Semester: II						
CHEMISTRY OF FUNCTIONAL MATERIALS (Category: Professional Core Course) Stream: CS (Theory and Practice)						
Course Code	:	22CHY22C		CIE	:	100 Marks
Credits: L:T:P	:	3:0:1		SEE	:	100 Marks
Total Hours	:	42L+ 30P		SEE Duration	:	3 Hours

Unit-IV- Advanced electronic materials and E –waste

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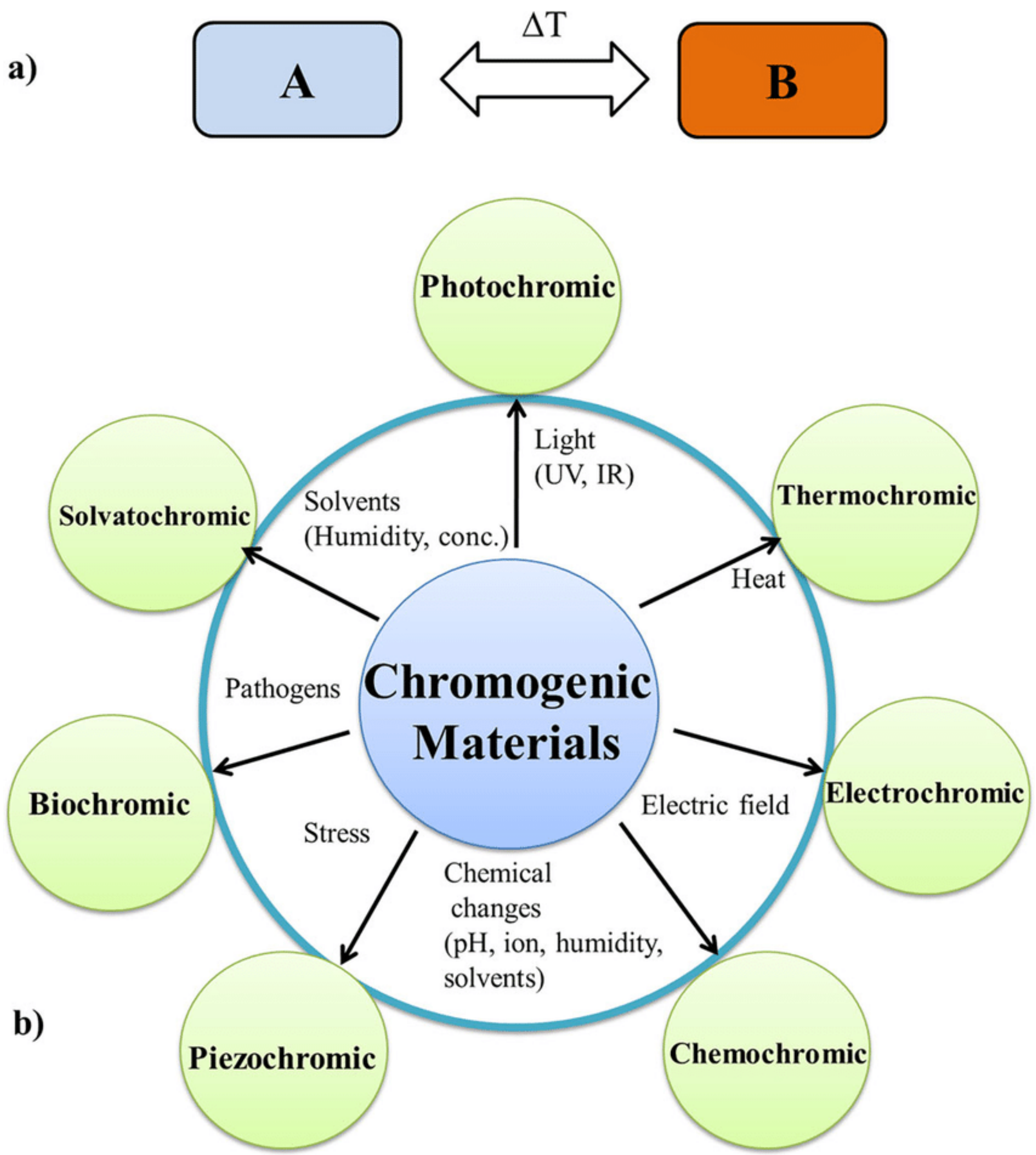
Unit –IV: Advanced electronic materials and E –waste

Materials, mechanism, examples, and applications of photochromic, thermochromic, electrochromic, electrostrictive, magnetostrictive, RFID, MEMS and NEMS, e-skin, e-nose devices.

E-waste - Types, environmental risks, recycle management.

Chromogenic Materials

These are the materials that show a reversible change in their optical properties when they are subjected to certain ambient conditions and different external stimuli, such as light, electric field, heat, humidity, gas exposure, and pressure.



http://dx.doi.org/10.1080/15583724.2019.1676775

Photochromism	Light
Thermochromism	Heat
Electrochromism	Electric current/potential/field
Solvatochromism	Solvents
Ionochromism	Ions
Magnetochromism	Magnetic field
Halochromism	pH
Piezochromism	Pressure (mechanical)
Chemochromism/vapochromism	Chemical agents/Vapor
Radiochromism	Ionizing radiation

