

Quantum Dots: Science and Applications

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Physics 3500

Nanochemistry

Why I chose this topic?

- **Useful Now:** I chose to research and present on the science and applications of Quantum Dots because of the many interesting and important applications currently in use by this nano-technology.
- **The Future is Bright:** The usefulness and application of Quantum Dot technology continues to expand and research is striving to bring their benefits to more and more technologically applied fields.

What are Quantum Dots?

- Quantum dots are semi-conductors that are on the nanometer scale.
- Obey quantum mechanical principle of quantum confinement.
- Exhibit energy band gap that determines required wavelength of radiation absorption and emission spectra.
- Requisite absorption and resultant emission wavelengths dependent on dot size.

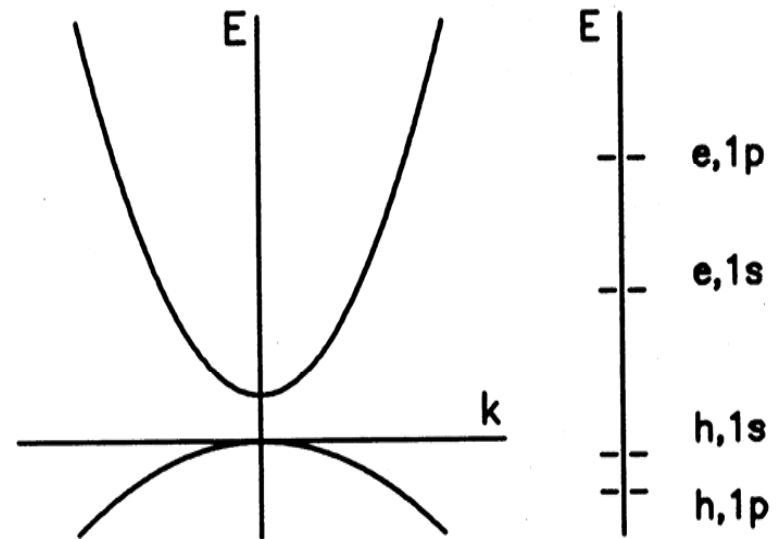
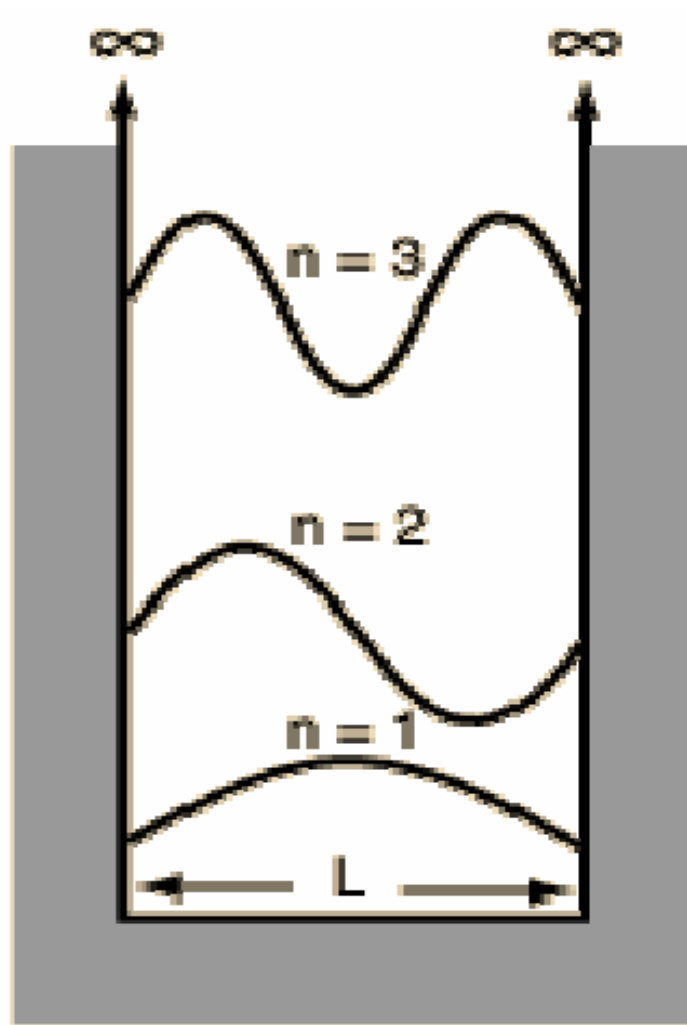


Fig. 1. Schematic plot of the single particle energy band gap. The upper parabolic band is the conduction band, the lower the valence.

