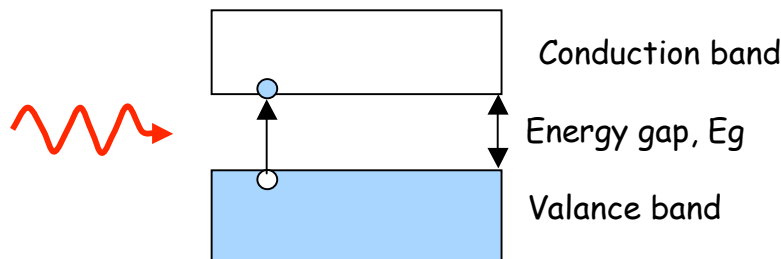


Quantum Dots-a particle in a box Modern Physics Lab

Background

In bulk materials, the energy bands that are quantized at the atomic level broaden into bands of energy where the levels inside the bands are so closely spaced, they are no longer considered to be discrete. In a conducting material, one of these bands of energy is only partly occupied, so the electrons in the material are free to move throughout it. In an insulator, there is a band of energy that is completely full of electrons (the valance band) and a band of energy above it (the conduction band) that is completely empty of electrons. These bands are separated by a large energy, so that it is very difficult for the electrons to get into the upper band where they would be free to move around. A semiconductor is like an insulator only the two energy bands are closer together, and it is easier to excite an electron into the conduction band where it can move around. The difference in energy between the bottom of the conduction band and the top of the valance band is called the energy gap, E_g . Electrons can be excited across this gap into the conduction band with an applied voltage or a **photon** with the appropriate energy. When the electron is excited into the valance band it leaves an empty space behind that we call a hole. The electron-hole pair is called an exciton (pronounced exit on). Once excited, the electron can move around in the conduction band, and the hole can move around in the valance band.



Quantum Dots are very small particles (on the order of nanometers) that are made of semiconducting materials. Because of the small size of the dot, the energy bands narrow to discrete energy levels much more like an atom's energy levels than a semiconductor's energy levels. The exciton is confined to the quantum dot in a manner analogous to a particle in a box. In fact, the lowest energy level of the quantum dot is given by the following equation:

$$\begin{aligned} E &= E_{hole} + E_{electron} + E_g \\ &= \frac{\hbar^2 \pi^2}{2m_h R^2} + \frac{\hbar^2 \pi^2}{2m_e R^2} + E_g \end{aligned} \quad (1)$$

where m_h is the effective mass of the hole, m_e is the effective mass of the electron, R is the radius of the dot, and E_g is the semiconductor band gap. You

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should recognize the equation for the energy of the hole and the electron are the same as the particle in the box. The term E_g is present because the particles are not in an empty box; they are in a semiconductor so they have a zero-point energy.

Library Research:

Read about the particle in a box, and see what you can find out about quantum dots. Why are they useful? What is photoluminescence?

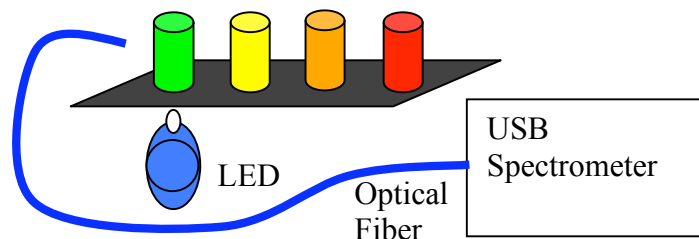
The Experiment

A. Quantum Dot Photoluminescence

When the exciton in the quantum dot is excited by the absorption of light, for example, it will emit light at wavelength that corresponds to the exciton energy given by equation (1). By determining the wavelength of the emission of light, you can calculate the energy and then the radius of the quantum dots.

1. Begin by downloading the spectrometer instructions from the website and familiarize yourself with the spectrometer and the software.
2. Measure the spectrum of the LED light source that you will be using to excite the quantum dots.

3. Measure the spectrum of each of the four vials of quantum dots by illuminating the dots in a direction that is perpendicular to the direction of light collection.



4. Plot each spectrum and put it in your lab notebook.
5. Determine the peak wavelength for each vial of quantum dots and from that wavelength, find the energy of the quantum dots.
6. Starting with equation (1) find an equation for the radius of the quantum dots.
7. For your dots, the following parameters apply

$$m_h = 5.47 \times 10^{-31} \text{ kg}$$

$$m_e = 7.29 \times 10^{-32} \text{ kg}$$

$$E_g = 2.15 \times 10^{-19} \text{ J}$$

Calculate the radius of each color dot.

8. Which color of dots has the largest radius? Is this consistent with your understanding of the particle in the box? Explain.

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B. Quantum Dot absorption

In order for the dot to produce photoluminescence, an exciton must be created. When the electron and hole recombine, they create the photoluminescence. In our experiment, the exciton is created by the absorption of light. The figure below shows one way that excitation and photoluminescence can happen. Incoming light of one wavelength is absorbed. The excited electron then can move to a lower energy level through non-radiative processes (like vibrations), and then it jumps down to a lower level emitting a photon. Note that the absorbed light has a higher energy than the emitted light. This difference in energy is called the Stokes Shift. In this experiment, you will measure the absorption of the Quantum Dots.

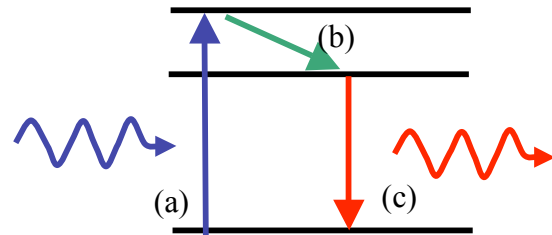


Figure 2 (a) shows the absorption of a photon causing an electron to move into an excited state. In (b) the electron moves down in energy due to non-radiative processes. In (c) the electron recombines with the hole and gives off a photon.

1. Instead of using the LED light source, you will use the broad-spectrum light source. In order to know how much is absorbed, you first need to know how much light you have. Begin by collecting the spectrum of the light source without a sample in place. Adjust the integration time to maximize the signal without cutting it off. Save the spectrum AND depress the yellow light bulb to record this as the reference spectrum.

2. Now turn off the light source and depress the dark lightbulb to record the background (or dark) spectrum.

3. Once you save the reference and dark spectra, put your sample in the sample holder. You may need to elevate it so that the light goes through the solution. In order to see the absorption spectrum, depress the button labeled "A". This button calculates the absorption from the spectra using the following calculation:

$$A_{\lambda} = -\log_{10} \left(\frac{S_{\lambda} - D_{\lambda}}{R_{\lambda} - D_{\lambda}} \right) \quad (2)$$

where D_{λ} is the background spectrum, R_{λ} is the reference spectrum, and S_{λ} is spectrum of the sample .

4. Now you should print the spectra and find the difference in wavelength between the absorption and the photoluminescence of each color of quantum dot.
5. Summarize your results. What patterns do you observe?