Photochromic Materials

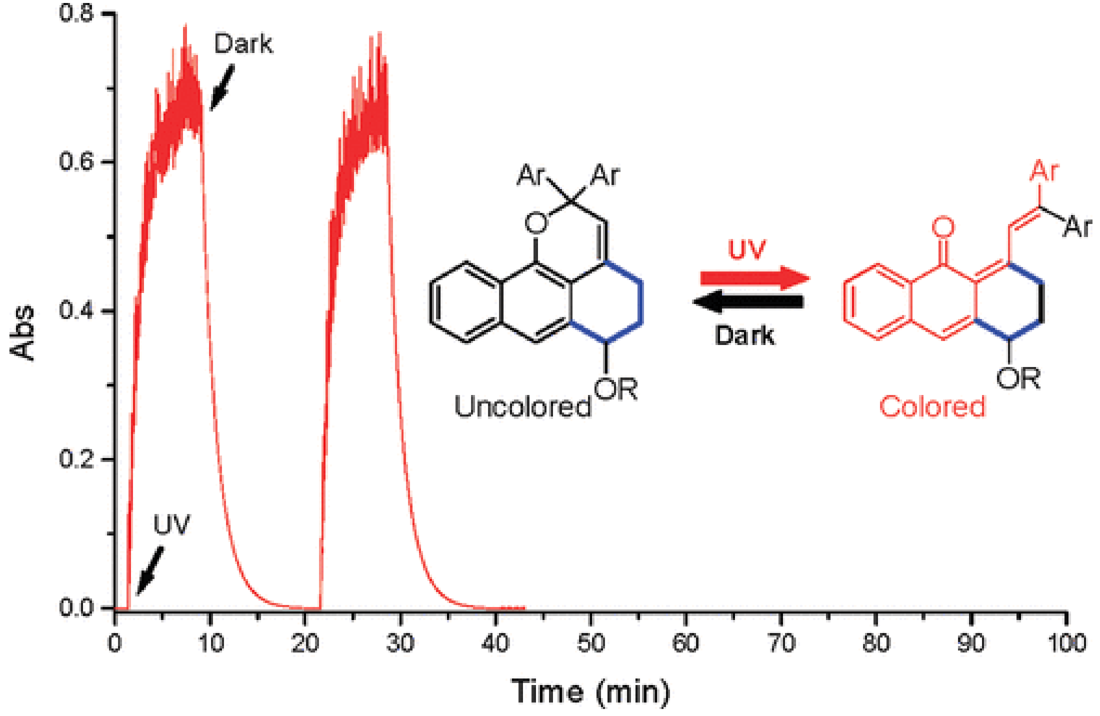
Photochromic materials are the one that changes from transparent state to a colored state when it is exposed to certain wavelengths of light, and it returns to transparency when the light is dimmed or blocked.

It is due to photoisomerization effect, when the chemical structure of the material can be reversibly transformed by the influence of absorbed light.

Light is one of the most attractive external stimuli to promote changes in chromic materials, since it is easy to control and non-destructive with high spatial and temporal precision .

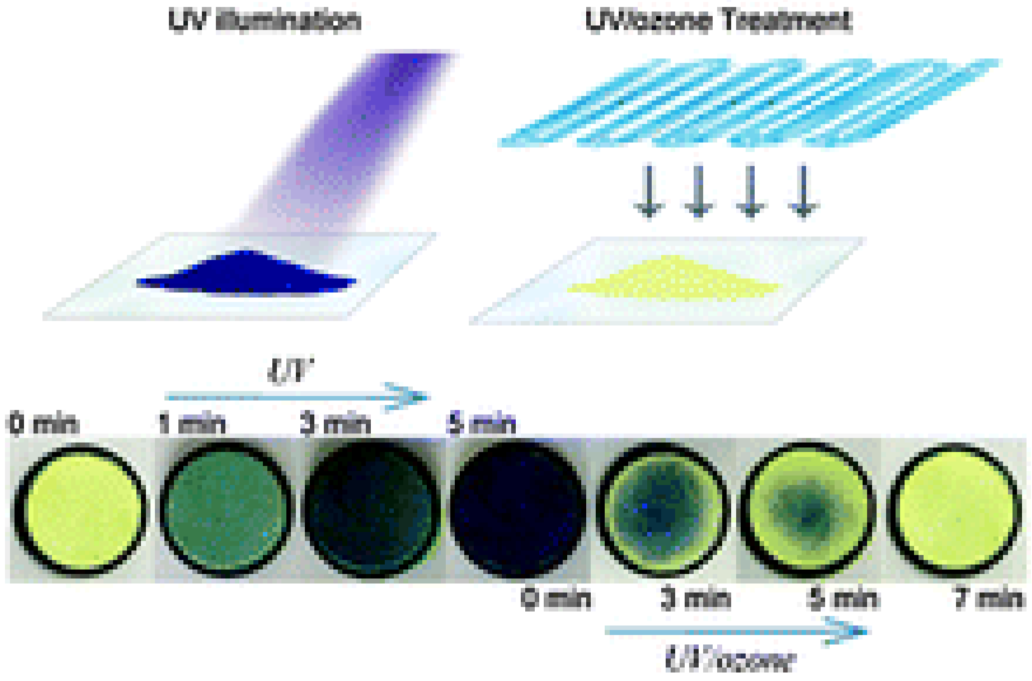
Photochromism can be observed in both organic and inorganic compounds, as well as their hybrid materials. This responsive behavior to light irradiation can be found in some metal oxides (Tungsten trioxide (WO_3), and molybdenum oxide (MoO_3), alkaline earth, metal halides, and some transition metals. The promising organic classes of photochromic molecules include dithienylethene, spiropyran, and azobenzene