Confinement - Infinite Square Well Potential



<http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/schr.html#c1>

Fig. 2. Quantized energy levels of a particle in a box.

Quantum Dots Description...

- The emission and absorption spectra corresponding to the energy band gap of the quantum dot is governed by quantum confinement principles in an infinite square well potential.
- The energy band gap increases with a decrease in size of the quantum dot.

Quantum Confinement

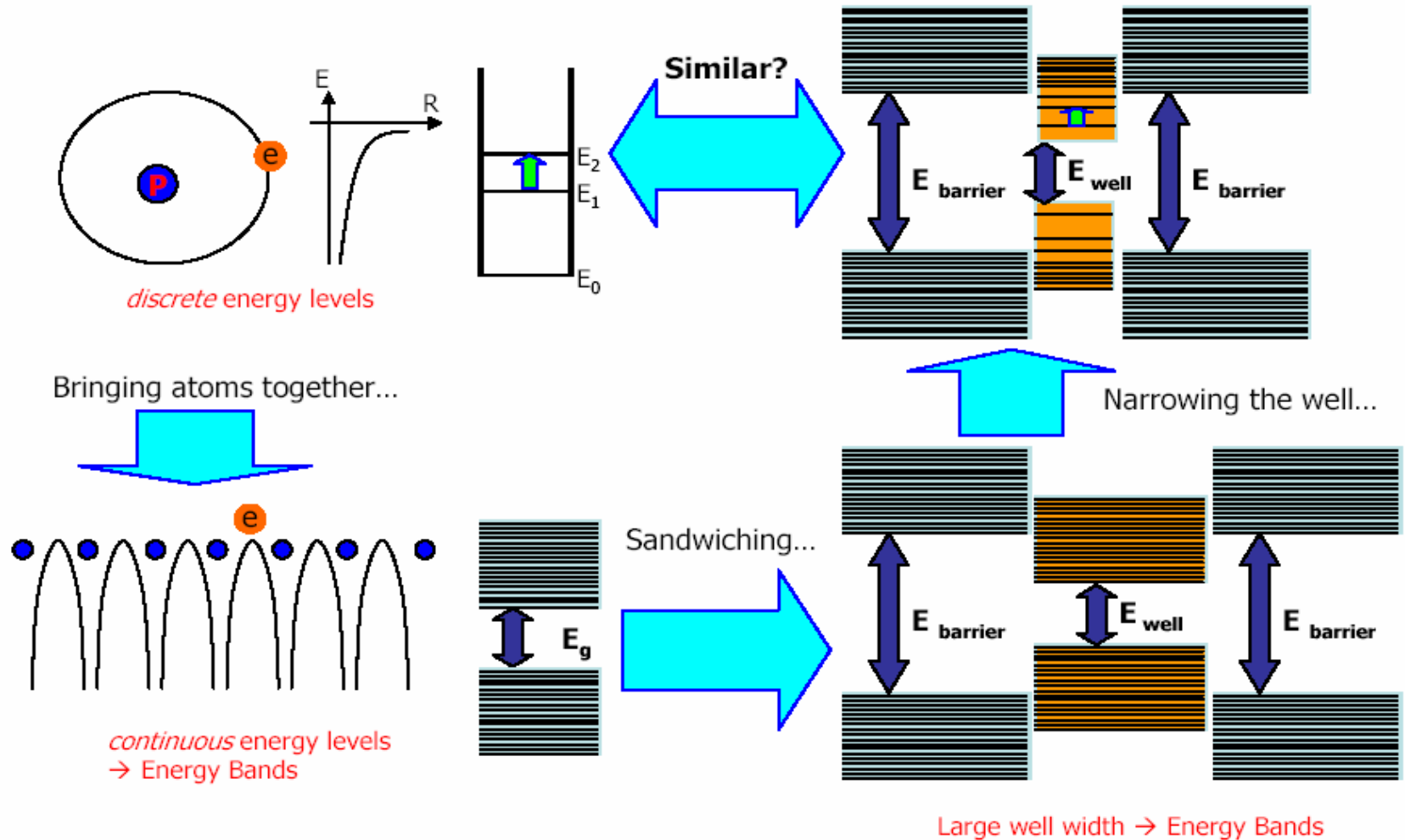


Fig. 3. As the energy well, or the particle, shrinks the gap in energy levels increases.

