Quantum Dots

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Determine radii of four differently-sized nanometer scale particles by application of quantum mechanics and by measuring peak wavelengths from their spectra.

Outline

- Introduction: What is a quantum dot?
- Theory: Quantization of energy & Bulk InP vs. InP in solution
- Apparatus & Methods: Transform collected spectra
- Results/Discussion
- Conclusion

Quantum Dots? Intro

- The dot: Semiconductor Nano-particles, Indium Phosphide (InP)

- Macroscopic investigation of a quantum system – fluoresced color in visible depends on the size of the particle.

- Spectroscopy, quantum & semiconductor physics

- <u>Goal</u>: determine the sizes of the quantum dots

Theory

- Bulk InP does not visibly fluoresce, but InP solution does. Why?
- $\lambda_{photon} \approx \frac{1240\ eV\ nm}{E_{gap}}$, $E_{gap,bulk} = 1.344\ eV$, $\lambda_{photon} \approx 923\ nm$
- Bulk InP emits in IR range. What's the difference? Boundary conditions.
- Quantum dot: particles in a box. Physical size of dot R constrains energy of emitted photons

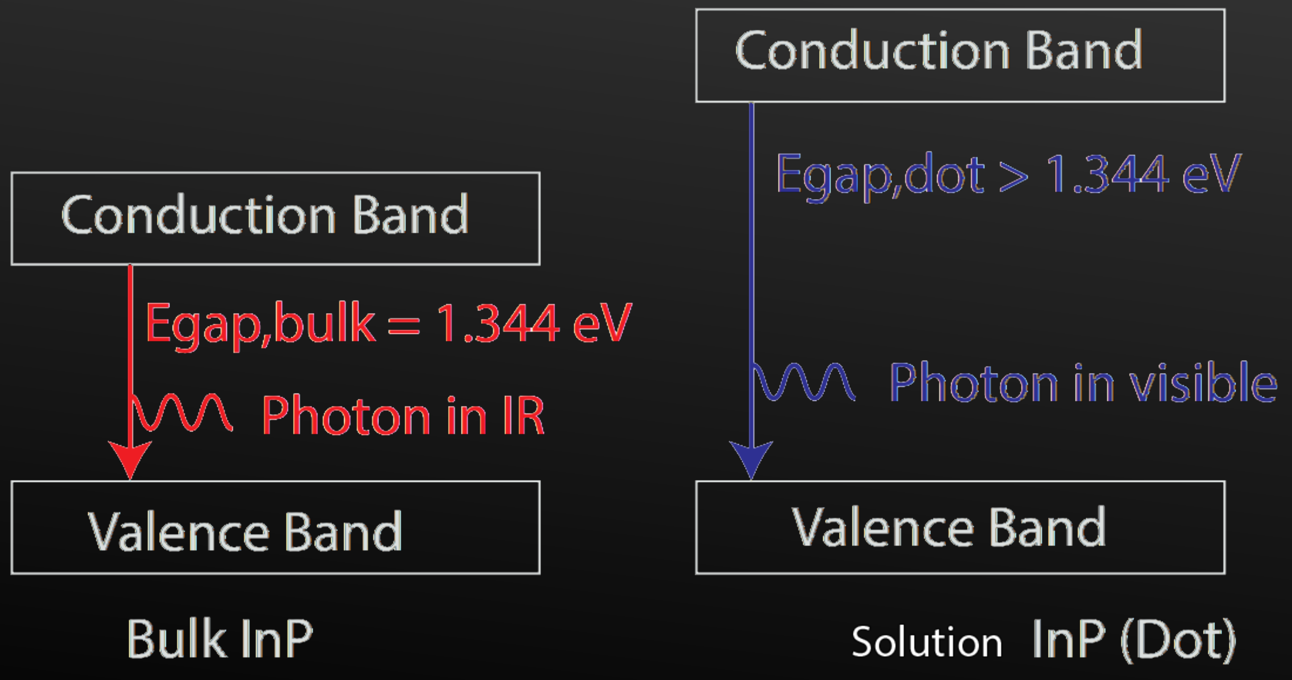
$$E = \frac{\hbar^2 n^2 \pi^2}{2m_e R^2} + \frac{\hbar^2 n^2 \pi^2}{2m_h R^2} + E_g$$

Increasing R reduces emitted photon Energy! We can measure E – then solve for R.