Photochromic Materials



Photochromic Fused-Naphthopyrans

$$\frac{x}{2}H_2O + WO_3 \underset{UV/ozone}{\overset{UV}{\rightleftharpoons}} H_xW^{6+}_{1-x}W^{5+}_xO_3 + \frac{x}{2}O$$



https://doi.org/10.1021/jo3003216

Photochromic Materials

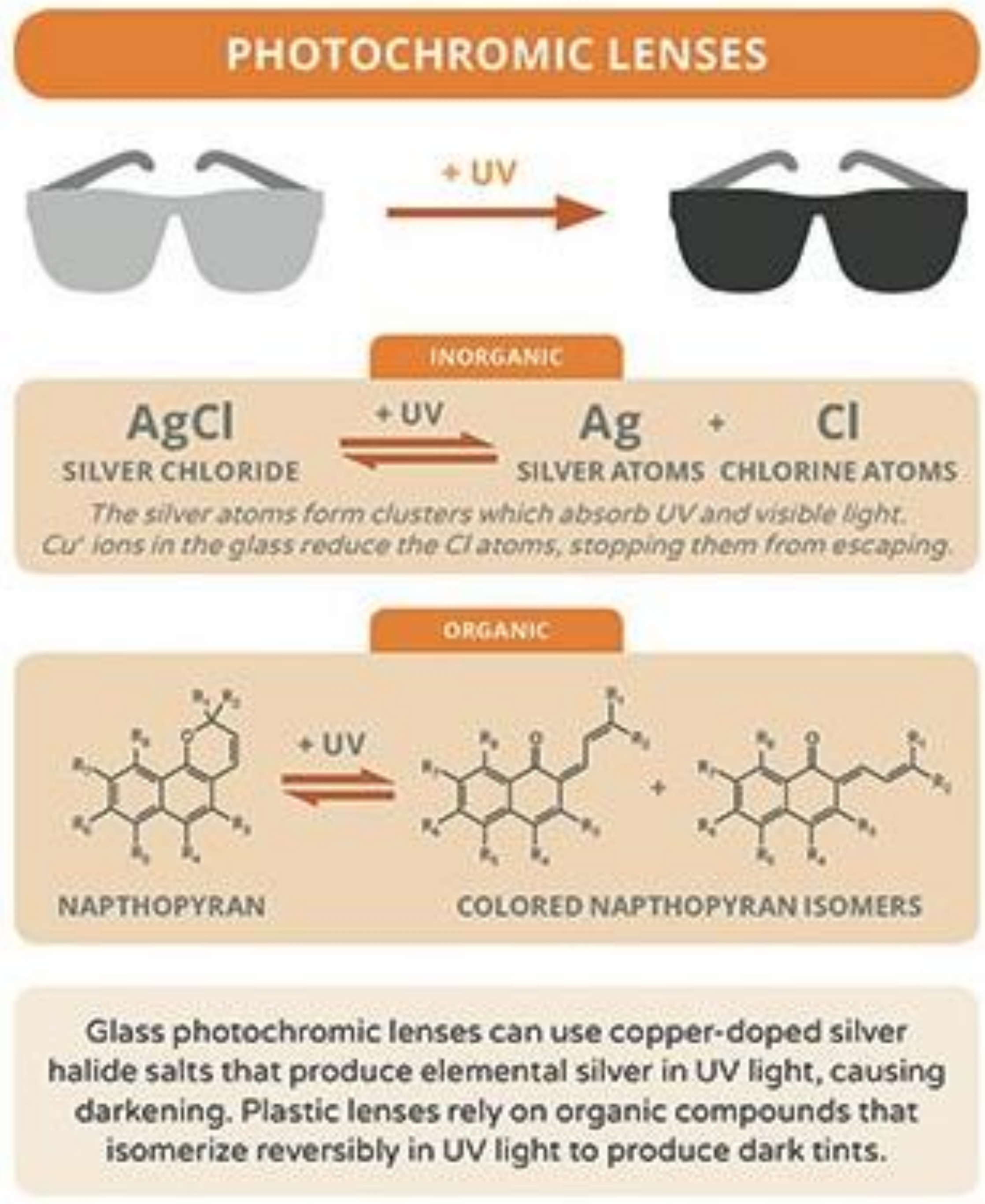
https://www.nikonlenswear.com/in/expert-advice/different-types-of-photochromic-glass-lenses/

Photochromic lenses are just like normal lenses but they automatically become dark when we move in the sunlight. Ultraviolet rays coming from the sun affect the molecules present in the photochromic lenses therefore, these lenses change their colors. These lenses get darker in bright lights and vice-versa.

Photochromic Materials

https://eyemantra.in/eyeglasses/photochromic-lenses/

- A lens is usually embedded with tiny silver halide and chloride molecules that darken when exposed to UV rays or sunlight.
- Due to a chemical process, the lens darkens when it is exposed to sunlight or UV light.
- As soon as the molecules are exposed to light, they move, change shape and absorb the light.



Photochromic Materials

Applications of photochromic materials:

1. **Supramolecular chemistry:** Photochromic units can be used to create molecules that can switch their shape, function or interactions with light.
2. **Data storage**: Photochromic compounds can be used to store information in optical media, such as CDs or DVDs, by changing their reflectivity or fluorescence with light.
3. **Solar energy storage:** Photochromic materials can be used to store solar energy by converting light into heat or electricity, and then releasing it when needed.
4. **Smart textiles :** Photochromic dyes can be used to make fabrics that change color with light, such as for fashion, art or medical purposes
5. **Photochromic glasses and lenses** :

Thermochromic Materials

Thermochromic materials change reversibly their color by a temperature change. Color transition is due to a change in crystalline phase or molecular structure.

