APPLICATION CHEMISTRY:

MATERIALS & DESIGN

(Nanotechnology)

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Nanotechnology

- **Nanotechnology** has been described as "the science of the very small with big potential".
- "Very small" in this context means of an order of **nanometres**
- One nanometre is **0.000000001 m**.
- It can be written as **1 nm or 1 x 10^{-9} m**.
- **Atoms and molecules are nano- and picometre sized**.
- Science involving nano-sized particles is called nanoscience.

Nanotechnology

Table 3.1 – the scale of length

Small	attometre	am	0.000000000000000001 m	1×10^{-18} m
	femtometre	fm	0.000000000000001 m	1×10^{-15} m
	picometre	pm	0.000000000001 m	1×10^{-12} m
	nanometre	**nm**	**0.000000001 m**	**1×10^{-9} m**
	micrometre	µm	0.000001 m	1×10^{-6} m
	millimetre	mm	0.001 m	1×10^{-3} m
	centimetre	cm	0.01 m	1×10^{-2} m
	metre	m	1 m	1×10^{0} m
	decametre	dm	10 m	1×10^{1} m
	hectometre	hm	100 m	1×10^{2} m
	kilometre	km	1000 m	1×10^{3} m
	megametre	Mm	1000000 m	1×10^{6} m
	gigametre	Gm	1000000000 m	1×10^{9} m
Large	terametre	Tm	1000000000000 m	1×10^{12} m

Buckyballs

- **Buckminsterfullerene**, is composed **entirely of carbon atoms**.
- Third **allotrope of carbon**
- A total of **60 carbon atoms** are present forming a sphere consisting of **five-carbon** and **six-carbon atom rings** arranged in the same pattern as a modern soccer ball.
- It is just less than a nanometer in size.

Buckyballs

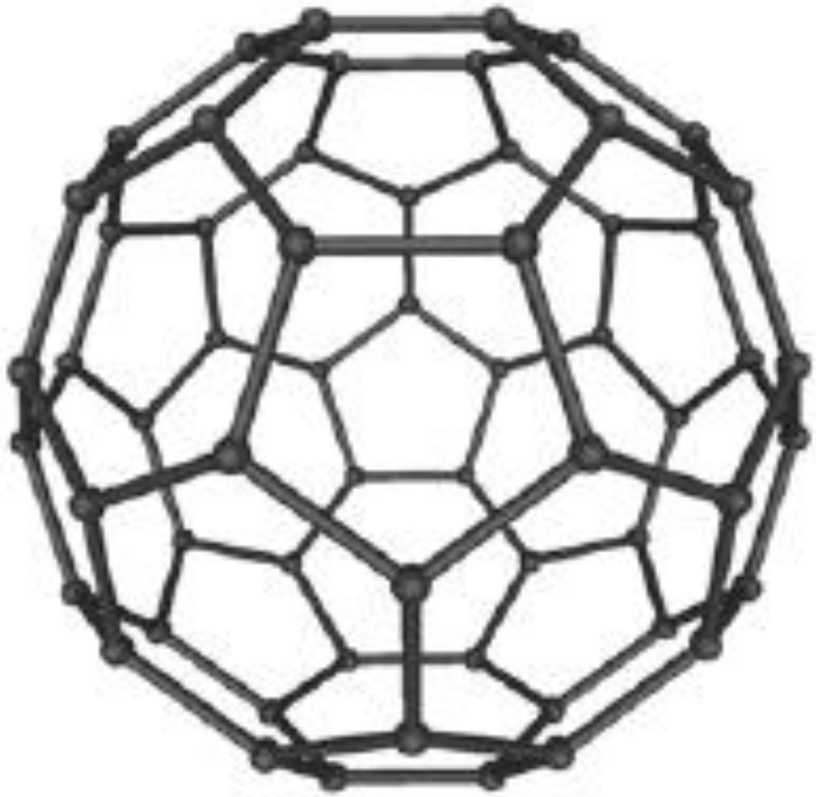


Figure 3.8 – a buckyball, or buckminsterfullerene

Buckyballs

- Buckminsterfullerenes were initially discovered in 1985 during experiments with carbon clusters in supersonic beams.

