saturated whilst maintaining their ratios.

Figures 2 and 3 show our experimental results. Figure 2 contrasts the case where the optical vortices for each spectral component in the white-light source are overlapping and not overlapping. When the vortices are not overlapping, the chromascope image reveals the chromatic patterns at the center of the beam. Figure 3 compares the experimental results to the theoretical predictions made by Berry. In both cases, the transition across the image from red to blue is clear. Note that neither image contains any green.

Although the detailed form of these patterns is complicated, the underlying principles, which give rise to these chromatic effects, can easily be understood. For each spectral component, there is a corresponding intensity zero. The dispersion of the vortices produces a line along which specific spectral components are not present. At one extreme, there is no blue component, at the other, there is no red component, and in the center, there is no green. This gives rise to a dominance of the complimentary colours, cyan, magenta (purple) and yellow. The absence of any green region over the entire beam cross-section is explained since it would require the red and blue vortices to be coincident, which they are not.



▲ Fig. 3: A comparison of the experimental results to the theoretical predictions (Berry, *New. J. Phys.*, 4 66).

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References

[1] Nye J.F and Berry M.V., 1974 *Proc. R. Soc.* A, **336** 165–190
[2] Nye J.F 1999 *Natural Focusing and Fine Structure of Light: Caustic and Wave Dislocations* (Bristol: Institute of Physics Publishing)
[3] Soskin M.S and Vasnetsov M.V, 2001, *Prog. Opt*,. **42** 219–276
[4] Gbur G., Visser T.D. and Wolf E, 2002, *Phys. Rev. Lett.*, **88** 013901
[5] Gbur G., Visser T.D. and Wolf E 2002, *J. Opt. Soc. Am.*, **19** 1694–1700
[6] Foley J.T. and Wolf E., 2002, *J. Opt. Soc. Am.*, **19** 2510–2516
[7] Ponomarenko S.A. and Wolf E., 2002, *Opt. Lett*,. **27** 1211–1213
[8] Popescu G. and Dogariu A., 2002, *Phys. Rev. Lett.*, **88** 183902
[9] Schouten H.F., Gbur G., Visser T.D. and Wolf E., 2003, *Opt. Lett.*, **28** 968–970
[10] Berry M.V., 2002, *New J. Phys.*, **4** 66
[11] Berry M.V., 2002, *New J. Phys.*, **4** 74
[12] Leach J. and Padgett M.J., 2003, *New J. Phys.*, **5** 154