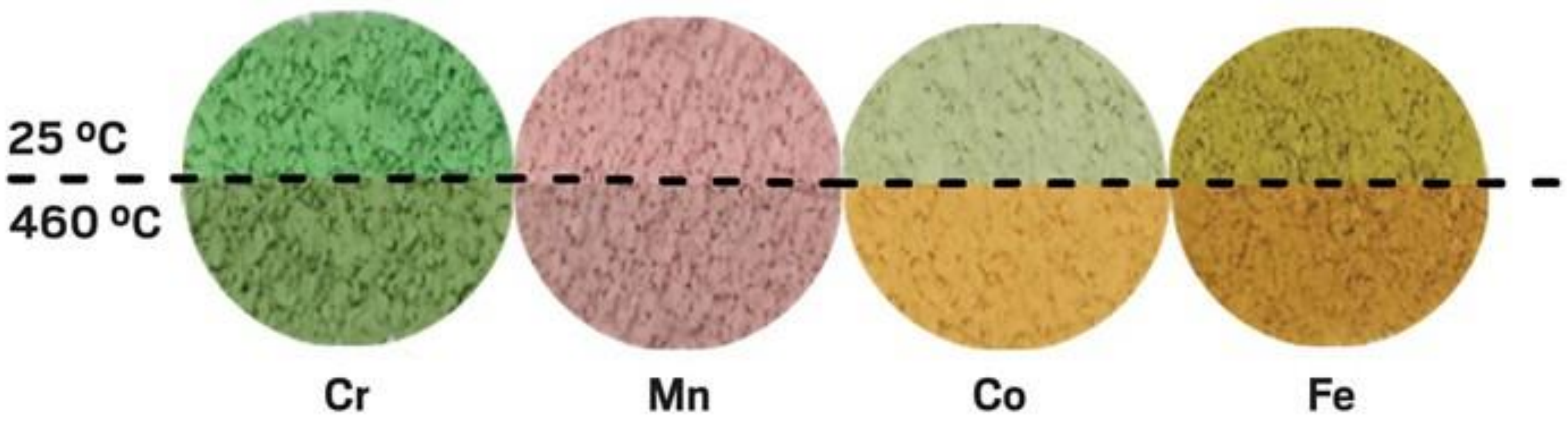
Liquid crystals are organic compounds that can reflect different colors at different temperatures, depending on their molecular structure and spacing. **Ex:** Cholesteryl esters, cholesteryl ethers, cholesteryl benzoates and cholesteryl oleyl carbonates. They are often used in thermometers, thermal cards, mood rings and other devices that require precise temperature measurements.

Leuco dyes are organic molecules that can change from colored to colorless or vice versa when they interact with other chemicals at certain temperatures. **Ex:** leuco dyes are crystal violet lactone, malachite green lactone, phenolphthalein and fluoran. They are often used in papers, polymers, inks and other materials that require a wide range of colors

Inorganic material: vanadium dioxide (VO_2), titanium dioxide (TiO_2), zinc oxide (ZnO), niobium dioxide (NbO_2), iron silicide ($FeSi_2$) and titanium sesquioxide (Ti_2O_3). These materials change their optical properties due to a change in their crystal structure or electronic configuration at certain temperatures.

Thermochromic Materials

Multicolored reversible thermochromic materials have been prepared with $Cr^{3+}/Mn^{3+}/Fe^{3+}/Co^{3+}$-doped $Er_3Ga_5O_{12}$

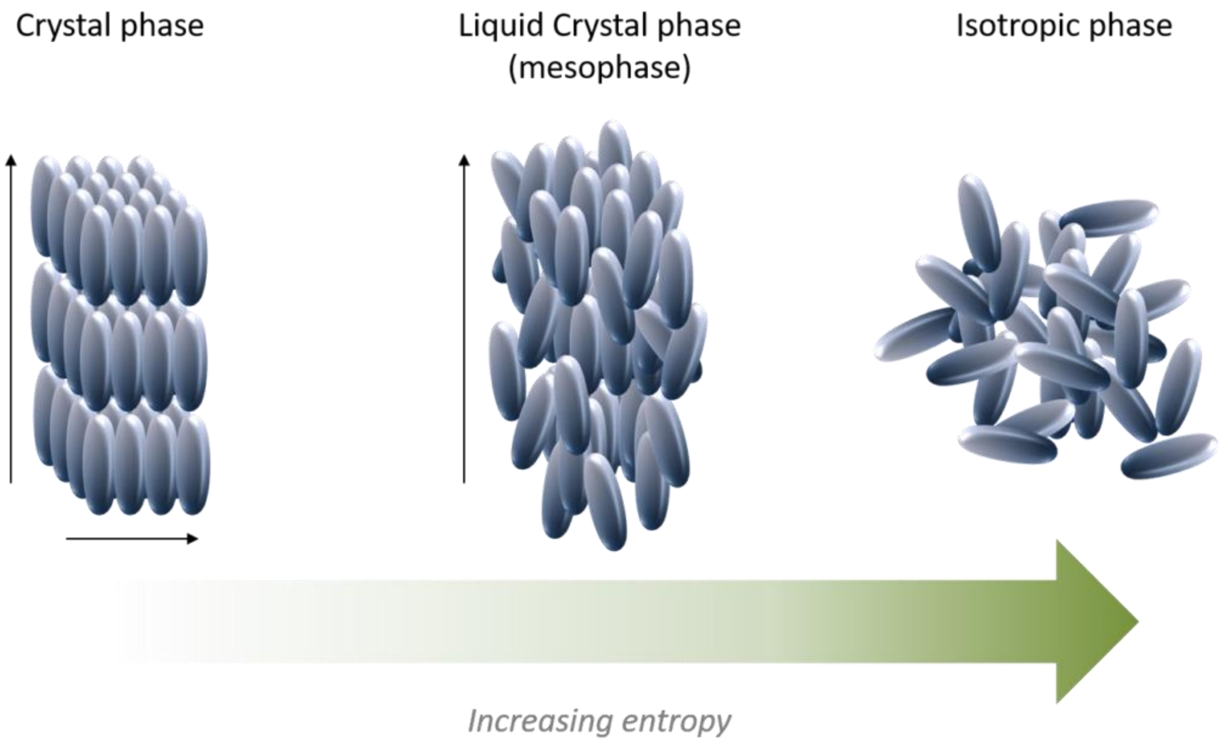


Erbium gallium garnet doped with chromium, manganese, cobalt, or iron ions changes color from room temperature (25 °C, top) to 460 °C (bottom).

https://doi.org/10.1021/acs.chemmater.8b04694

Liquid Crystals for LCDs

Liquid crystals are state of matter which has properties between those of conventional liquids and those of solid crystals.



