Production of light by solids and emission spectroscopy

Physics 102 **Workshop #4** **Feb. 14 – Feb. 15, 2008**

Name: ________________________________ **Instructor: _____________**
Lab Partner(s): _________________________ **Time of Workshop: _____**

General Instructions

- Workshop exercises are to be carried out in **groups of three.**
- **One report per group** is due by the end of the class.
- Each week's workshop session would typically contain **three sections**. The first two sections must be completed in class. The third section should be attempted if there is time.
    1. A pre-lab reading and assignment section
    2. Experiment section
    3. Practice questions and problems

The last two workshops dealt with properties of light as a wave. This workshop session would be dedicated to understanding another basic property of light. How is light produced by a filament? We will take a basic look at spectroscopy.

This workshop is a qualitative workshop. This means the emphasis is on observation and not the precision of numbers recorded.

Part I: Production of light by solids

Recall: all waves are produced by a vibrating source. Electromagnetic (EM) waves are produced by a vibrating charge. As light is an electromagnetic wave with wavelength between 400 nm (violet) and 700 nm (red), the charge-sources can be viewed as vibrating with a wavelength in this range. This is the simplest of all models for the production of light.

What is the frequency range of visible light? Speed of a light wave can be assumed to be $c = 3 * 10^8$ m / s.

Frequency of violet light = _____________________ Hz.

Frequency of red light = ______________________Hz.

Frequency range = ____________________ Hz.

You would be observing the light emitted by a Tungsten filament. There are three Tungsten filament lamps mounted on stands placed in your station. Each of the Tungsten filament lamps is connected to the power supply through a variac. A variac is a device used to change the voltage applied to the filament. You will also need a diffraction grating element (a small transparent sheet mounted on a white slide holder) to make your observations.

Observing the Tungsten filament

Consider the light filament when no voltage is applied to it (when it is turned off).

Is the filament at room temperature?

Does it emit any light?

From your observations, would you say whether the following statement is true / False? "At room temperature, an object (such as the filament in the experiment) does not emit any electromagnetic waves".

Connect the variac to the light bulb, starting with the zero voltage setting on the variac. Then, raise the voltage until you reach the smallest value for which you observe light to be emitted from the filament. Record this value. Also record the color of the light that is emitted.

Voltage applied = _________________ V.

Color of filament = ___________________.

Why does the filament emit light when the applied voltage is increased?

Now look at the light through the diffraction grating. Place the grating next to your eye or your glasses. Do not look directly at the filament. Try to focus on the grating element and not the filament. Make sure that there are no secondary light sources in your field of view.

Record the color(s) of light that you see. Record them in ascending order of intensities.

The diffraction grating element is a set of parallel, evenly-spaced slits ruled on a transparent sheet. These slits are very finely ruled (several thousand slits per centimeter). The slits produce the same interference effects on light as you saw in lecture with just two slits (the Young experiment). But: The large number of slits is more effective in separating colors.

You would see bands of colors when you look through the grating element. **From the statement in the previous paragraph, can you explain why you see selected bands of light?** Can you relate what you learned during the interference and diffraction workshops to how a diffraction grating element works? (Last section of workshop #3)

Apart from visible light, filaments are also capable of producing ultra violet and infra red rays. **Compare the temperature of the filament when no voltage was applied and when minimal voltage was applied (You do not have to measure the temperatures. Place your hand near the filament to measure the warmth). How would you account for the change in temperature? Does the increase in temperature increase the production of either of the invisible waves (UV and IR)?**

Raise the variac setting to the maximum setting of 120 volts. **What is the color of light that is produced by the filament?**

Now view the light through the grating. **Record the color(s) of light that you see. Record them in ascending order of intensities.**

Compare your observations of the color(s) as seen by the unaided eye, relative to that seen through the grating. Based on what you see, would you say that the following statement is true or false?

"White light is a composite of a set of colors, including red, green and blue, of roughly equal intensity."