- As well as C_{60}, other sized balls have been created.

- Unlike other forms of carbon, **fullerenes may be soluble**, as shown in the photograph below.

- **C_{60}** is **pink** and C_{70} is red in solution.

Buckyballs

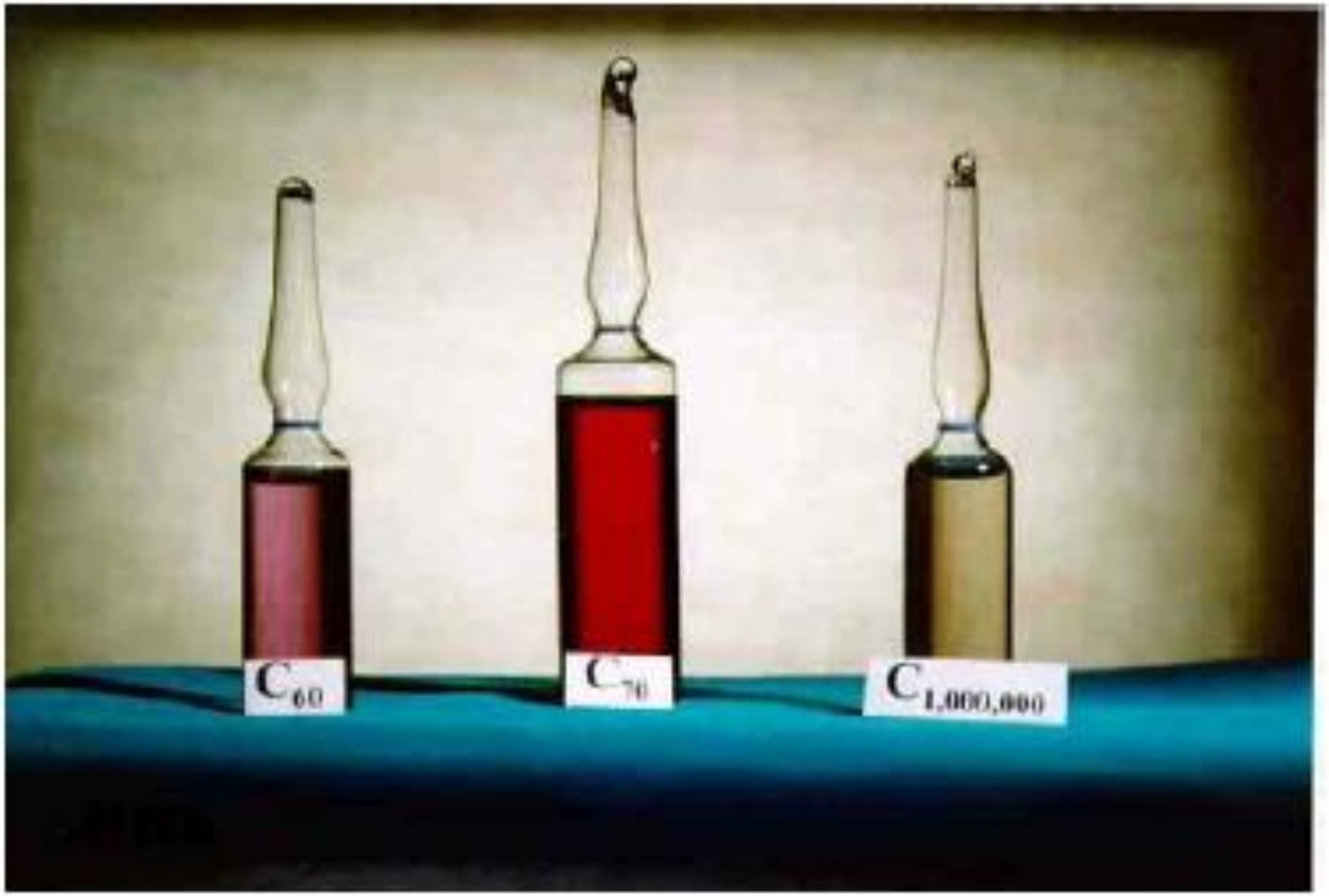


Figure 3.9 – bucky balls in solution

Buckyballs

- Buckyballs have unusual properties which led to a lot of excitement about their potential.