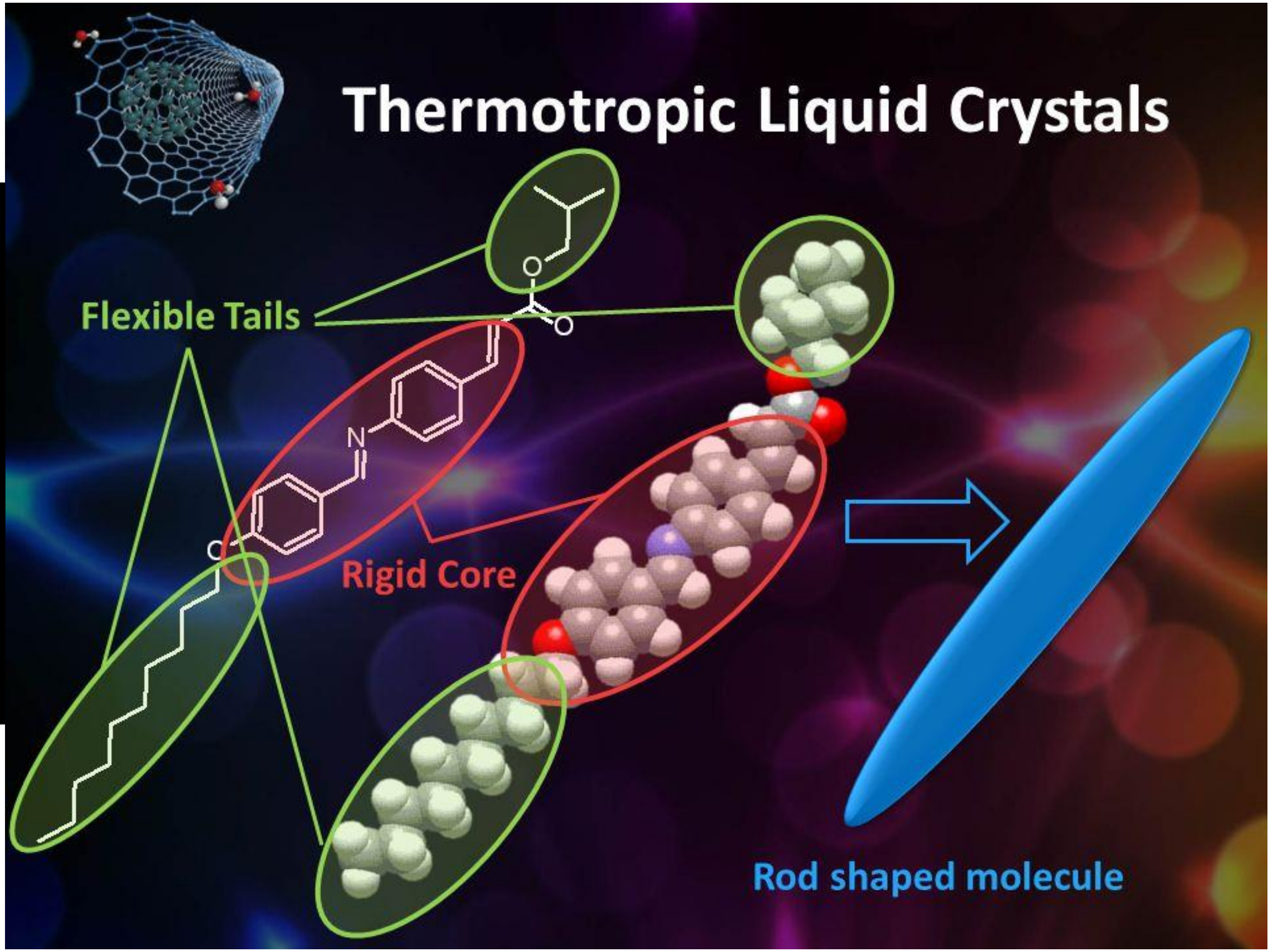
Thermochromic Materials

Thermotropic

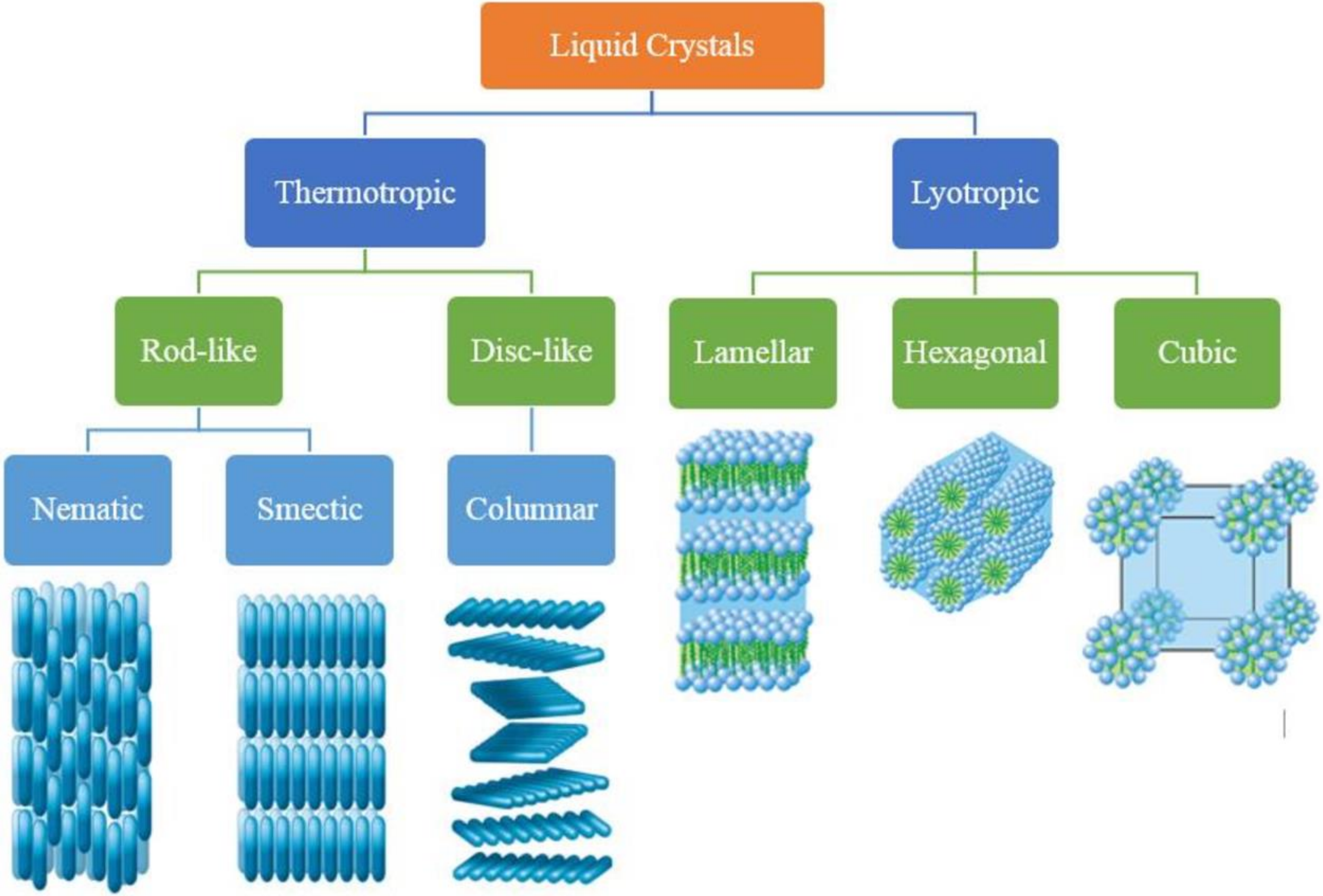
- Phase transition depends on temperature
  - Nematic
  - Smectic
  - Cholesteric

