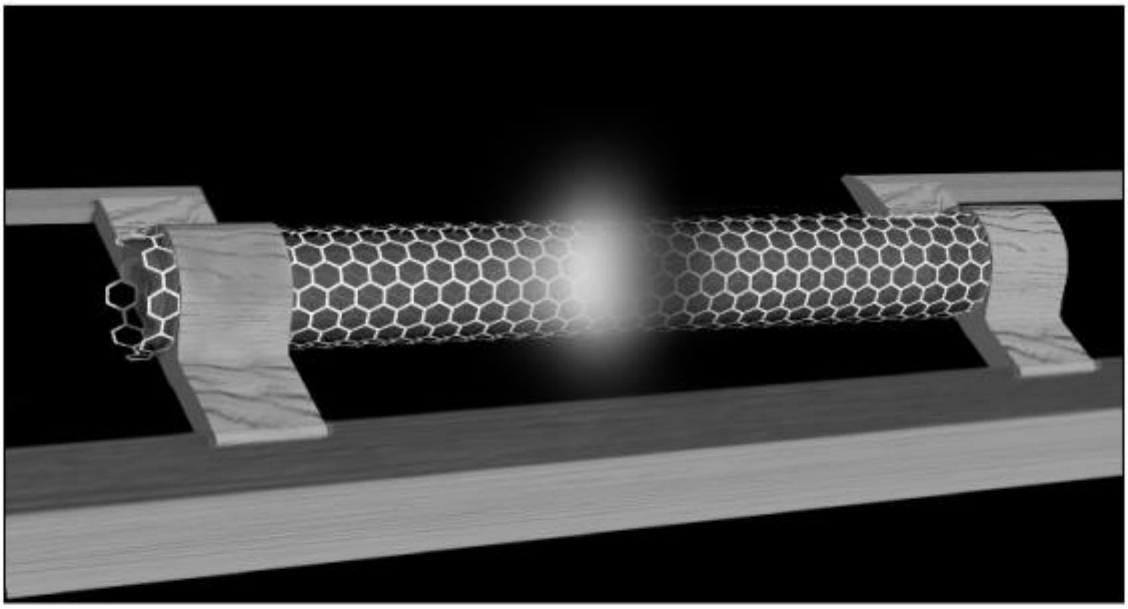
Lecture-11. Quantum leaps with quantum dots

Quantum dots are nano-size crystals that emit light; the wavelength they emit depends on the size of the crystal. Quantum dots are composed of various materials, such as lead sulfide, zinc sulfide, cadmium selenide, and indium phosphide. Quantum dots are useful because, depending on their size and composition, they emit a particular wavelength, or color, of light after an outside source, such as an ultraviolet light, excites the electrons in them. Quantum dots produce light in a way similar to atoms, as we discuss in the next section. The ability to tailor the color of light emitted by a group of quantum dots is very useful in medical diagnostics, as we discuss in Chapter 10. The rules that describe electron orbitals (also called energy levels) — and dictate that electrons are only allowed to be in certain energy levels within an atom — are called quantum mechanics. Because electrons in these nano-size crystals behave in a similar way, they are called quantum dots.

Quantum dots are useful because when you add energy to their electrons, the electrons act like they're in one big atom — and (as any physicist could tell you) when you add energy to the electrons in any atom, what you get is light. This occurs when an electron moves to a higher energy level and then falls back again to its normal energy level. The same is true for quantum dots — zap them and they glow. One way to add energy to quantum dots is to shine an ultraviolet light on them. It turns out that the smaller the quantum dot, the larger the gap between energy levels — which means more energy is packed into the photon that's emitted when an electron falls from a higher energy level to its normal energy level. A small quantum dot emits higher-energy photons — with a shorter wavelength — than a large Q-dot can. Think of this light in terms of color: A quantum dot of a particular size — a relatively large size, to be exact — emits red light, which is the longest wavelength of visible light; smaller quantum dots produce different colors. If you keep going down smaller and smaller, you'll eventually get to a tiny quantum dot that emits blue light — the shortest wavelength of visible light. If you come up with really large quantum dots (okay, we're being a little silly here), you might get them to emit infrared light; incredibly teensy quantum dots might emit ultraviolet light, outside the visible spectrum. So where do you get quantum dots? (No, you can't find them at Wal-Mart — at least not yet.) It turns out that it's possible to grow a large number of quantum dots in a chemical reaction — but the methods used range from simple wet-chemical setups (in which you precipitate zinc sulfide crystals) to complicated methods such as chemical-vapor deposition. You can control the size of a particular batch of quantum dots — ensuring that they all emit the same wavelength of light — by controlling the length of time you allow the reaction to run. But what do you do with them once you've got 'em?



Light is light, no matter where it comes from — and if a nanotube generates light at a specific wavelength, it's similar to the light generated at the same wavelength when electrons move between these two states (each with its own energy level) in an atom or molecule:

Conductance: An electron in a conductance state is free to move around from atom to atom in the nanotube. Electrons in a conductance state have a higher energy level than those in a valence state.

Valence: An electron in a valence state occupies an orbital in the outer shell of an atom in a nanotube, at a lower energy level than those in a conductance state.

Now, remember, electrons tend to be lazy; an electron with more energy wants to get rid of it somehow. That's why an electron kicks out a photon when it settles down from a conductance state into a valence state. The difference in energy between the two states is emitted as light. The energy level of an electron in a carbon nanotube is determined by the diameter of the nanotube; as with quantum dots, a smaller diameter means a higher energy level. Therefore, the wavelength of the light generated also depends upon the diameter of the nanotube. Think of a guitar: Each string has a different diameter, and emits only one certain note. In a similar way, only a certain wavelength of light is emitted by each size of carbon nanotube. In effect, you can "tune" a nanotube to emit light at the energy level you choose. Researchers believe that optoelectronic devices — say, the amplifiers used in fiber-optic circuits by the communications industry — could be built making use of this effect. (At the moment, nobody's figured out how to use this effect to play "Stairway to Heaven.")