Observe the relative intensity of blue light (through the grating) as the temperature T of the source is raised. For this purpose, bring the variac setting back to zero. Then, slowly raise the voltage, all the way through to the maximum value possible.

Carefully observe how the relative strength of blue light changes, relative to that of red light. **Which statement below, would you say is consistent with what you see?**

1. **As T increases, the relative intensity of blue light to red light increases.**

2. **As T increases, the relative strength of blue light to red light decreases.**

From your observations above is temperature directly related to wavelength or inversely related to wavelength?

When the temperature is just high enough for light to be emitted, is it visible light of the longest or the shortest wavelength that is emitted? Is it visible light of the smallest or largest frequency that is emitted?

In your past experience, have you seen light emitted by a solid, when the temperature is gradually increased? Think of common household appliances and you should definitely be able to name at least one appliance that does this.

Relationship between peak wavelength and temperature

Now, consider a solid at a given, fixed temperature T. At this temperature, the solid would be emitting EM waves with different wavelengths. Each wavelength would have a different strength. There would however be a dominant wavelength (wavelength with highest strength) for the entire spectrum of waves emitted.The dominant wavelength (color) is also called the peak wavelength and is denoted by λ_P. The peak wavelength, λ_P shifts as the temperature of the filament is changed. Hence λ_P can be expressed as a function of temperature.

Based on your observations of the Tungston filament, which of the following statements is likely to be true?

1. **If the temperature T is increased, then the peak wavelength increases.**

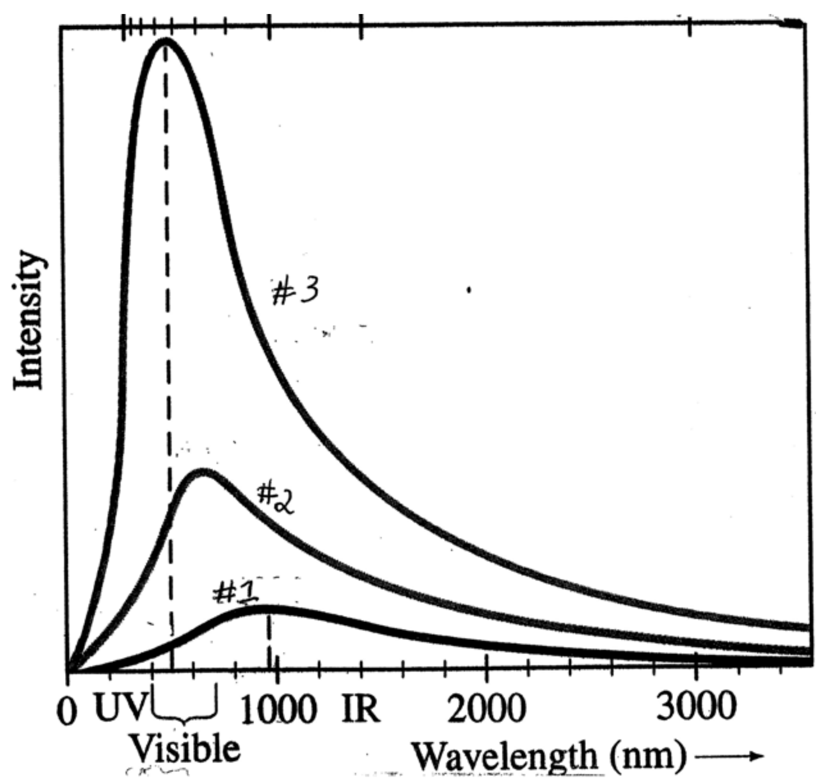
2. **If the temperature T is increased, then the peak wavelength decreases.**

Explain your decision below, based on your observations in this workshop.