- They:

  - may be **harder than diamond**
  - may be **more slippery than Teflon**
  - may be **insulators or conductors**

Buckyballs

- Buckyball can **enclose an atom of another element inside itself**.
- This can be a reactive element or molecule such as a lanthanum atom.
- The highly reactive atom becomes **trapped** – while it is **protected by the carbon cage it cannot react**, but as soon as the cage is removed it can react again.
- The structure below shows a lanthanum atom in the centre of a buckyball.

Buckyballs

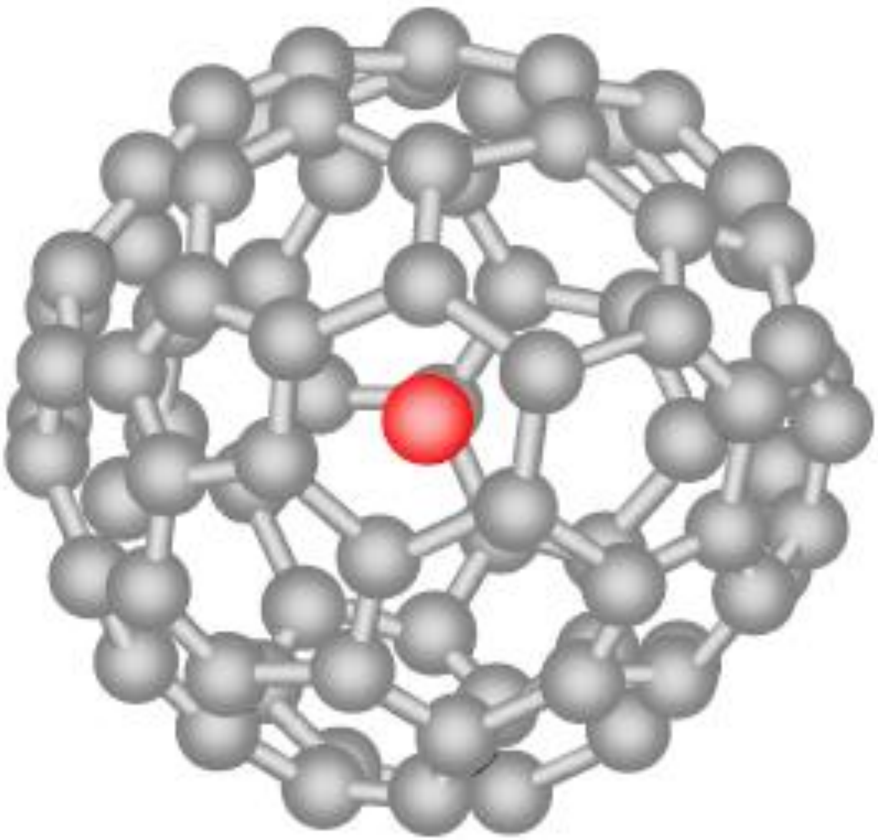


Figure 3.10 – lanthanum atom caged in a bucky ball

Application of buckyballs

- for drug delivery (testing).
- drug molecules can be attached to a buckyball → attached to an antibody.
- Antibodies are Y-shaped proteins that can recognize and attach to antigens.
- Viruses, bacteria and diseases have unique antigens.
- Just like with magnetic nanoparticles, medicine can be sent only to place where it is needed, leaving healthy cells alone
- http://www.youtube.com/watch?v=1QwyMWM0Jjg&feature=related

Carbon nanotubes

- **Cylindrical in structure** and also **resemble a rolled-up sheet of graphite**, with the **carbon molecules arranged in repeating hexagons**.
- They have a **diameter of a few nanometers** and **can be open at both ends**, **sealed at one end or sealed at both ends**.

