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Demonstrating Absorption Spectra Using Commercially Available Incandescent Light Bulbs

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Abstract

In introductory astronomy courses, I typically introduce the three types of spectra: continuous, absorption line, and emission line. It is standard practice to use an ordinary incandescent light bulb to demonstrate the production of a continuous spectrum, and gas discharge tubes to demonstrate the production of an emission line spectrum. The concept of an absorption spectrum is more difficult for students to grasp. A variety of commercially available light bulbs can be used to demonstrate absorption spectra. Here I discuss the use of specialty incandescent light bulbs to demonstrate the phenomenon of absorption of the continuous spectrum produced by a hot tungsten filament. The bulbs examined include the GE Reveal bulb, yellow anti-insect lights, colored party bulbs, and an incandescent "black light" bulb. The bulbs can be used in a lecture or laboratory setting.

1. BACKGROUND

Spectroscopy is key to our understanding of the Universe. As such, every introductory astronomy text discusses the formation of spectra. Like most professors, I had long been using a clear glass tungsten light bulb to demonstrate the production of a continuous spectrum by a hot dense object. I also used various gas discharge tubes to demonstrate the discrete emission spectra of gases. Finally, I would ask students to imagine putting a cool gas between the light bulb and themselves to produce an absorption spectrum. The two demonstrations elicited oohs and aahs. The final "thought experiment" generally fell pretty flat. It became all too clear that I had to find a visually appealing (and practical) demonstration of absorption spectra!

2. METHODS

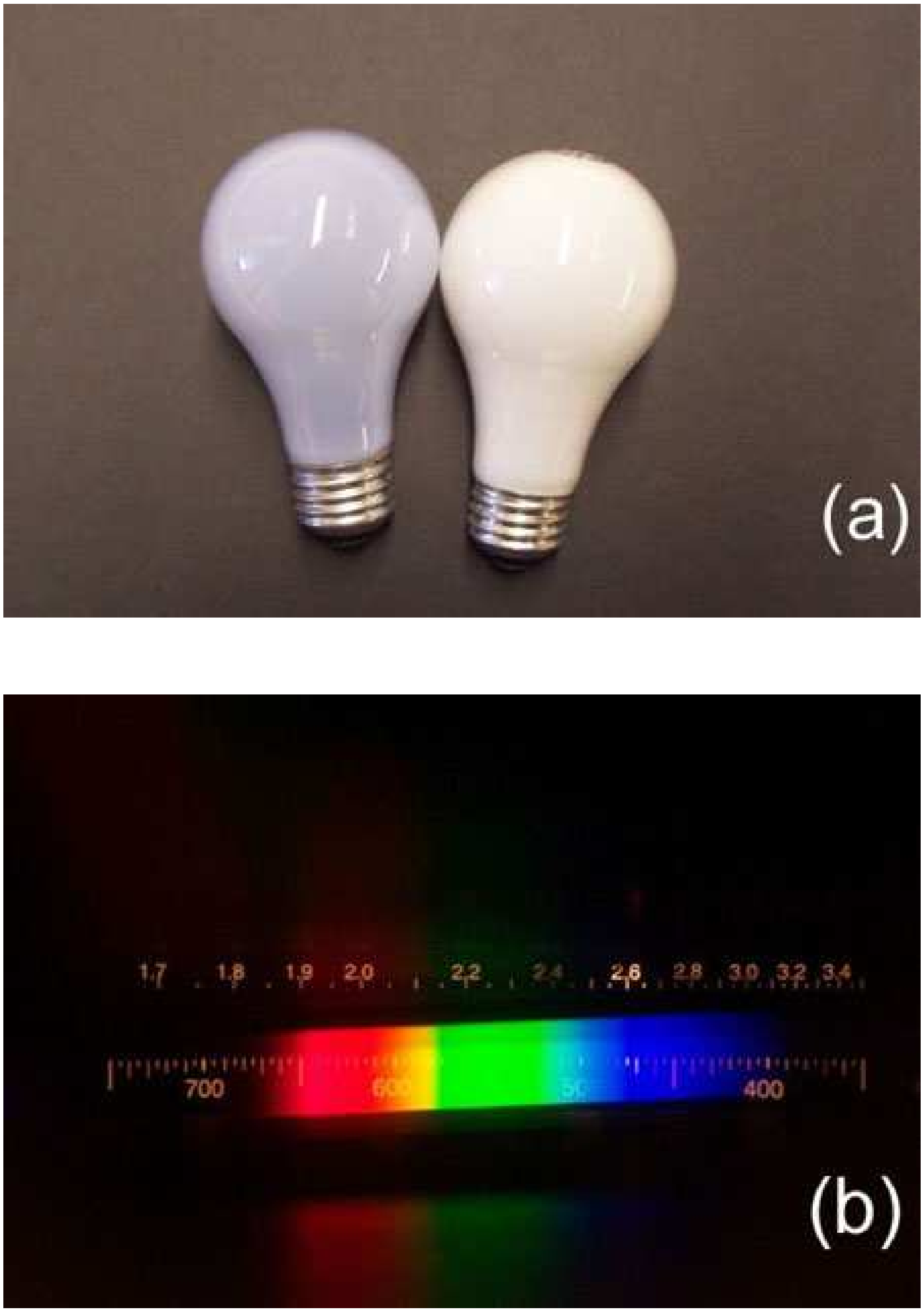
The tungsten filament in any standard incandescent light bulb produces a continuous spectrum. The glass surrounding the light bulb both transmits and absorbs light. A variety of specialty incandescent bulbs are easily (and cheaply!) purchased from any local department or home improvement store. I purchased a number of such bulbs with distinctly different glass coatings or compositions. The light bulbs examined for distinct absorption features included a GE Reveal bulb, a GE yellow Bug Lite, a GE black light, and three GE colored party bulbs (red, green, and blue).