Lyotropic

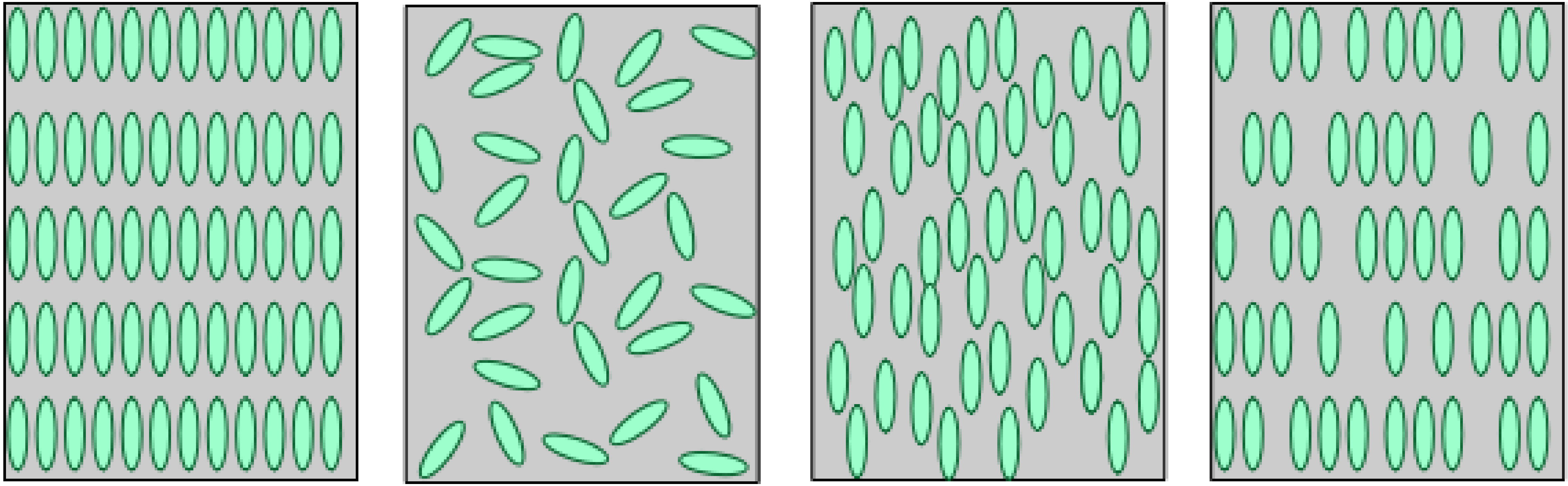
- Phase transition depends on temperature & concentration