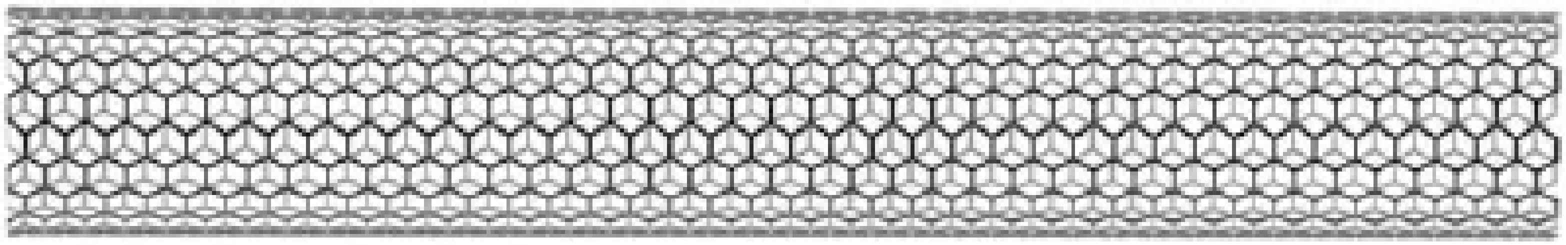


Figure 3.11 – a carbon nanotube open at both ends

Carbon nanotubes

- Carbon nanotubes are ‘Mini but Mighty’, they are many times **stronger than steel**.

- The mechanical (stiffness, strength, toughness), thermal and electrical properties of pure buckytube materials enable a multitude of applications, from **batteries** and **fuel cells** to **fibres** and **cables** to **pharmaceuticals** and **biomedical materials**.

- They are found in the batteries of most laptop computers.

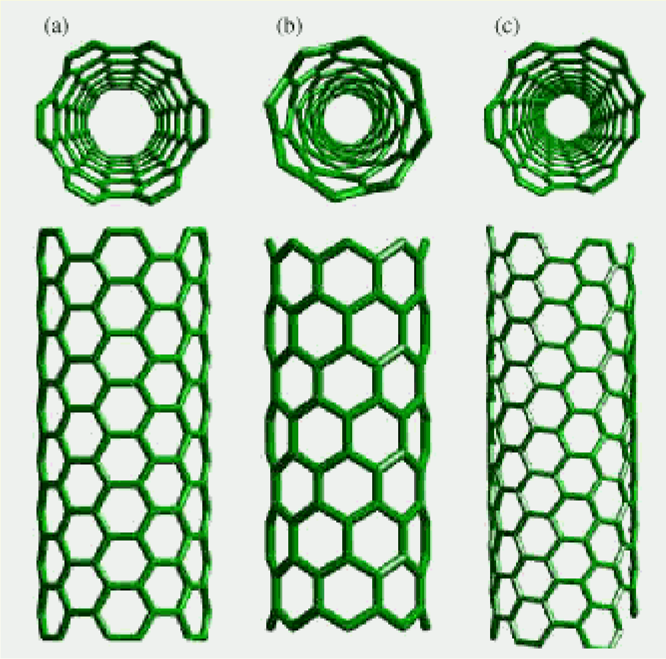
Carbon nanotubes

- **World's smallest test tube** - from **carbon tubes**

- **One end of the tube is closed by a fullerene cap** that contains both pentagons and hexagons.

- The tube has a **volume of 10^{-24} dm^3**.

- (a) armchair, (b) zigzag, (c) chiral



Carbon nanotubes

Figure 3.12 – a carbon nanotube closed at one end – a nano “test-tube”

Carbon nanotubes

- The nanoscale test tube below has **various derivatives attached**.
- These could, for example, be **immobilised enzymes enabling fast reactions in the synthesis of new drugs**.
- There are distinct advantages of carrying out these reactions on the nanoscale.
- In a normal test tube, the particles have to collide to react and these collisions rely on random movement.

Carbon nanotubes

- In many reactions not all the particles react, or unwanted side-products are produced
- These problems result in reduced yield. By contrast, a nanoscale reaction, where **individual molecules are brought together, can have an exceedingly high yield**.