The spectrum of each bulb was examined with a Project Star spectroscope. The spectroscope is placed on a ring stand to steady it, and an image of the spectrum is recorded using a digital camera. The spectroscope was wavelength-calibrated using the 546 nm green Mercury line in the overhead fluorescent lights. In nearly every case, it is best to turn off the room lights and close window blinds to reduce contamination effects from ambient sunlight or room light. If the students will be dealing with the bulbs up close, it is best to remind them that they should exercise caution because many of the bulbs will rapidly heat up!

The above approach—using a wavelength-calibrated Project Star spectroscope secured on a ring stand or steadied by the students' elbows on the desk top—works best within the context of a laboratory or a small lecture class of about 30 students or fewer. Students should be asked to calibrate their spectroscopes and record the full wavelength range of the spectrum visible to them, as well as the wavelengths of any absorption bands. In larger lecture classes, it is probably best to set up a number of stations around the room and have students move from one source to another; each station will need to be "shielded" (something as simple as a trifold posterboard would work).

3. RESULTS

The GE Reveal bulb is marketed as the bulb that is made to "specially filter out yellow rays that hide life's true colors." This is accomplished by the use of neodymium in the glass. Upon heating, Nd reacts vigorously with oxygen to form neodymium oxide, Nd_2O_3, a light blue powder (Note 1). If you examine the GE Reveal bulb in comparison with a GE "soft white" bulb, you'll notice that it has a bluish tint (Figure 1a). The spectrum of the GE Reveal bulb exhibits two broad absorption lines in the yellow region of the spectrum (Figures 1b and 1c). These correspond to a fairly broad absorption band, from about 560 to 590 nm, in the yellow region of the spectrum because of the Nd_2O_3 in the glass (Note 2). Ask your students to evaluate the advertising claim that these bulbs produce "color-enhanced *full-spectrum* light"!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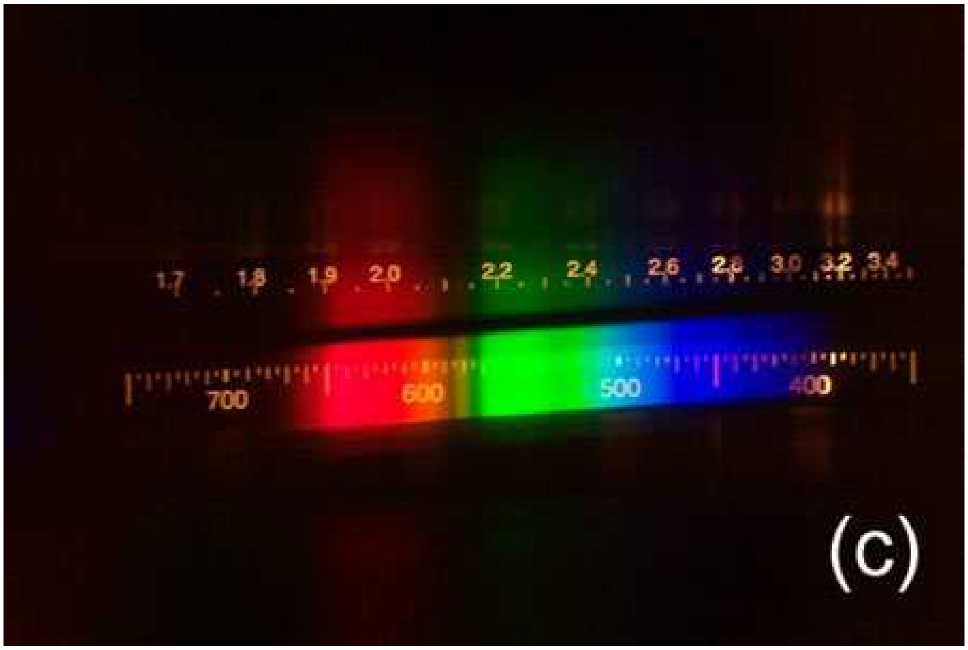


