Atomic Emission Spectra

Light, Energy, and Electron Structure

Introduction

Spectrum tubes, fluorescent light bulbs, novelty "plasma globes," and glowing "neon" signs all have one thing in common—they contain a gas that glows a specific color when a high voltage is applied to it. In this demonstration, this color will be viewed through a Flinn C-Spectra™. It is a holographic diffraction grating that separates, or diffracts, light in the same manner as a traditional ruled diffraction grating. It is ideal for the simple observation of spectral emission lines that make up the observed colors of the glowing gases. The advantage to the C-Spectra is that it can be held at any angle and the emission spectrum can still be easily observed. In Part B, an inexpensive "plasma globe" will be prepared from a Tesla coil and a simple light bulb.

Concepts

- Emission spectra
- Diffraction

Materials

C-Spectra™
Marekizer wire coil
Light bulbs, clear, 60-W, 2
Scissors
Spectrum tube
Spectrum tube power supply
Tesla coil

Safety Precautions

Do not touch the spectrum tube and/or power supply while they are on because the voltage running through it is quite high. When the power supply is turned on, the spectrum tube will become very hot in a short period of time. Turn off the spectrum tube power supply and allow the spectrum tube to cool completely before removing it from the power supply. Do not look directly into the sun through the diffraction grating film.

A Tesla coil produces high-voltage, low-current electricity at a very high frequency. The electric shock produced by the Tesla coil is minimal. However, presenters or students with medical conditions (e.g., heart conditions) that may be affected by high voltage electricity should not operate or touch a Tesla coil. The electric sparks will produce a burning, tingling sensation on the skin. Do not spark the same area of skin for more than one or two seconds. A small amount of ozone is produced by the sparks of the Tesla coil. Ozone is toxic by inhalation. Operate the plasma globe in a well-ventilated room. Do not touch the metal base of the light bulb, or the metal coil when the Tesla coil is turned on. A strong electric shock may result. Touch only the glass dome of the light bulb when performing the demonstration. Caution students about the shocking sensation they will feel before they touch the plasma ball. The demonstrator and all observers should wear safety glasses. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

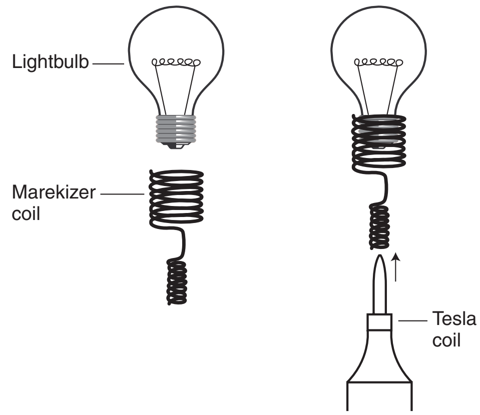
Part A. C-Spectra

1. Insert the spectrum tube into the spectrum tube power supply. Plug in the spectrum tube power supply and turn it on. Turn off the lights.
2. Observe the light being given off by the gas in the tube through the C-Spectra. Look to either side of the spectrum tube to see the emission line spectrum for the gas.

Part B. Plasma Globe

1. Screw the light bulb in to the large-diameter opening of the Marekizer coil. See Figure 1a.
2. Slide the smaller-diameter opening of the Marekizer coil over the Tesla coil needle. See Figure 1b.

3. Plug in the Tesla coil and turn off the lights in the classroom.
4. Turn on the Tesla coil and twist the adjustment knob on the Tesla coil until the light bulb glows dimly and several plasma sparks can be seen inside the bulb.
5. Slowly bring your fingers close to the light bulb dome until the sparks jump to your fingers. A sharp tingling sensation will be felt on the tips of your fingers. If the pain in your fingertips from the sparks is too harsh, turn down the intensity of the Tesla coil using the adjustment knob.
6. The sensation that is felt when touching the Marekizer is unusual and may also be painful and stunning to some students. However, the electric sparks produced by the Tesla coil are not harmful. Inform and caution students about the sensation they will feel if they decide to touch the Marekizer so that they will not be startled the first time they touch it. Students should not be required or forced in any way to touch the light bulb if they are not comfortable doing it.

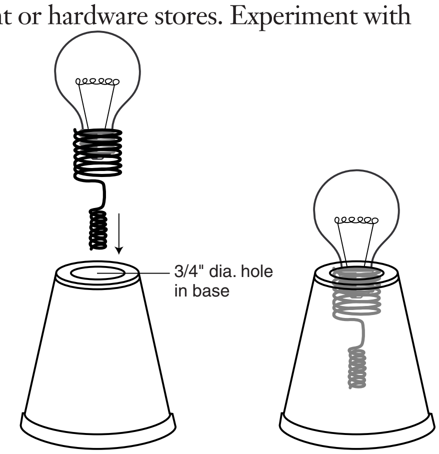


Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste.

