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A Simple Demonstration of Absorption Spectra Using Tungsten Holiday Lights

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Abstract

In a previous paper submitted to the Demonstrations section (Birriel 2008, *Astronomy Education Review,* 7, 147), I discussed using commercially available incandescent light bulbs for the purpose of demonstrating absorption spectra in the classroom or laboratory. This demonstration solved a long-standing problem that many of astronomy instructors face trying to demonstrate how astronomical objects, such as stars, exhibit absorption spectra. In this paper, I briefly describe using a strand of tungsten holiday lights to demonstrate absorption spectra and discuss the advantages and disadvantages of using a holiday light strand versus the previously discussed, full-sized incandescent light bulbs.

1. INTRODUCTION

Over the course of five semesters, I used several commercially available tungsten light bulbs to demonstrate how different glass envelopes surrounding a tungsten filament can produce various absorption features and allowing students to view first hand objects that produce absorption spectra. Students observed the spectra of the bulbs using hand-held, slit spectrometers in a class room lecture setting. Most students were able to clearly identify the absorption bands in the light bulb spectra and expressed a sense of interest during the demonstration.

However, I did observe some recurring problems over the years. The class size ranged from 30 to 40 students and the room itself was at full capacity at 48 students. There were usually about five to eight students who complained that they found it difficult to center the spectroscope slit on the light source. I encouraged students who were experiencing such difficulties to move closer to the light source, but most were reluctant to do so. Students also found it difficult to compare bulbs that simply differed in “cutoff” wavelength, such as the GE soft white bulb versus the GE yellow “bug lite.”

Personally, I experienced some difficulties with the setup myself. I occasionally found myself burning my fingers while switching bulbs to avoid lengthy delays between demonstrations (and this was with two alternating setups and some cooling time between)! In addition, setting up for the demonstration required a considerable amount of “luggage” from the demonstration room to the lecture room, including two tall ring stands, two light bulb sockets, a large box of light bulbs, and a large box of slit spectroscopes. Finally, there was the inevitable bulb breakage. I began to wonder if there might be a useful alternative that could quickly but effectively convey the concept of the absorption spectrum.

2. MATERIALS AND METHODS

The required materials are quite simple: a strand of mini, colored holiday tungsten lights [Figure 1(a)], a strand of mini, clear “white” holiday bulbs, a set of diffraction grating slides, and some tape. In the case of the colored strand of lights, one or more color bulbs should be replaced with a clear bulb which will serve as your

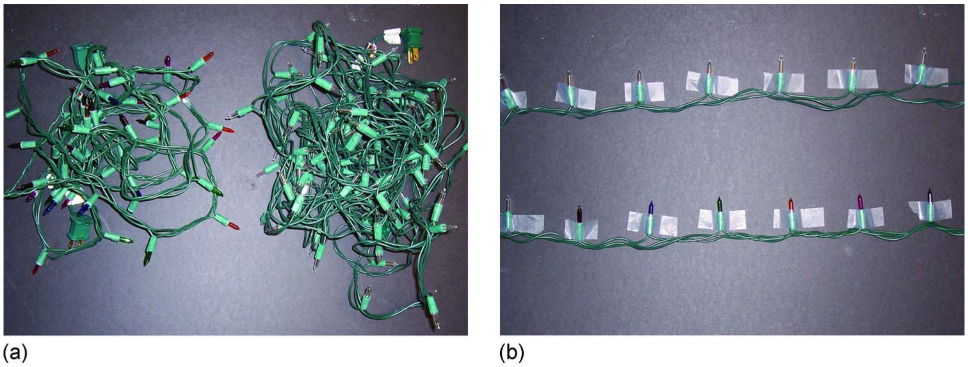
(a) (b)

Figure 1. (a) The strands of miniature, tungsten bulb holiday lights. The holiday light strands shown here are of the "steady burn" variety. (b) In the course of the demonstration, the light strands are taped horizontally along the wall or blackboard, for the purposes of comparing the spectra of various colored light bulbs, it is important to orient the colored bulbs parallel along the strand. This makes it much easier to observe differences in wavelength cutoffs

"continuous spectrum" for comparison. You can also replace some bulbs with a purple bulb from Halloween holiday light strands. Though it initially takes time outside of class to setup a pattern of bulb colors along the strand (i.e., clear, red, blue, green, orange, and pink), you will ultimately find it a useful investment of time as this allows all students to observe the bulbs in a single visual "shot."