Figure 1. (a) The GE soft white and the GE Reveal bulbs. Notice the bluish tint of the Reveal bulb. (b) The spectrum of the soft white bulb. (c) The spectrum of the Reveal bulb. Notice the prominent absorption lines in the yellow.

The GE yellow Bug Lite (Figure 2) is designed for outdoor use and is marketed as "the porch and patio light that bugs don’t see." These bulbs are to be used in areas where the consumer desires to avoid attracting bugs. A comparison of the spectrum of this bulb with that of the soft white bulb (Figure 1b) reveals that the violet portion of the spectrum (from about 400 to 450 nm) has been damped out! This is much more difficult to see without a direct comparison, but very observant students do notice. Ask your students if they have ever noticed the color of so-called bug zappers; these are essentially fluorescent bulbs with no phosphor coating. Bug zapper bulbs emit at 365 (some at 350) nanometers and also in the usual blue and other mercury lines, accounting for the blue-violet color. (There is strong evidence that many kinds of bugs do in fact see better in the shorter wavelength end of the spectrum!)

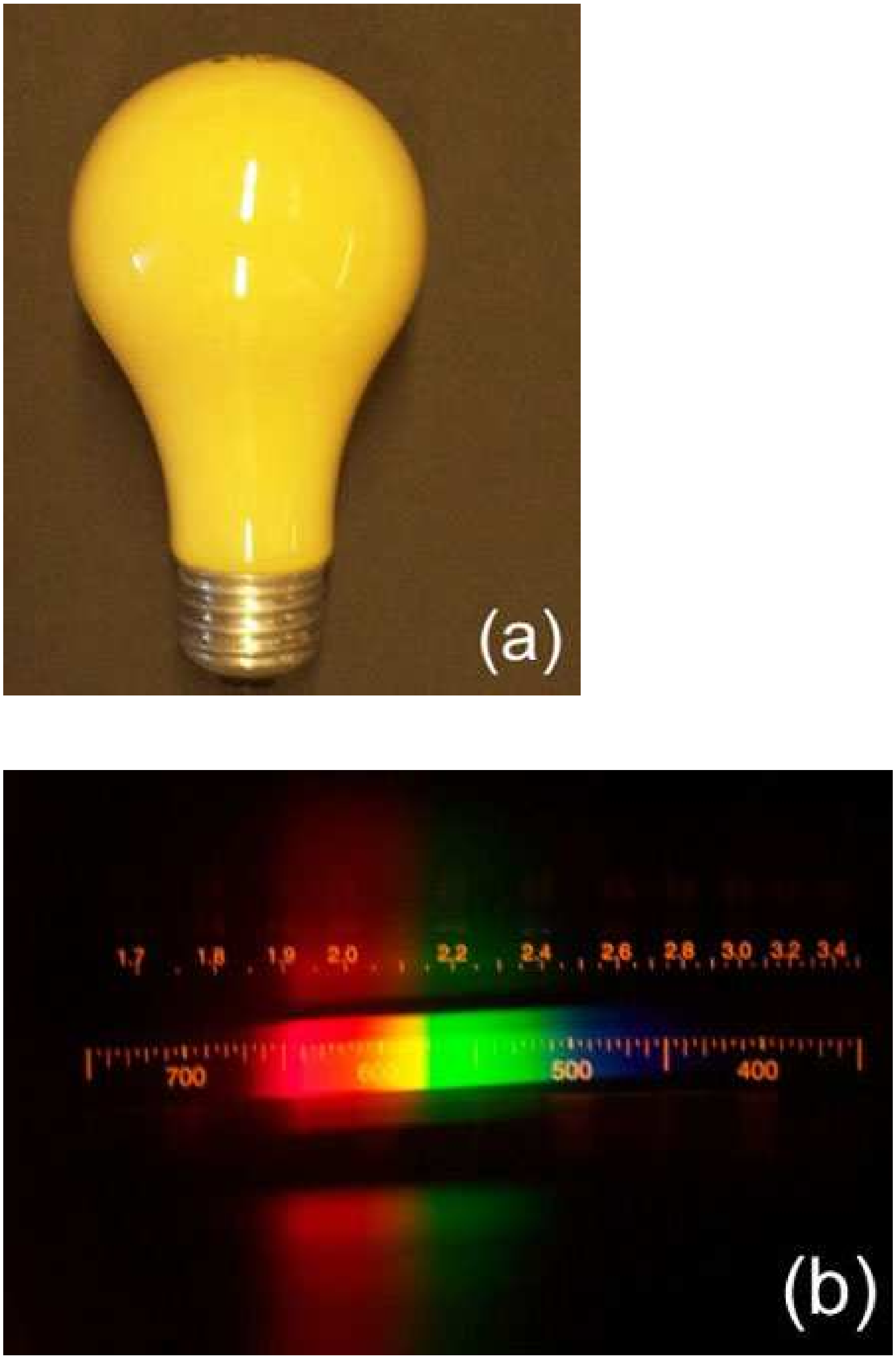
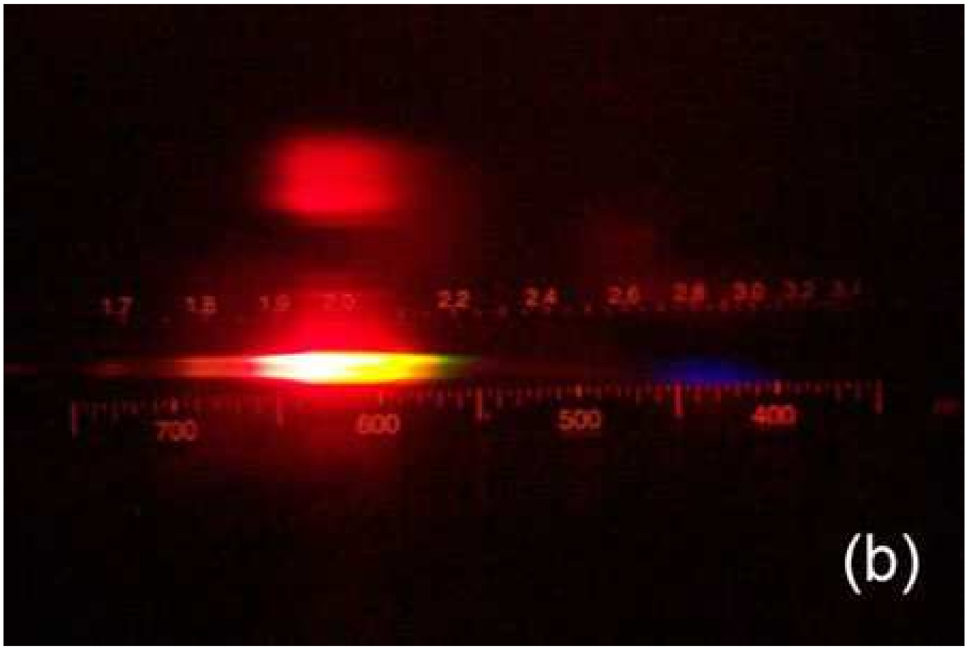


Figure 2. (a) The GE Bug Lite. (b) The spectrum of the Bug Lite. Notice how the violet end is partially extinguished compared with that of the soft white light in Figure 1b.

