Modern Materials

What are modern materials?

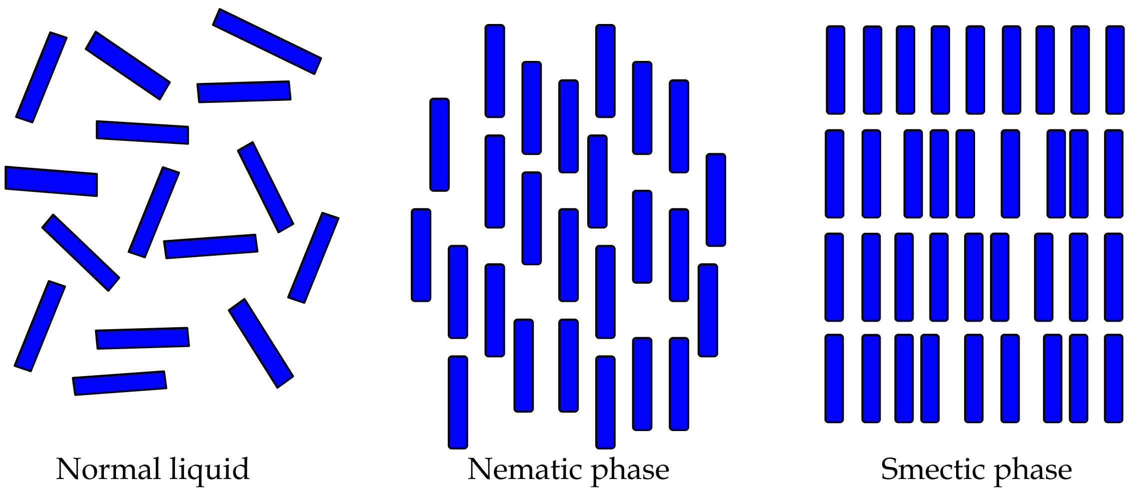
Modern materials refer to the materials with properties that traditional materials do not possess. The chemical or physical properties of these materials can be changed by external factors like temperature, light and electrical charges, so as to meet specific requirements in modern technologies. Two important modern materials, liquid crystals and nanotubes, are discussed below.

What are liquid crystals?

Liquid crystals were first discovered in 1888, by Austrian botanist Friedrich Reinitzer when he was studying a cholesterol-like substance (cholesteryl benzoate). When heated, it first became a milky liquid and then turned into a clear liquid as its temperature rose. Upon cooling, the reverse process occurred. This turbid viscous phase is called the liquid crystal phase. Unlike solid that have very little translational freedom, liquid crystal possesses some degree of translational freedom with certain orientation preference in one or two direction. This is also different from true liquid as the molecules in true liquid have no intrinsic order. Liquid crystal shows unique properties of optical anisotropy and sensitivity of orientation to electromagnetic field. This class of material generally has several characteristics such as, rod or disc like molecular structure, rigidity along the long axis and possession of strong dipoles.

Depending on the nature of the ordering, liquid crystals can be classified into three categories: nematic, smectic and cholesteric. Molecules in nematic phase have no positional order but tend to align in the same direction as the director. Molecules in smectic phase show some degree of two-dimentional order. They align towards the direction of the director and tend to arrange in layers or planes. When compared with nematic phase, smectic phase shows a lower degree of freedom.

Cholesteric or chiral nematic phase arises when the molecules that made up the nematic phase are chiral. In the chiral nematic phase, the molecules line up in positions that they are slightly twisted from the molecules next to them giving rise to a helical-like arrangement. The overall arrangement of the molecules can be treated as a stack of nematic molecules twisting in a small angle for each layer.



What is the function of liquid crystal in LCD?

For a LCD to work, liquid crystals are packed between a polarizer and an analyser which are arranged in 90^o from each other. When light passes through the polarizer, it will be polarized in the direction allowed by the polarizer. Without the presence of cholesteric (twisted nematic) liquid crystals in between the polarizer and the analyser, the polarized light will be completely absorbed by the analyser. In such case, no light can pass through that area of LCD and a dark region will appear. With the presence of cholesteric phase liquid crystals that are naturally twisted, the polarized light will be guided by the molecules in each layer of the liquid crystals, and thus rotates in the same direction as the twisted nematic molecules as it passes through the liquid crystal layers. The degree of twisting of the polarized light can be controlled by adjusting the thickness of the liquid crystal in between the polarizer and the analyser. As a result, the polarized light is rotated by the desired angle and hence can pass through the analyser to give rise to bright region on the LCD. However, when a potential is applied across the electrodes, it also applies a field across the liquid crystals and thus untwists the liquid crystal molecules. This will disturb the twisted stacking of the cholesteric phase and the rotation of the polarized light. As a consequence, light cannot pass through the pair of polarizer and analyser.