Energy bands

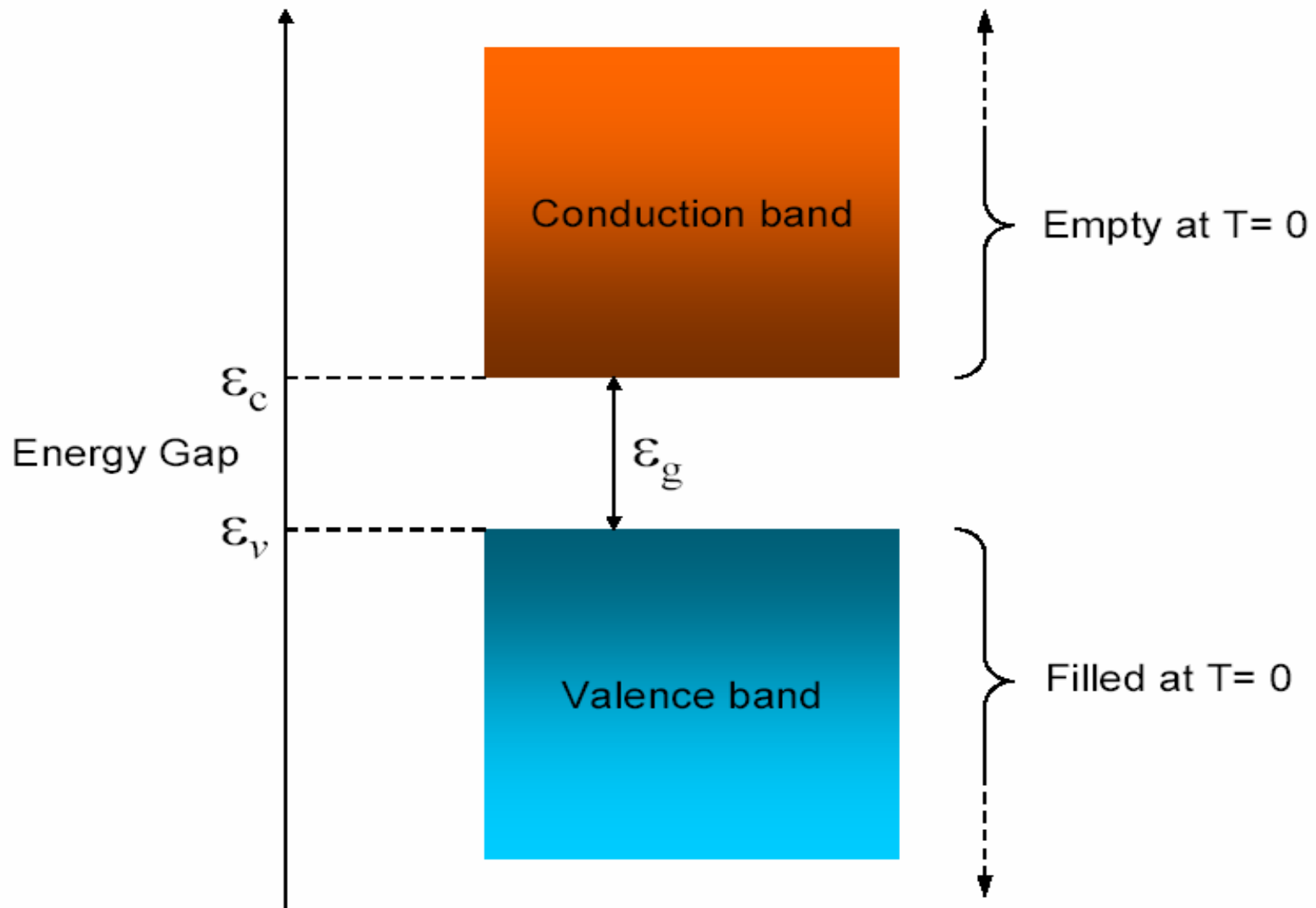


Fig. 4. The energy band gap associated with semi-conducting materials. In order to produce electric current electrons must exist in the conduction band.

Medical Imaging and Disease Detection

- Can be set to any arbitrary emission spectra to allow labeling and observation of detailed biological processes.
- Quantum Dots can be useful tool for monitoring cancerous cells and providing a means to better understand its evolution.
- In the future, Qdots could also be armed with tumor-fighting toxic therapies to provide the diagnosis and treatment of cancer.
- Qdots are much more resistant to degradation than other optical imaging probes such as organic dyes, allowing them to track cell processes for longer periods of time.
- Quantum dots offer a wide broadband absorption spectrum while maintaining a distinct, static emission wavelength.

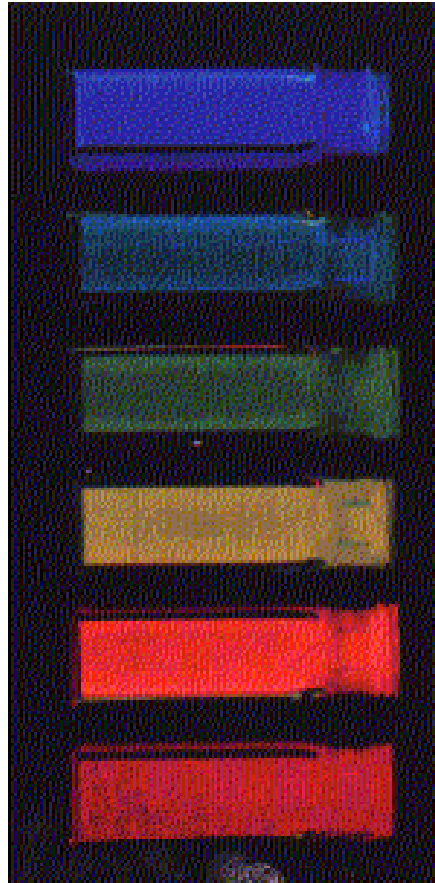


Figure 5. Solutions of quantum dots of varying size. Note the variation in color of each solution illustrating the particle size dependence of the optical absorption for each sample. Note that the smaller particles are in the blue solution (absorbs blue), and that the larger ones are in the red (absorbs red).

Quantum Dot LEDs

- Used to produce inexpensive, industrial quality white light.
- Marked improvement over traditional LED–phosphor integration by dot’s ability to absorb and emit at any desired wavelength.
- Produce white light by intermixing red, green, and blue emitting dots homogenously within the phosphor difficult to accomplish with the traditional LED-phosphor set up.

Solar Cells and Photovoltaics

- Traditional solar cells are made of semi-conductors and expensive to produce. Theoretical upper limit is 33% efficiency for conversion of sunlight to electricity for these cells.
- Utilizing quantum dots allows realization of third-generation solar cells at ~60% efficiency in electricity production while being \$100 or less per square meter of paneling necessary.
- Effective due to quantum dots' ability to preferentially absorb and emit radiation that results in optimal generation of electric current and voltage.

Other Future Quantum Dot Applications...

- **Anti-counterfeiting capabilities:** inject dots into liquid mixtures, fabrics, polymer matrices, etc. Ability to specifically control absorption and emission spectra to produce unique validation signatures. Almost impossible to mimic with traditional semi-conductors.
- **Counter-espionage / Defense applications:** Integrate quantum dots into dust that tracks enemies. Protection against friendly-fire events.
- Research continues. The possibilities seem endless...