The party bulbs make an interesting group (Figure 3). The spectrum of the red party bulb exhibits a distinct, broad absorption band in the green and blue spectral regions. On the other hand, the green and blue party bulbs exhibit no distinct absorption bands. For the purposes of demonstrating a distinct absorption band, the red party bulb is clearly the best in this group.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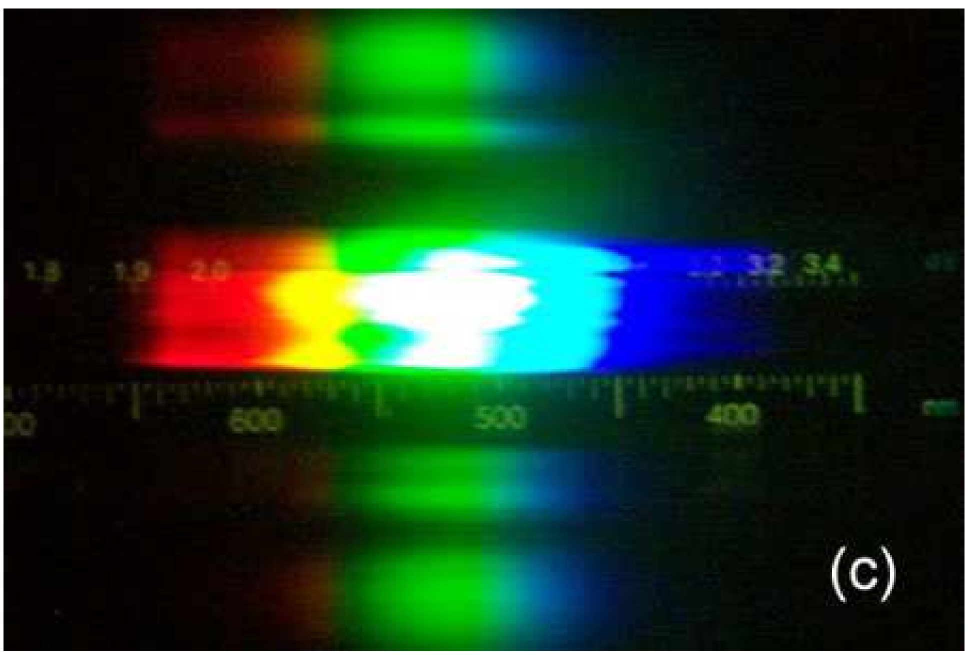
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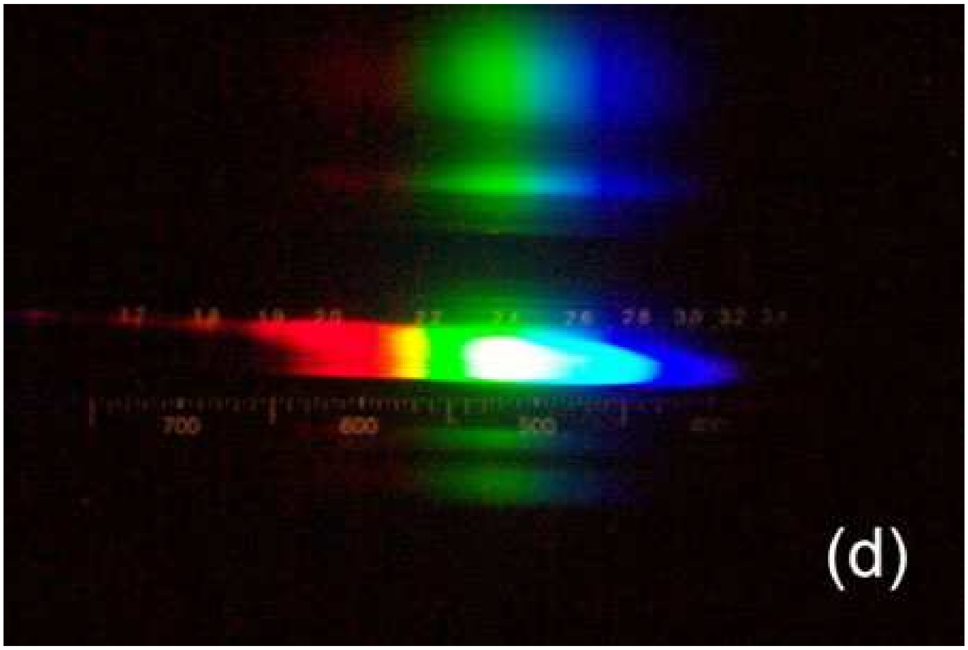

