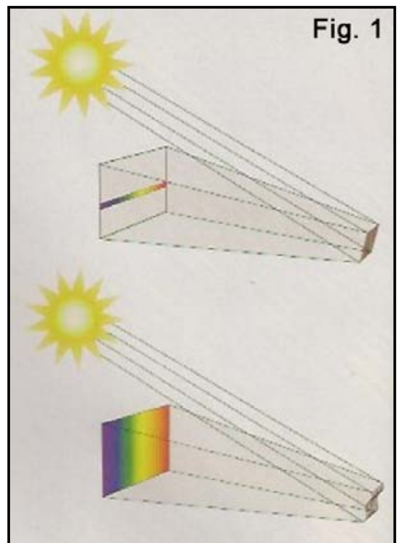
Wavy Diffraction Gratings

Stephen F. Jacobs, Professor Emeritus
College of Optical Sciences
The University of Arizona
Tucson, AZ 85721

One way to turn people onto Science is to let Science speak for itself. An excellent example is the brilliant colors of the spectrum. And what could be a more convenient light source than the sun? Thanks to the invention of surface relief holography, large inexpensive diffraction gratings are now readily available. We see them everywhere: billboards, greeting cards, book covers, bumper stickers, wrapping paper, Christmas decorations, etc. So you place a large flat diffraction grating in the sunshine and produce a brilliant spectrum of colors for the public to enjoy.

This was tried by sculptor Dale Eldred, who mounted a 53’ diffraction grating atop Crawford Hall at Case Western University in 1987, in commemoration of the 1887 Michelson-Morley Experiment. The only trouble was the colors were too directional and too brilliant. A viewer had to be in just the right place to see the colors at all, and then they were too intense for eye comfort.



(Top) Flat grating spreads colors only horizontally. (Bottom) The wavy grating also spreads colors vertically.

A nice solution to this problem is to arrange a tradeoff between viewing brightness and viewing solid angle. E.g., attach the diffractive material to a wavy substrate, such as sinusoidally curved corrugated metal roofing. The diffraction grating spreads the colors horizontally, while the wavy substrate can be oriented to spread the light vertically by virtue of geometric optics. Fig. 1 shows how this works.

In 1996 a 50 x 14’ wavy grating was mounted atop Tucson’s City Hall underscoring the then popular slogan, ‘Tucson is becoming Optics Valley”. Fig. 2 shows the construction phase; Fig. 3 shows the finished project, as viewed from Tucson Convention Center.


Fig. 3

Our design matched the vertical spreading to that of the grating's (horizontal) spreading of the colors, which is about 30 degrees. Regrettably, it appears that sinusoidal corrugated metal roofing is available in only one pattern: wavelength 2 2/3" (= 67.7 mm), with peak-to-peak amplitude ½" (= 12.7 mm), which is too deep for our design. Therefore we had to flatten the metal some using machine shop rollers.

It's a nice mathematics exercise to estimate the desired amplitude for flattening. This could be done graphically or analytically as a check. Remember to orient the grating grooves perpendicular to the corrugation grooves. My answer was to reduce the sinusoidal peak-to-peak amplitude by a little more than a factor of two. The grating material was manufactured by Spectratek. Contact mkelem@Spectratek.net.

One lesson learned from the City Hall project was that the ultraviolet in Tucson's sunshine wiped out the colors in just a few years' time, leaving only a drab gray. We had to renew the grating material with an ultraviolet-absorbing overlaminate (3M 7735FL), which has held up so far for 10 years. The colors are still visible from several miles away.

Recently, a new holographic material. called Ripples, has become available that achieves the effect of the wavy substrate, thereby eliminating the need for a corrugated substrate. However, the effective amplitude of the wavy sinewave is much greater than that used in the City Hall grating. This results in much greater spreading and consequentially much reduced brightness seen by the viewer. For outdoor applications it is still necessary to protect from ultraviolet radiation by use of an overlaminate.


Fig. 4

Later the same year a smaller wavy diffraction was mounted over the entrance to Flandrau Science Center on the campus of the University of Arizona. (See Fig. 4.) This grating is frequently used by classes to teach how a diffraction grating works:

$$d\,[\text{Sin}\,\alpha + \text{Sin}\,\beta] = n\,\lambda$$

and to practice estimating. E.g., by knowing the wavelength of, say, green light, (540 nm), and estimating the angles of incidence and diffraction, one can deduce the grating constant d. Note that a distant viewer sees the entire diffraction grating in a single color because the range of angles subtended is small. However, a closer viewer sees many different colors because the range of angles is greater.

This is a good example of Science contributing to Public Art; then Public Art contributing to Science Education.

To learn more about how diffraction gratings work, go to www.optics.arizona.edu/sinewave/DiffractionGratings.pdf for "How a Diffraction Grating Works, Without Equations." Here we show pictorially how water waves interfere constructively and destructively, just as light waves do with a diffraction grating. Also, for a more advanced treatment of diffraction gratings go to www.optics.arizona.edu/sinewave/AdvancedDiffractionGratings.pdf for "Experiments with Diffraction Gratings," an outline I used in my optics course at the Optical Sciences Center. E.g., after experimentally estimating the grating constant d, as described above, one can predict the theoretical spectral resolving power and compare this with the experimentally observed resolving power using the two yellow sodium D-lines, (589.0 and 589.6 nm in wavelength). The sodium D-lines are visible in the spectrum of yellow low pressure sodium lamps. (Not to be confused with high pressure, pinkish colored sodium street lamps).

If there's still more interest in diffraction gratings and spectroscopy, you can learn about the spectra of night lights, that teachers like to call "the fingerprints of the atom," by going out at night holding a transmission grating in front of your eye [1, 2]. You can easily find half a dozen different spectra to admire. It's a beautiful and convenient introduction to spectroscopy. For spectrum identification, search the Internet for Night Spectra Quest.

The author is grateful to Cele Peterson for finding friends to help pay for the City Hall Rainbow Project, as it was called. A large pictorial history of City Hall Rainbow Project may be found at the Cele Peterson Arizona Collection of Pima County Public Library.

References

Jacobs, Stephen F., "Night Spectra Quest," The Physics Teacher 33, 380 (1995).
S. F. Jacobs, "Challenges of Everyday Spectra," J. Chem Ed. 74, 1070 (1996).