Thermochromic Materials



Thermochromic Materials



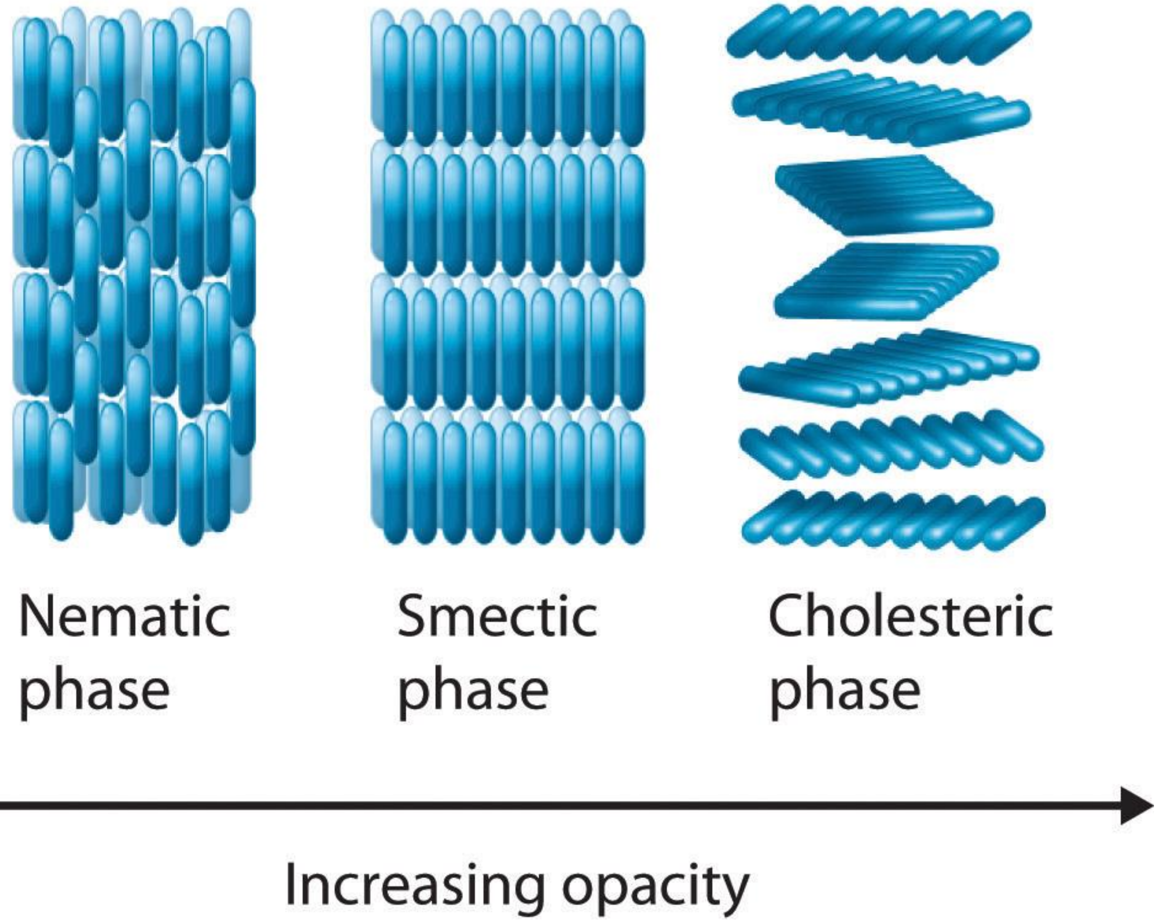
Solid phase: orientation and periodicity

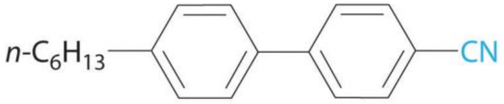
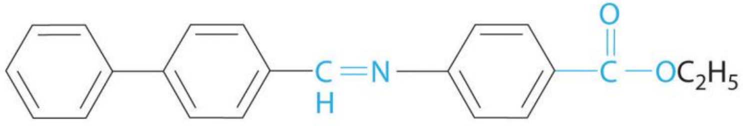
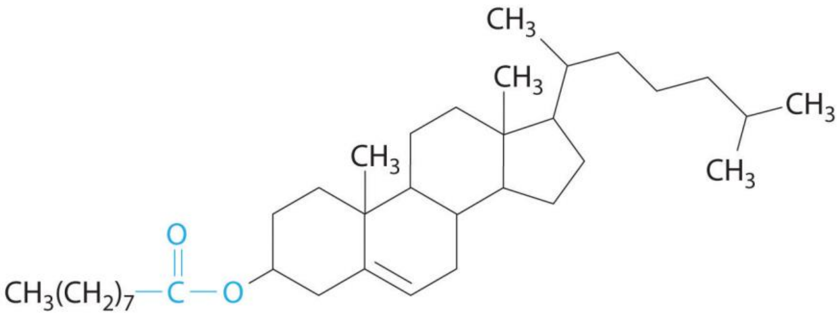
Liquid phase: no orientation or periodicity

Nematic phase: orientation, no periodicity

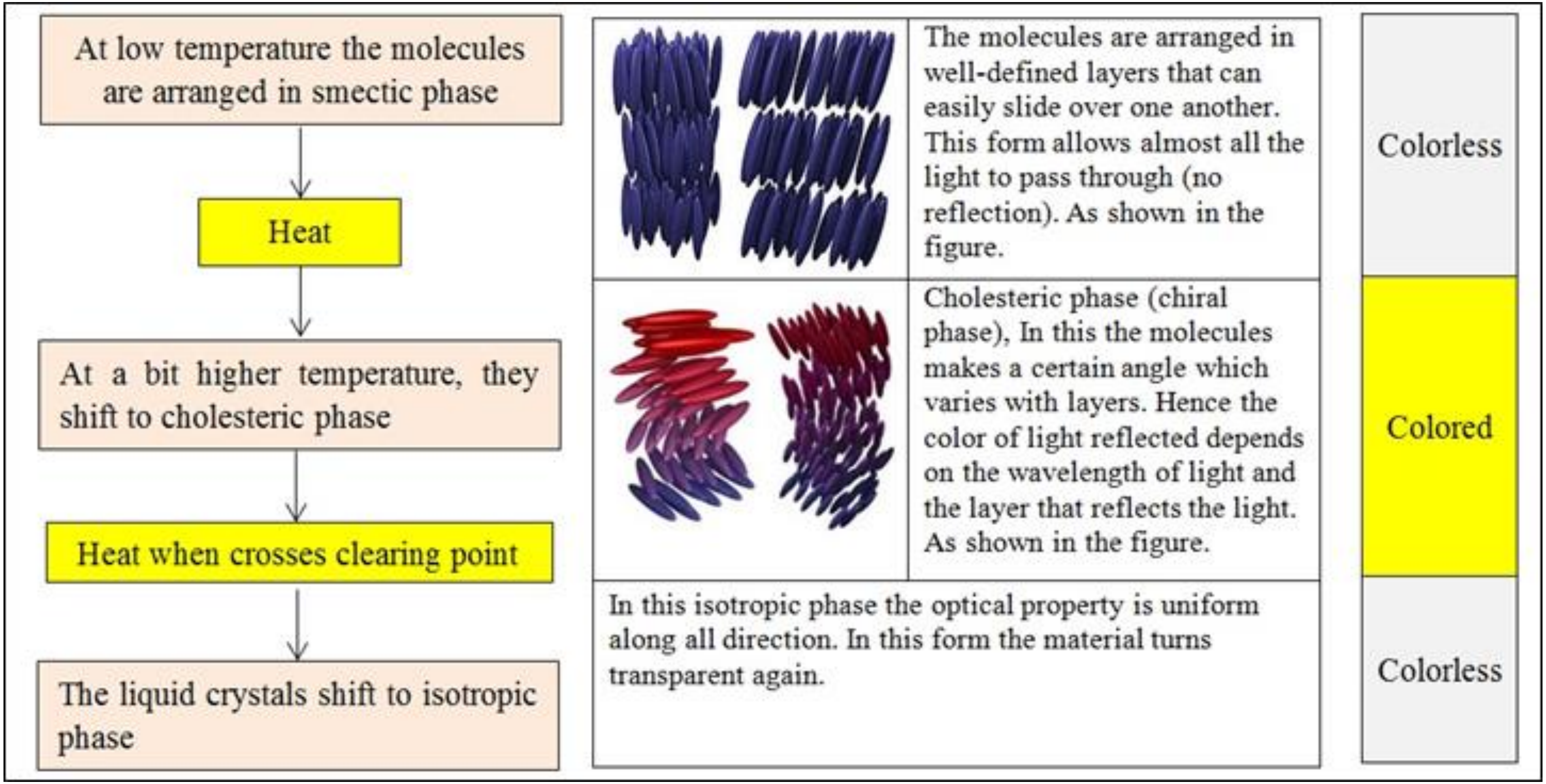
Smectic phase: orientation with some periodicity