Theory

- The InP solution has a larger band gap energy than the bulk InP, by amount ΔE.

- A larger band gap results in an emitted photon of greater energy.



Apparatus

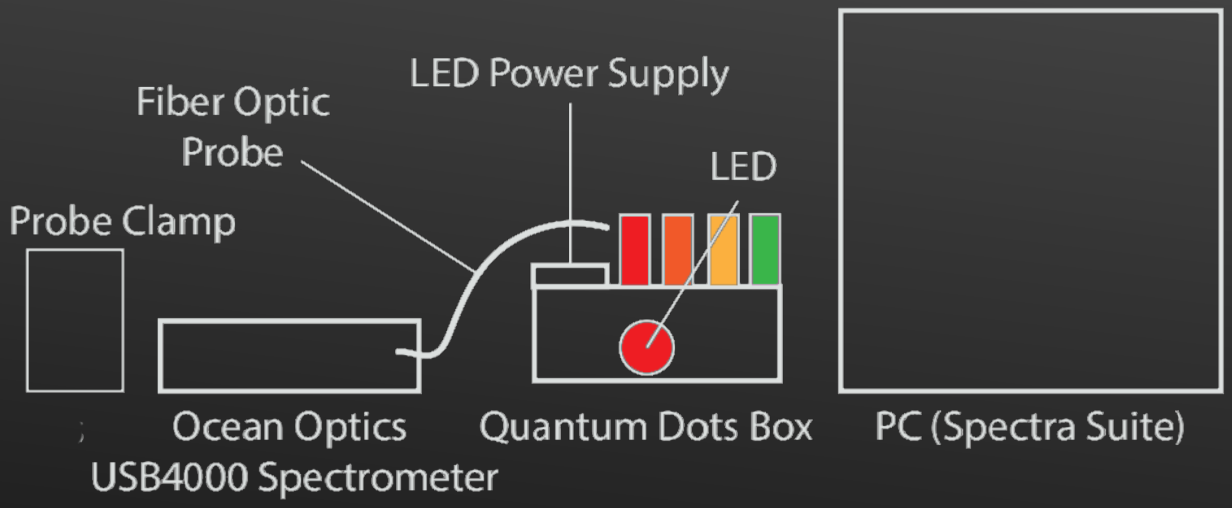


Fig. 1 – Line diagram of experimental setup.

Fig. 2 – Photograph of the quantum dot vials.
Source: CENCO

Methods

- Illuminate each vial with $400\ nm$ excitation source.
- Measure peak emission wavelengths of spectroscopic samples for each quantum dot. Only the peak wavelength matters.
- Transform emission wavelength to energy using $E = \frac{hc}{\lambda}$
- Once the energy is known, we solve for R.