Tips

- Due to the holographic nature of the C-Spectra, every segment of the C-Spectra contains the ability to produce the same pattern. Thus, the C-Spectra can be cut into small pieces for student use. Use scissors or a paper cutter to cut the piece of C-Spectra into 1.5 inch squares. The rigidity of the film eliminates the need for placing the squares in 35-mm slide frames.
- C-Spectra is washable and can be cleaned with a soft cloth and mild detergent. Take care as the C-Spectra will scratch.
- When using several different spectrum tubes, space them at least one meter apart to reduce interference from adjacent tubes.
- C-Spectra can also be used to observe flame tests of metal ions such as sodium, potassium, lithium, calcium, strontium, and copper. The spectra of these metal ions will be observed as diffracted, diffused flames, not as discrete lines. If nichrome wire is used for the flame test, the diffraction of the light emitted from it can also be observed. Better results are obtained using a slit in front of the burner to produce a narrow beam of light.
- The Marekizer coil should have an indefinite life span if it is stored properly. The light bulb has a limited life span but should last for at least fifty demonstrations. To improve the lifetime of the light bulb, do not operate it continuously for more than a minute, and allow the light bulb to cool between demonstrations. Store the light bulbs in paper towels to prevent breakage.
- Clear, incandescent replacement light bulbs are available at most home-improvement or hardware stores. Experiment with various styles and sizes of unfrosted light bulbs. High-wattage light bulbs glow brighter and have more visible electric arcs than low-wattage bulbs. Light bulbs that are rated 40- or 60-W work well.
- To insulate the wire coil and base of the light bulb in order to prevent electric shocks from these regions, place a Styrofoam® cup over the metal, as shown in Figure 2. Cut a ¾″-diameter hole (approximately) in the bottom center of an 8-oz Styrofoam cup. Carefully insert and screw the wire coil into the hole until the light bulb dome reaches the bottom of the cup. Use a small amount of transparent tape to secure the cup to the bulb, if necessary. This cup will prevent students from touching the metal coil. See Figure 2.
- Hold a fluorescent light bulb in one hand and touch the operating Marekizer Plasma Globe with the other. Watch as the fluorescent light bulb glows!



This occurs because the high-frequency electricity travels over the surface of the body, instead of through it. The electricity from the Tesla coil travels over the surface of the body from one hand to the other, causing the fluorescent light bulb to glow. If the electricity were only able to travel through the body, the internal resistance would greatly decrease the power output to the hand holding the fluorescent light bulb.

- These demonstrations are most effective in a dark room.

Discussion

Spectrum tubes consist of a gaseous element or compound in an evacuated glass tube equipped with metal electrodes. When a high voltage is applied across the electrodes, the gas molecules inside the tube interact with the high-energy electrons provided by a high-voltage power supply and absorb the electrons' energy. The energy provided by the external electrons is strong enough to promote, or "excite," the ground-state electrons of the gas molecules. The molecular electrons "jump" from their ground state to various excited energy levels. A few moments later, through *spontaneous emission*, the electrons naturally "fall" from these excited energy levels back to a lower energy level, or all the way to the ground state. When the excited electrons relax, energy is released in the form of a *photon* of light. The wavelength of the photon is dependent upon the energy that is released. The higher the energy change, the shorter the wavelength of light. If the photons have wavelengths in the visible portion of the electromagnetic spectrum (400–700 nm), then the glass tube will glow with a visible color that is characteristic of the gas inside the tube. Just as a fingerprint is unique to every individual, each element emits a characteristic color pattern of light after excitation.

A traditional ruled diffraction grating is a glass or metal plate that contains many equally spaced parallel grooves. The grooves are generally etched using a diamond cutter. Diffraction gratings prepared in this manner are called master gratings (see Figure 3). These master gratings are then used to manufacture *replica gratings*, which are formed by pouring a liquid plastic on the mastergrating, allowing it to harden, and stripping it off. The stripped plastic is then fastened to a flat piece of glass or other backing and becomes the diffraction grating film.

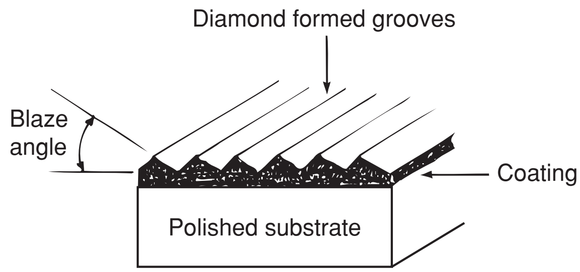


Figure 3.