The holiday light strands employed here are of the "steady burn" variety, but one can also use the "multifunction" variety in steady burn mode. Each bulb used in this demonstration operates at a voltage of 2.5 V and the bulbs are spaced approximately 3 in. apart. The strand is powered by a standard 120 V (USA) electric outlet. Using the larger, older holiday light bulb strands is problematic because the filament is long enough that it is generally mounted on several prongs and forms a "V" or chevron, which results in the formation of a double spectrum for those observers close-up and a general loss in resolution to those further away when the spectra happen to overlap one another.

To demonstrate absorption spectra, it is necessary to use the tungsten bulb holiday lights. Holiday light strands composed of light-emitting diode (LED) lights will produce emission spectra. While in principle, one might want to use these to demonstrate the appearance of an emission spectrum, explaining how the LED produces emission is more complex than invoking the Bohr model which the students' will likely already be familiar. Gas discharge tubes also allow the student to observe for themselves the emission spectra of H, He, etc., which feature prominently in most textbooks. For these reasons, this author prefers to defer to the use of the commonly available gas discharge tubes to demonstrate emission spectra.

The diffraction gratings used in this demonstration should (1) be inexpensive and so easily replaced if lost or damaged, (2) have a bright first order spectrum, (3) have a dispersion capable of revealing broad absorption bands, and (4) be large enough to allow comparison of six to seven different colored light bulbs at the same time. This author has found that commercially available 2×2 in.^{2} diffraction grating slides with between 500 and 750 lines/mm work well. There are a number of sources for such diffraction grating slides. I have used diffraction grating slides from both Arbor Scientific and Educational Innovations for this demonstration. The grating from Arbor Scientific (Item 33–0980) has 750 lines/mm and produces a very bright first order spectrum at a cost $3.00 for each slide. This grating is of very sturdy construction, with a plastic 2×2 in.^{2} slide frame and a grating housed between two glass plates. The dispersion is large enough that the spectrum produced by each bulb is fairly far from the bulb making it somewhat challenging for the novice observer to associate the various spectra with their source bulbs. Thus, one would probably want to avoid gratings with more than 750 lines/mm. The grating slide from Educational Innovations (Item PG-415) has 500 lines/mm and produces spectra that are not quite as bright as the former but do have the advantage of a significantly lower cost: a package of 30 gratings in the standard 2×2 in.^{2} cardboard slide frame (but no protective glass plates) costs $17.75 or $0.59 per slide. Though not as sturdy as the former grating slides, the Educational Innovations gratings work just as well.

Tape the two strands (clear white and colored) horizontally, one-above-the-other [Figure 1(b)] and well above eye-level of the seated students. It is irrelevant which strand is on the top. When mounting the colored light strand, take particulary care to keep the orientation of each bulb parallel to all other bulbs. This setup will enable students to easily compare the spectra of various bulbs. In the largest of classrooms, one should probably hang one long strand (50–100 ft in length) of both the clear and the colored light bulbs simultaneously on each wall so that all students can easily observe the strand closest to them.

Before turning on the white light strand, discuss with students the nature of the bulbs. Inform them that the each bulb is nothing more than a miniature tungsten filament light bulb that is heated by an electric current. Remind the students of Wien's blackbody law and ask students to discuss with a nearby peer what kind of spectrum the hot filament should produce: continuous, emission, or absorption. When students have made their predictions, turn on the white light strand and ask them to observe the spectrum of the filament.

Now turn off the white light strand and turn on the class lights. Inform the students that the colored lights on the next strand are identical to the white light bulbs in every aspect except that these have been painted on the outside with a transparent color lacquer. The light from the filament must then pass through the colored glass bulb to reach them, the observers. Then ask the students to predict what the different paint colors on the glass bulbs might do to the light emitted by the filament. Have them jot down their predictions.