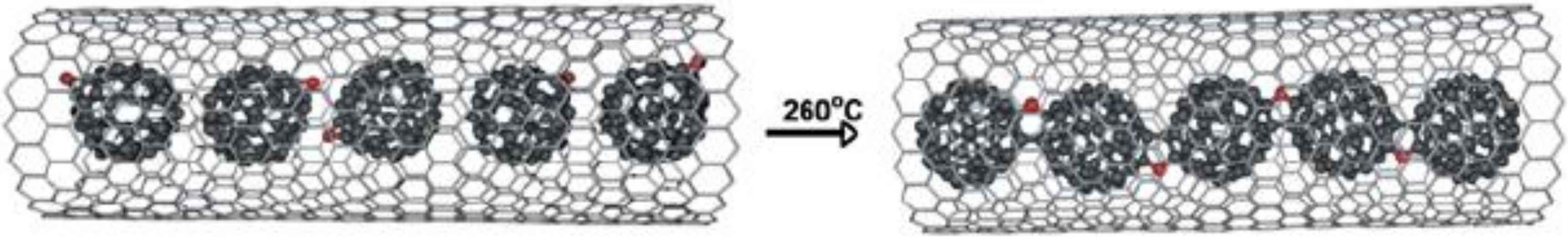


Figure 3.13 – a chemical reaction in a nanotube – polymerisation of $C_{60}O$ to form $(C_{60}O)_n$

Carbon nanotubes

- Another kind of structure being developed involves **buckyball cages containing trapped atoms**.
- These **buckyball cages are then entrapped inside a nanotube**, rather like peas in a pod.
- Purpose - to **investigate the structure as an information storage display**

- **Other application :**
- nanotube transistors.
- Transistors are devices that can act like an on/off switch or an amplifier for current and are used in electronic equipment.
- Scientists have been able to use semiconducting nanotubes as compact, more efficient alternatives to conventional transistors.

Carbon nanotubes

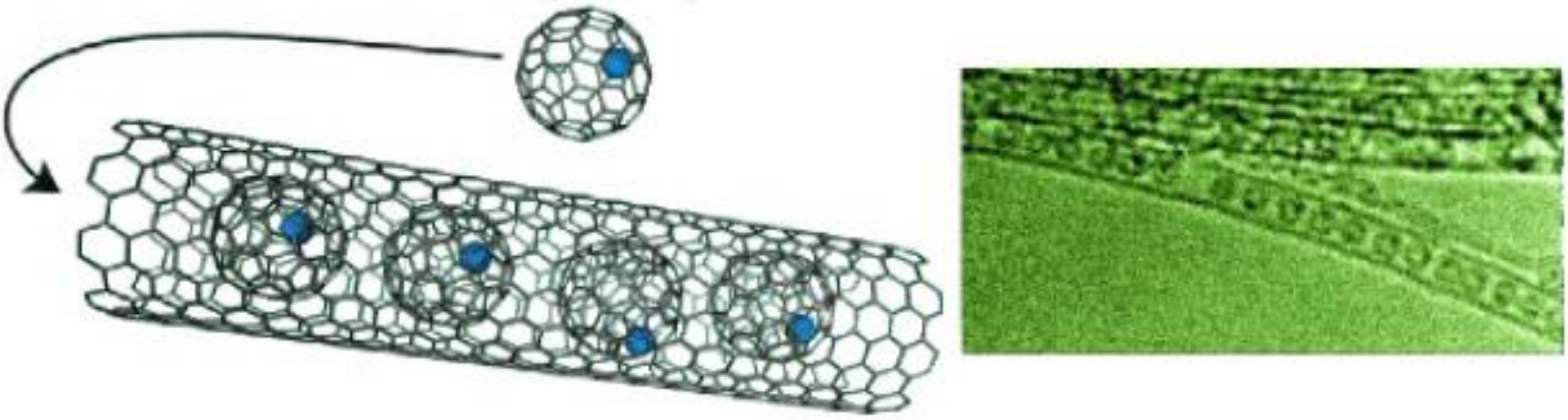


Figure 3.14 – "Peas in a pod" – bucky balls containing trapped atoms, themselves inside a carbon nanotube

http://www.youtube.com/watch?v=19nzPt62UPg&feature=related
http://www.youtube.com/watch?v=zQAK4xxPGfM

Supramolecular chemistry – making super-molecules

- **Supramolecular** - “beyond the molecule”.

- **Molecules that recognise each other** - same way that biological molecules such as enzymes recognise and bind other molecules,

- Lehn, Cram and Pedersen created synthetic molecules **called crown ethers that recognise and bind** (form a complex with) **metal ions**.