C-Spectra is a holographically produced diffraction grating. Holographic diffraction gratings are different from traditional ruled diffraction gratings in that they are formed by an interference fringe field of two laser beams whose standing wave pattern is exposed to a polished substrate coated with photo resist (see Figure 4). Processing of the exposed medium results in a pattern of straight lines with a sinusoidal cross section as opposed to a sawtooth-like cross section of a ruled grating. Holographic master gratings are replicated by a process identical to that used for ruled gratings.

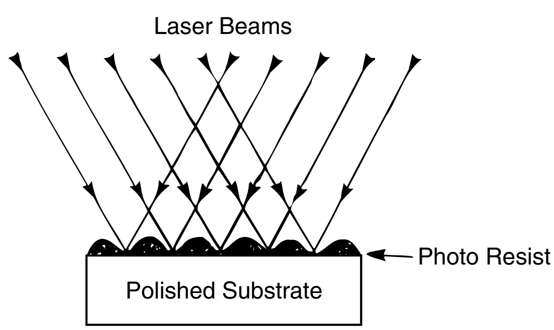


Figure 4.

When light strikes the grooves on the diffraction grating film, it is separated, or *diffracted*, into its component wavelengths. This characteristic makes diffraction gratings ideal for studying the emission spectra of light sources, such as gases in spectrum tubes.

When the light from a gas in a spectrum tube is viewed through the diffraction grating film, the individual emission lines can be seen to either side of the spectrum tube. Holographic gratings are an ideal choice for spectroscopy experiments because they produce less stray light than ruled gratings. In fact, they can reduce stray light by a factor of 10 to 100 below that of ruled gratings.

Several sets of repeating emission lines may be observed through a diffraction grating. Each of these sets of lines represent an *order* of the spectrum, with the intensity of the lines further away from the light source being less intense than those directly adjacent to the light source. *Blazing* is a term that refers to the angle of the grooves on a diffraction grating. By controlling the *blaze angle* (see Figure 3) of a ruled master grating, a large fraction of the energy can be concentrated in a single order.

Due to their sinusoidal cross section, holographic gratings cannot be easily blazed and their efficiency is usually considerably less than a comparable ruled grating. One exception occurs when the groove-spacing-to-wavelength ratio is nearly one. In this case, a holographic grating has virtually the same efficiency as a ruled grating. For example, a holographic grating with 1800 grooves per millimeter (556 nanometer spacing) has essentially the same efficiency at 500 nanometers as a ruled grating. C-Spectra, available through Flinn Scientific (Catalog No. AP1714), contains 200 grooves per millimeter (5000 nanometer spacing). In general, the angular dispersion of diffraction orders is increased as the number of grooves per millimeter is increased. Therefore, if more diffraction orders need to be viewed, a holographic diffraction grating with fewer grooves per unit length should be chosen.

Most high-wattage (>60-W), incandescent light bulbs are filled with a mixture of argon and nitrogen gas under a lower-than atmospheric pressure. When the high-voltage electrons pass through the bulb, the electric sparks extending from the filament (electrode) glow with a lavender or bluish color. This color is characteristic of the visible glow produced by an argon-nitrogen spectrum tube. The low pressure inside the bulb favors long electric arcs that dramatically extend from the filament to the grounded glass dome. Under normal operating conditions, the light bulb emits a “white light” and not blue- or lavender-colored light. This is because the heated tungsten filament emits photons that cover a broad range of wavelengths in the visible spectrum. The broad range of “colorful” wavelengths blend to form “white light.”

A Tesla coil provides high-frequency, high-voltage electricity, at a low current. In a Tesla coil, the high-voltage “recharges” approximately 30,000 times or more per second. This rapidly repeating cycle of high voltage maintains the proper excitation energy for the gas molecules in the glass tube.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Systems, order, and organization
- Evidence, models, and explanation

Content Standards: Grades 5–8
- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, transfer of energy

Content Standards: Grades 9–12
- Content Standard A: Science as Inquiry
- Content Standard B: Motions and forces, conservation of energy

Acknowledgments

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Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Atomic Emission Spectra* activity, presented by Lee Marek, is available in *Light, Energy, and Electron Structure*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for the *Atomic Emission Spectra* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1714	Flinn C-Spectra™
AP1327	Spectrum Tube Power Supply
AP1334	Hydrogen Gas Spectrum Tube
AP6761	Marekizer Plasma Globe
AP1594	Tesla Coil
AP5443	Tesla Coil, with On/Off Safety Switch

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.