Now, turn on the colored holiday lights and turn off the lecture hall lights. Students should place one white light bulb at either end of their field of view in the grating slide, this should allow them to view all six or seven different colored bulbs in a single shot. Students should discuss the differences in spectra: (1) Which spectra are missing complete bands of colors? (2) Which appear to simply have some colors "damped" down? (3) Encourage the students to think about the paint coatings in terms of "filters," for example, the red paint is clearly "filtering out" or absorbing light in the middle portion of the spectrum. Now, ask them to think about what are those missing color bands most appropriately called? Lead them to the idea of the continuous spectrum of the bulb filament being selectively absorbed by the different lacquer coatings. They should discuss with their neighbors how the broad absorption patterns they observe are indicative of the differences in the chemical composition of the different lacquer pigments. It is a small stretch from here to introduce the concept of the hot, dense stellar core producing a continuous spectrum and the outer layers of the star producing absorption lines that depend (in part) on chemical composition.

To be effective, all lecture room light sources need to be turned off and all windows shaded. Students can then use their diffraction grating slides to observe the resulting spectra from their seats. As seen in Figure 2, the spectra of the red and blue bulbs show strong absorption bands. The orange bulb shows absorption of light at the violet end of the spectrum whereas the green bulb shows strong absorption in the red end. The pink bulb shows some absorption in the green portion of the spectrum. Finally, the purple bulb taken from the Halloween strand shows only a faint violet emission.

3. DISCUSSION

From the student perspective, this particular setup has a number of advantages over that which I previously described (Birriel 2008). The mini bulbs used in the tungsten holiday light strand appear as point sources to all students. So, they can use diffraction grating slides to observe the spectra without the frustration of aligning a slit on a source bulb. In addition, they can more easily compare the absorption spectra of each color light bulb to the continuous spectrum of the clear bulb.

For the instructor, there are also a number of advantages as well. First off, there is significantly less bulk for this setup: the materials can easily fit into a single box. In addition, there is no need to change light bulbs and little chance of burning one's fingers as the small bulbs stay relatively cool to the touch. Both the setup time and the time required for demonstration are significantly less than the previously described demonstration using incandescent light bulbs. Finally, there is significantly less chance of bulb breakage.

This demonstration is quite effective at conveying the basic concept of the absorption spectrum but it does have two disadvantages. First it lacks some of the pedagogical pizzazz of the previous demonstration. For example, as discussed previously, the GE Reveal bulb markets itself as a "full spectrum" bulb but students can easily observe the strong absorption bands in the spectrum of this bulb and challenge this marketing claim. There are several other interesting aspects of the incandescent bulb demonstration that can be used to stimulate student thought (see Birriel 2008). In addition, if students are too far from the light strand, the spectra become narrow and difficult to observe, so some students may still have to move about the classroom and position themselves closer to the lights. Finally, the purple bulb from the Halloween holiday strand is fairly faint and students will find it difficult to observe its spectrum unless they are within about 4 ft of the strand, so this bulb worth excluding in all but the smallest group settings.

4. EXTENSION: INSTRUMENTAL SPECTRAL RESPONSE

Figure 2 was obtained using a Kodak EasyShare CX7430 with the Educational Innovations 500 lines/mm grating taped to the front of the camera lens. While both the blue and purple bulbs exhibit no red spectral features in the image, the spectra of both bulbs do in fact have weak red spectral features that are visible to the human eye. If some students have cell phones with cameras, they can be asked to place the grating slide just in front of the camera lens and obtain a similar digital photo. Students can then compare the sensitivity or "response" of the camera to that of human vision!