Results

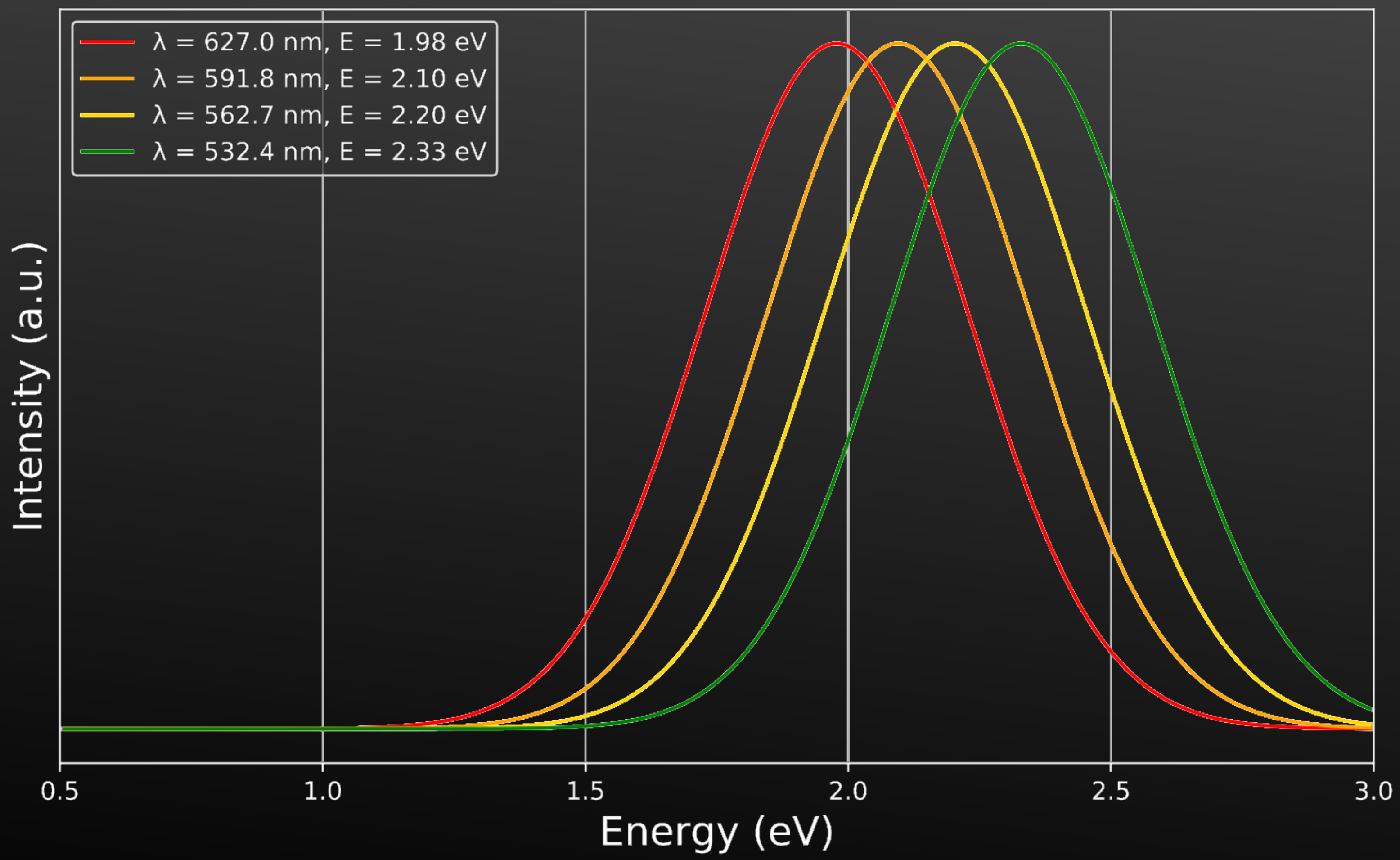


Fig. 3 - Peaks are normalized for easy comparison of locations. The curves are generated by a single-peak Gaussian function.

$$E_{peak} = \frac{hc}{\lambda_{peak}}$$

$$E = \frac{\hbar^2 n^2 \mathrm{p}^2}{2m_e R^2} + \frac{\hbar^2 n^2 \mathrm{p}^2}{2m_h R^2} + E_g$$

Results

Dot Color	λ_{peak} (nm)	E_{peak} (eV)	Radius (nm)
Green	532.4 ± 1.5	2.329 ± 0.007	2.4 ± 0.3
Yellow	562.7 ± 1.5	2.204 ± 0.006	2.5 ± 0.3
Orange	591.8 ± 1.5	2.095 ± 0.005	2.7 ± 0.3
Red	626.9 ± 1.5	1.978 ± 0.005	2.9 ± 0.3

Fig 4 – Experimental results.

Color	Peak Wavelength (nm)	Radius (nm)
Green	540	2.367454
Yellow	570	2.533894
Orange	600	2.718174
Red	630	2.924941

Fig 5 – Manufacturer provided values.

Conclusion

- Color (λ) of InP solution shown to depend on size of the InP particle. Band gap energy dependence on R observed.
- Nano-particle exhibits macroscopic behavior predicted by quantum theory.
- Calculated nano-particle sizes in agreement with the manufacturer values.

Sources

1. Griffiths, David Jeffrey, and Darrell F. Schroeter. Introduction to Quantum Mechanics. Cambridge University Press, 2019.
2. Modern Physics, by Kenneth S. Krane, 3rd ed., Wiley, 2020, pp. 326–357.
3. Operating Instructions, 1751-18 CENCO Quantum Dots Lab Manual