Figure 3. (a) 25 W red, blue, and green GE party bulbs. (b) The spectrum of the red bulb shows a broad absorption band in the green and blue. (c) The spectrum of the green bulb shows no absorption bands, but the red and violet ends of the spectrum appear less intense than the central green and blue portion of the spectrum. (d) The spectrum of the blue bulb exhibits stronger emission in the blue and violet regions and less intense emission in the red region of the spectrum.

The GE incandescent black light has a very dark purple glass. The packaging on the bulb explains that the special glass "allows near ultraviolet to pass through but filters out nearly all visible light." That sounded promising! As you can see in Figure 4b, the orange and yellow portions of the spectrum are missing, and the short wavelength emissions in blue and violet are most prominent.

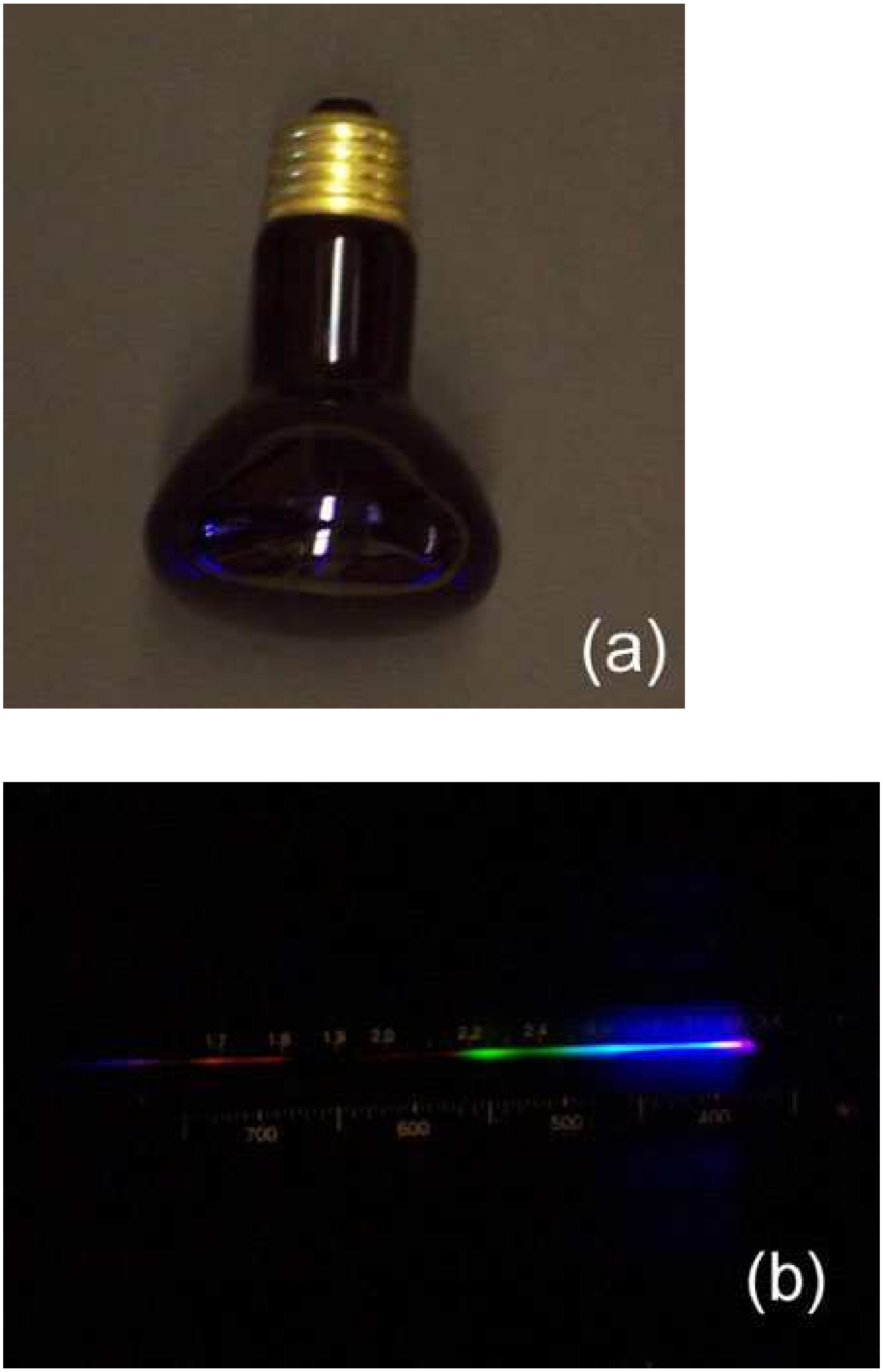

Figure 4. (a) The 50 W GE black light bulb. (b) The spectrum of the black light bulb lacks nearly all the colors except an emission in the blue-violet and a faint emission in green and red.

4. DISCUSSION

These light bulbs help the students make a real-world connection with absorption spectra. The hot tungsten filament emits a continuous spectrum, and the glass between the filament and the observer, like a cooler gas between a star and the observer, absorbs light and creates the dark lines or band in the spectrum. In addition, the striking differences in the colors of the bulb glass help make a connection between absorption and dependence on chemical composition.

To be effective in a classroom setting, any given absorption spectrum must have distinct absorption lines or bands. This makes the Reveal bulb, the red party bulb, and the black light the most useful for classroom demonstrations. It is important to note that the low intensity of visible light emitted by the red bulb and the black light will generally necessitate that students get fairly close to the source. In large lecture sections, it might be necessary to set up several light bulbs around the room. In addition, the absorption lines in the Reveal bulb are missed by some students, so it is a good idea to prompt students by asking if anything is missing in the middle portion of the spectrum.