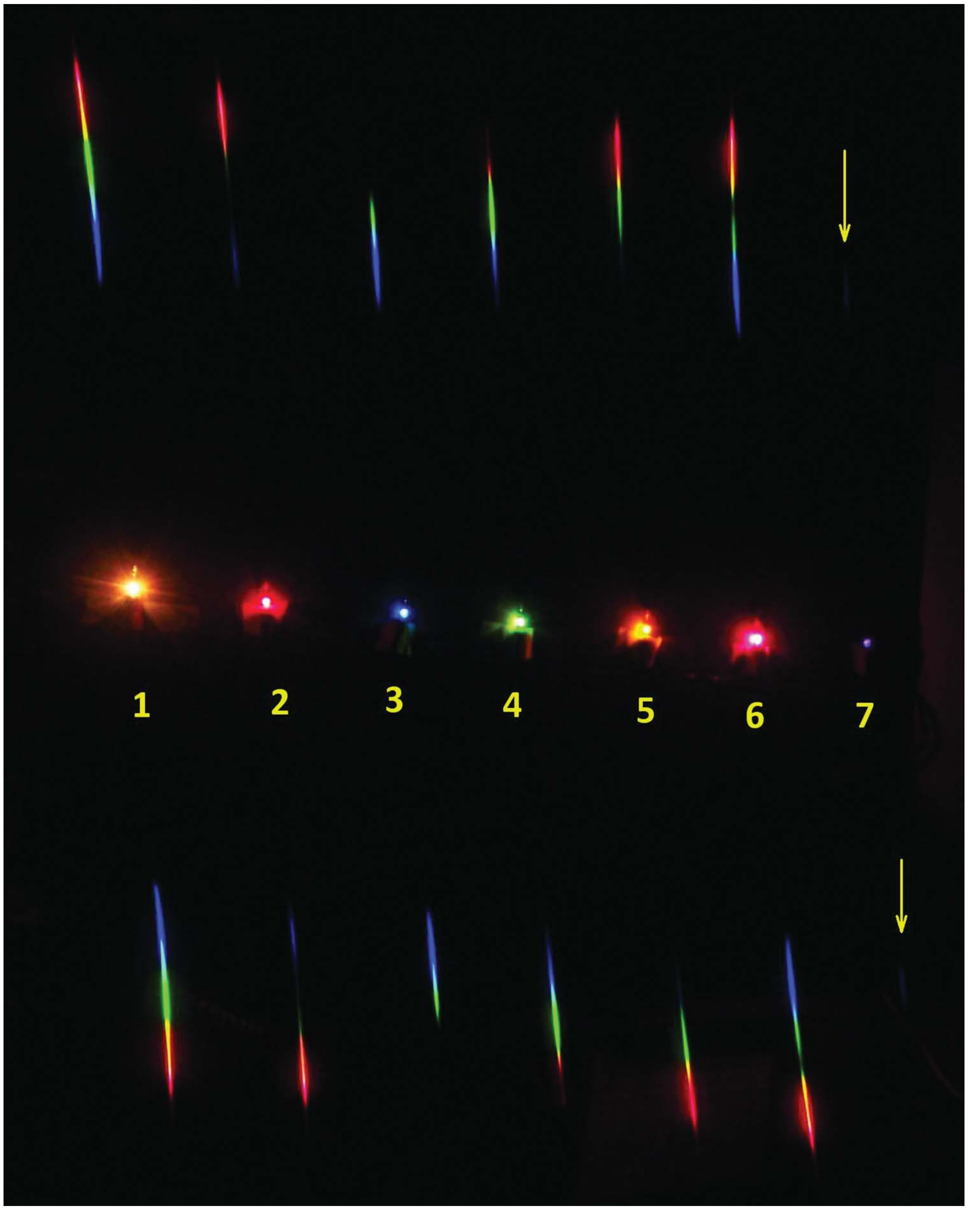

Figure 2. The absorption spectra of the holiday light strand obtained using a Kodak EasyShare CX7430 with the Educational Innovations 500 lines/mm grating taped to the front of the camera lens. Bulb 1, which appears yellowish in the photograph, is actually a clear white bulb and serves as the full spectrum comparison. Bulb 2, which appears reddish here, is a red bulb whose spectrum exhibits an absorption band in the green and blue portion. Bulb 3 is a blue bulb and in the digital image, it exhibits strong absorption in the red, orange, and yellow spectral regions; however, the human eye actually detects a faint emission in the red that does not appear in the digital image. Bulb 4 is a green bulb: its spectrum exhibits a damping or cutoff at both the violet and red ends of the spectrum. Bulb 5, which appears yellow in the image, is actually an orange bulb: its spectrum exhibits a strong damping or cutoff primarily in the violet portion. Bulb 6 is pink and its spectrum exhibits a weak absorption feature in the yellow and green region. Finally, bulb 7 is a 2.5 V purple bulb taken from a Halloween holiday light strand; visible in the image is a weak blue emission (denoted by the yellow arrows) but the human eye can also detect a weak red emission that is not recorded by the digital camera

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References

Birriel, J. 2008, *Astronomy Education Review*, 7, 147.