When liquid crystal is used in calculators or watches, seven pairs of electrodes (*i.e.* pair of polarizers) are required to display each number. These seven pairs of electrodes are arranged in the shape of an "**8**". A mirror is placed under the analyser, when there is no potential applied, the entered light can pass through both polarizers and be reflected by the mirror beneath. This particular segment of liquid crystal therefore appears as clear (colourless). However, when a potential is applied across the electrodes, light cannot pass through the analyser and thus no light is reflected by the mirror. This causes that segment to appear as a dark region. By manipulating these seven segments of electrodes, numbers 0 to 9 can be displayed accordingly.

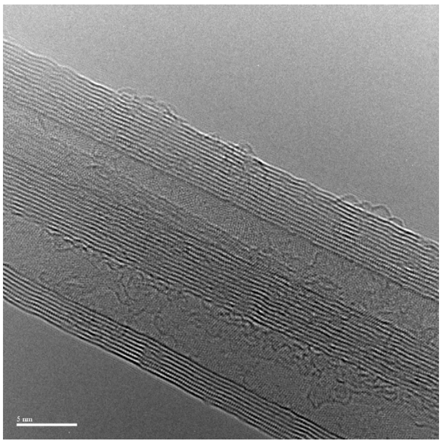
What are nanotubes?

Nanotubes are micro-tubes with diameter in the range of nanometer (10^{-9} m). To appreciate better the order of magnitude at the nanometer scale, one can imagine that the size of a 1 nm nanotube is just about $1/10^8$ of the diameter of a football. This difference in order of magnitude is similar to the comparison between the diameters of the earth to the football! From that, one may admire the state-of-the-art technology in dealing with the nanomaterials.

One of the most important types of nanotube is carbon nanotube. Carbon nanotube was first discovered by Ijima in 1991. He found that there are tubular form of carbon structures in the deposit from the anode during the direct-current arcing of graphite for the preparation of fullerenes. These tiny tubes are made up of graphene sheets (the atom-thick carbon sheets that stack up to form graphite) that roll up into a tubular structure. If just one sheet of graphene is rolled up, it is called single-walled carbon nanotube. When more than one sheet of graphenes roll up into a concentric cylinder, a multi-walled carbon nanotube is formed.

Carbon nanotube is actually the new allotropic form of carbon other than the diamond, graphite and fullerene. Carbon nanotube shows many unique properties like very high mechanical strength (Young Modulus equals to 1.8

Tera Pascal and tensile strength of 200 Giga Pascal). It is actually the strongest fibres that we found today. Electronic properties of carbon nanotube are also unique as it can be metallic or semi-conducting depending on how the graphene sheets roll.



Transmission electron micrograph of multi-walled carbon nanotube

What are the potential applications of carbon nanotube?

There are numerous important potential applications of carbon nanotube and the first one is nano-circuit. Due to the limitation of the manufacturing of the present silicon semiconductor industry, the present development of CPU and other chip set are getting slower and touching the lower limit. In order to further increase the power of computer, a smaller and more precise circuit fabrication method is needed. Carbon nanotube is the most promising solution for this bottle neck. Single-walled carbon nanotubes with diameter of about 1 nm comprise either semiconductor or metallic property, depending on the way of rolling of the graphene sheets. Single-walled carbon nanotubes have been increasingly used in electronic industry where metallic-nanotubes are used as conducting wires, and semiconductor-nanotubes are functioned as logic gates. Companies like Intel and IBM have already started their investigations in substituting silicon semiconductors with carbon nanotubes and other nanowires. In August 2001, IBM announced the first carbon nanotube transistor to demonstrate the "NOT" gates function. Although there is still a long long way before we could really use carbon nanotube to make computers, we should admit that nano-circuit and nano-chipset are not scientific fictions anymore.

The second application is the carbon nanotube field emission display (CNT-FED). Carbon nanotube based flat panel display is a new type of display. Under electric potential, the vertically aligned nanotube arrays act as source of field emission electrons, the electrons then hit the phosphor arrays and emit light. The advantages of nanotube display over liquid crystal display are: higher display resolution, lower power consumption, wider viewing angle, increased brightness, faster response rate and a wider operating temperature *etc.* Some manufacturing companies have already produced several prototypes of nanotube colour display and soon a commercial product may be available in the market.

Another important application of carbon nanotube is nanotube-composites (combine two or more different materials) as carbon nanotube has high strength and low weight (a hundred times stronger than steel but only one sixth of the weight). Experimental results showed that carbon nanotubes are capable of increasing the toughness of the composites as well as yielding better compressive loading when it is added to polymers. Therefore, it is increasingly used in heavy industry to manufacture machinery moving parts and cutting tools. It is also under on-going research to employ as one of the key materials for the construction of space elevator.

Questions

1. What are the structural features of substances that exhibit liquid-crystalline behaviour? Use the structural formulae of some typical liquid crystalline materials to explain your answers.
2. Draw a schematic diagram to illustrate the working principle of a LCD display.
3. Explain the properties of carbon nanotube in relation to its chemical structure.
4. NASA has a plan to build a space elevator using carbon nanotubes as the cable. Search for information about the applications of carbon nanotubes in space exploration. Write a short report of not more than 500 words to summarize your findings.

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