- Bind to each other by **noncovalent effects**, including **hydrogen bonding** and **van der Waals forces**.

Supramolecular chemistry – making super-molecules

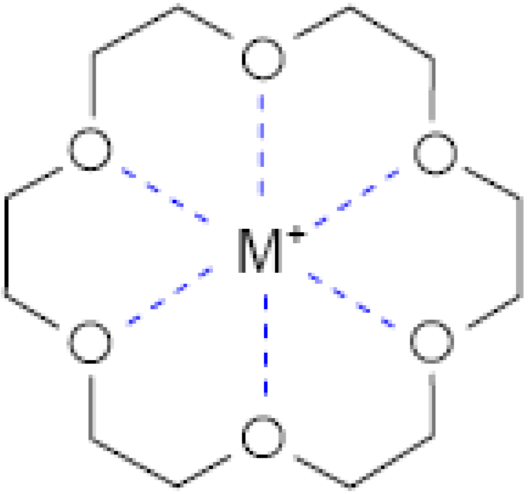


Figure 3.15 – a metal ion bound by a crown ether molecule

- These super-molecules are being **designed to be catalysts**, to **transport drugs**, to **transmit electricity** and to **harvest light**, among many other things.

- In 1999 a research group in the Netherlands made the first molecular motor.
- The motor is powered by light and the molecule rotates about a carbon-carbon double bond.

Quantum dots

- **Emitting photons one at a time**.

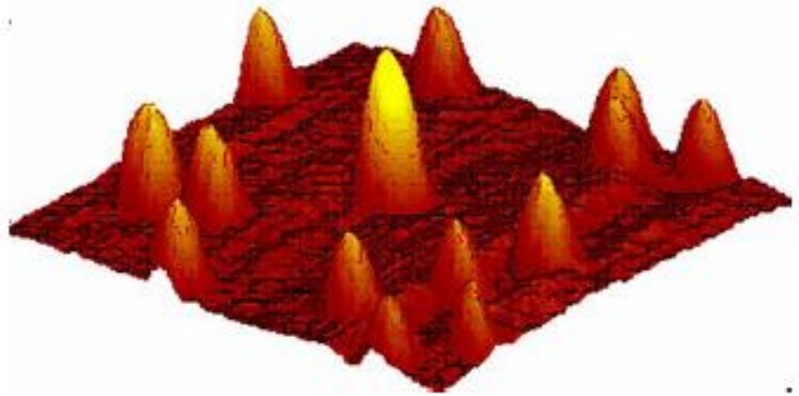


Figure 3.17 – a quantum dot

- based on **quantum dot technology**.
- **Quantum dots are devices that contain trapped electrons**.

Quantum dots

- They are **made from semiconductor materials** such as silicon and **have dimensions that are typically between a few nanometres and a few microns**.

- The size and shape of these structures, and therefore the **number of electrons they contain**, **can be precisely controlled**

Quantum dots

- Quantum dots – **behave more like atoms** than like the bulk material.

- **When excited, they emit light, and the dots can be tuned to emit light of a specific wavelength**, and **even to emit single photons**.

- **Toshiba's quantum-dot emitter** reliably **generates single photons on demand when excited by short optical pulses**.

Quantum dots

- Other nanotech application:
- **Kodak Ultima inkjet paper** - "fix" the dyes in the bottom two layers. The top layer contains ceramic nanoparticles to further stabilize the image. Prints predicted to last for up to 100 years.
- **Sunscreens** contain particles of titanium dioxide. In the sunscreens the particle size is close to nano-size. At this size it still reflects UV light but doesn't give such a white appearance as larger particles.
- **Nanocomposites** - made by grinding down clays or ceramics to a nano-sized powder. The powder is mixed with a polymer to form the material.

Instruments

- **Atomic Force Microscope (AFM)** together with the **Scanning Tunnelling Microscope (STM).**

- These instruments allow us **to see individual atoms on surfaces**.

Promise and possible problems of nanotechnology

- Many applications only require very small amounts of nanoparticles, so this **reduces risks considerably**.
- However some uses involve large quantities, for example sun screens.
- **Large scale manufacture can carry the same risk of explosion** as production of other materials which have a small particle size and hence **large surface area**