If the class has a laboratory component, all these light bulbs can be examined. In that case, one could have students explore additional concepts, such as energy conservation and infrared emission, as noted below. Students could also be asked to examine other specialty bulbs, such as heat lamps, halogen bulbs, and compact fluorescent bulbs.

It should be noted that one must be careful not to take the analogy too far. Clearly, the bulb is a solid and not a gas. In addition, the absorption features that the students observed are broad bands due to electron transitions in molecules, as opposed to discrete lines due to electron transitions in the atoms of a gas. Nonetheless, these demonstrations can help students understand how an intervening substance can produce absorption features in the otherwise continuous spectrum produced by a hot, dense object.

5. EXTENSION: ENERGY CONSERVATION AND INFRARED EMISSION

In each case, the glass absorbs some of the visible energy emitted by the tungsten. This is a great opportunity to get the students thinking about energy conservation. Ask the students what is happening to the energy that the glass absorbs. If the glass is absorbing energy, it must heat up and emit infrared radiation.

A very good example of this involves a comparison of the GE black light with an incandescent white light bulb of the same power rating. For example, students could compare a 60 W black light with a 60 W white light bulb. (Alternatively, if one purchases a 50 W black light, GE does manufacture a 52 W "energy saver" white light bulb.) The visible light absorbed by the purple glass envelope of the black light results in a much higher temperature of the glass, and hence a much warmer "feel" near the bulb. In fact, the black light gets much, much hotter! If an infrared camera or thermometer is available, students can examine the differences in infrared emission from each of these bulbs.

Notes

Note 1. Properties of Nd, Nd_2O_3: *CRC Handbook of Chemistry & Physics*, 66th edition, 1985–1986, B-25, B-117.

Note 2. Spectral Power Distribution Curves for Selected GE Bulbs:
http://www.gelighting.com/na/business_lighting/education_resources/learn_about_light/distribution_curves.htm

Acknowledgments

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