Radiation curves

As just discussed, at a fixed temperature T, a solid will, in general, emit electromagnetic waves (radiation) that cover a range of wavelengths. But the intensity I of radiation produced will vary with the wavelength λ. This variation is displayed by what is known as a radiation curve. A radiation curve is a graph of the intensity I versus the wavelength λ.

Below is a graph of three radiation curves, labeled as #1, #2 and #3. For each curve, obtain a rough value for the peak wavelength λ_P.



What are the values of the peak wavelength λ_P?

For curve #1:

For curve #2:

For curve #3:

One of these curves represents measurements at a temperature of 6,000 K. Another corresponds to T of about 4,200 K, while the remaining one corresponds to T of about 1,000 K. Identify which curve corresponds to which temperature. Explain.

In what range of radiation (infrared, visible or ultraviolet) does the peak wavelength lie for curve #1? Predict the color of the radiation.

In what range of radiation (infrared, visible or ultraviolet) does the peak wavelength lie for curve #1? Predict the color of the radiation.

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PART II Emission Spectroscopy

In this part of your workshop, you will use a spectrometer to examine the spectra of a variety of light sources.

A ***spectrum*** is the result of dispersing a ray of light into its constituent colors. Spectroscopy is the study of spectra. The importance of spectroscopy is that as light is broken into its components, spectral features—such as absorption and emission lines—may be identified, which tell us a great deal about the chemical composition of the source among other things. Spectroscopy has been one of the main reasons for major advancements in the field of astronomy. Spectroscopy has been used to determine the properties like chemical composition, velocities, etc. of celestial bodies.

Among the earliest experiments on spectroscopy were Isaac Newton's 1666 observations of the solar spectrum. He used a prism to disperse the Sun's rays, obtaining a luminous band with a continuum of colors, very much like a rainbow. Though he never detected features such as lines or bands in the solar spectrum, he correctly established that what we call white light is actually a mixture of six primary or fundamental colors.

A *spectroscope* is an instrument used to generate a spectrum, namely, a dispersion of light into its constituent colors. Strictly speaking, the term *spectroscope* refers only to a device utilized for visual observation of spectra. Photographic recording of spectra is achieved via a *spectrograph*, while a digital recording is obtained via a *spectrometer*. Two types of spectroscopes are now currently in use: prism-based spectroscopes and grating-based spectroscopes. While early spectroscopes were mostly of the prism type, most units now employ diffraction gratings.

Prism-based spectroscopes

This was the kind of device originally used by Newton and by major observatories of the late 19th and early 20th centuries. A prism is a triangular-shaped piece of glass using the principle of refraction to disperse a light beam into its components. This happens because a ray of light is refracted (or bent) as it passes from air to glass, and this refraction varies slightly with wavelength. One big disadvantage of prism-based spectroscopes is that the incoming light is not linearly dispersed, meaning that the distances between the various constituent wavelengths are not equal. The blue end of the spectrum tends to be stretched, while the red end is compressed.

Grating-based spectroscopes

A diffraction grating is a solid surface with a large number of evenly spaced, parallel lines etched on one side (usually from 200 to 1,000 per mm). It uses the principle of diffraction to disperse the constituent colors of light (Bragg's law). This happens because a ray of light is subjected to bending by diffraction (or interference) as it reaches the grooves on the grating, to an amount that is dependent, again, upon the specific wavelength of light. Grating-based spectroscopes suffer from the drawback that they create multiple spectra.

All kinds of spectroscopes in use today operate either on the refraction or dispersion principle. Many special adaptations of the prism and grating types—have been constructed to suit special needs. Prisms and gratings have been combined to produce hybrid spectroscope designs. A grism, for example, is a right-angle prism with a transmission grating at its base. Grisms have been successfully used in the Hubble Space Telescope NICMOS camera.

Using the STAR Spectrometer

Hold the spectrometer so that you can read the labels on its top surface. The narrow end of the spectrometer (at the bottom) holds the diffraction grating which disperses the light into its component colors. The wide end (at the top) holds a piece of plastic film that serves two funtions

1. At the right (inside the small square opening in the front) is a clear slit through which light enters the spectrometer.
2. The rest of the film (the part visible through the wide opening in the front) contains a calibrated scale that lets you record the wavelength of interesting features in the spectra you observe.

The rest of the structure is just there to hold everything in place, and to keep out light other than light that has passed through the slit.

Hold the spectrometer so that your eye is looking through the grating in the narrow end. You should be able to see two rows of calibration marks and numbers. Pay attention to the lower row. This gives the wavelength (in nanometers, or nm) of the light in the spectra that appear above it.

To observe a spectrum, keep holding the spectrometer up to your eye, and turn until the slit at the right-hand side of the front is pointed at the source of light you want to examine. (This is the most counter-intuitive part of the whole procedure. Most people are tempted to just aim the middle of the spectrometer of the light source. Aim the right side instead.) When you have the spectrometer aimed properly, a spectrum of the light source should appear above the wavelength scale.

Observing spectra

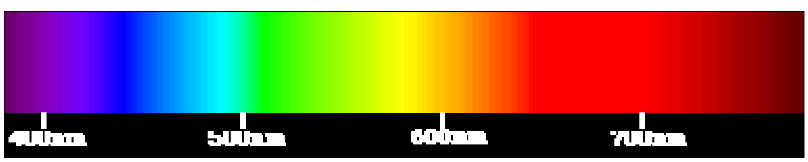
You will now observe the color of light emitted by excited gases of elements in sealed glass tubes called "spectrum" tubes. Direct current, DC, high voltage electrons are used to excite the atoms in the spectrum tube. High voltage means 1000 to 2000 volts. This is more than 10 times normal household voltage which is 120 volts AC.

The excited atoms release the energy they gained. Some of this energy is in the form of heat and some is in the form of light. The billions of excited atoms release energy. The excited atoms do not all emit the same energy light because the amount of energy that excited them may differ, but there are limitations on the colors they do emit. The kind of light energy that can be emitted by excited atoms is unique for an element. The pattern of "lines' or colors emitted can be used to identify an element. An powerful extension of this is the ability to measure amounts of an element by measuring the brightness of the emitted light. The emission lines can be seen when you look through the spectroscope at the light source. You will be able to observe the "line" spectrum for the elements and record the spectral lines.

Your T.A. will set up a variety of light sources for you to study in the lab. For each light source, follow the procedure given here:

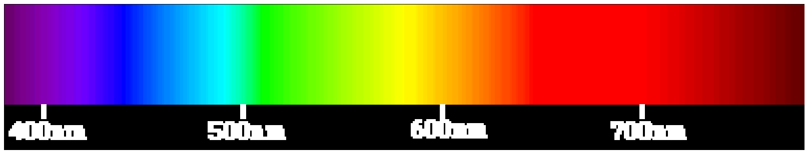
1. Make a careful sketch of its spectrum below. Note emission lines, absorption lines, where the colors look strong or weak, or anything else you need to give a good description of what you see.
2. Classify the spectrum into the categories continuous spectrum, emission-line spectrum, and absorption-line spectrum, or whatever hybrid category you feel best describes the spectrum.
3. If the spectrum has lines, note their wavelengths in nanometers.
4. Identify the chemical composition of the source of light, give it. If not, state whether the problem is insufficient reference material, or whether instead the kind of spectrum is unsuitable for learning the chemical composition of the light source.

Spectral lines for element 1 (______________________).



Spectral lines for element 2 (______________________).

Spectral lines for element 3 (____________________).



Spectral lines for element 4 (____________________).

How do these emission spectra compare in terms of colors and numbers of emission line positions?

Are the spectra identical?

From your observations above, fill out the following:

1. **Element with greatest number of visible lines: ______________________.**
2. **Longest wavelength of spectral lines:___________________ nm.**
3. **Colour of light with longest wavelengh:____________________.**