Thermochromic Materials



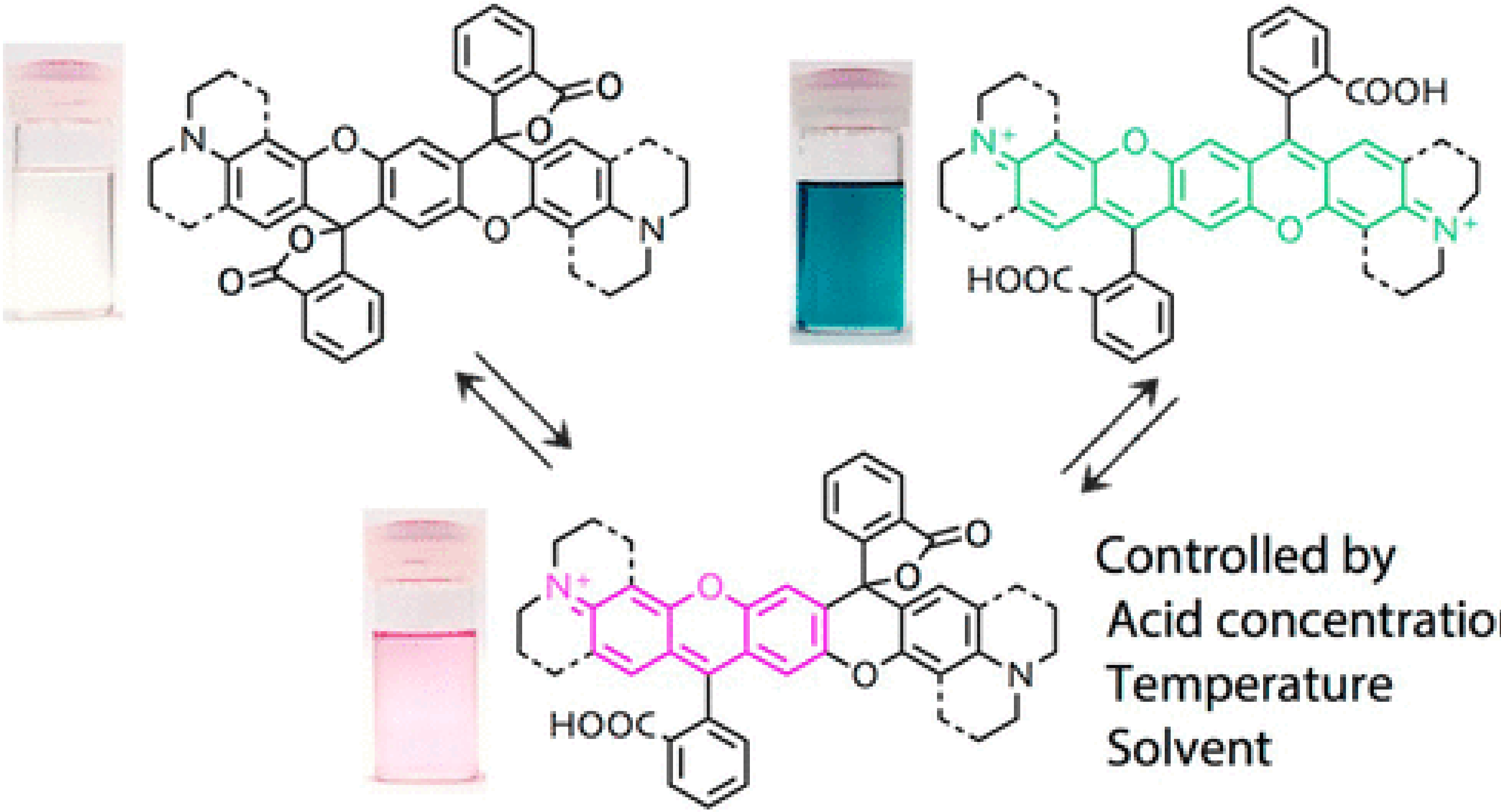
Structure	Liquid Crystal Phase	Liquid Crystalline Temperature Range (°C)
	Nematic	14–28
	Smectic	121–131
	Cholesteric	78–90

Thermochromic Materials



Thermochromic Materials

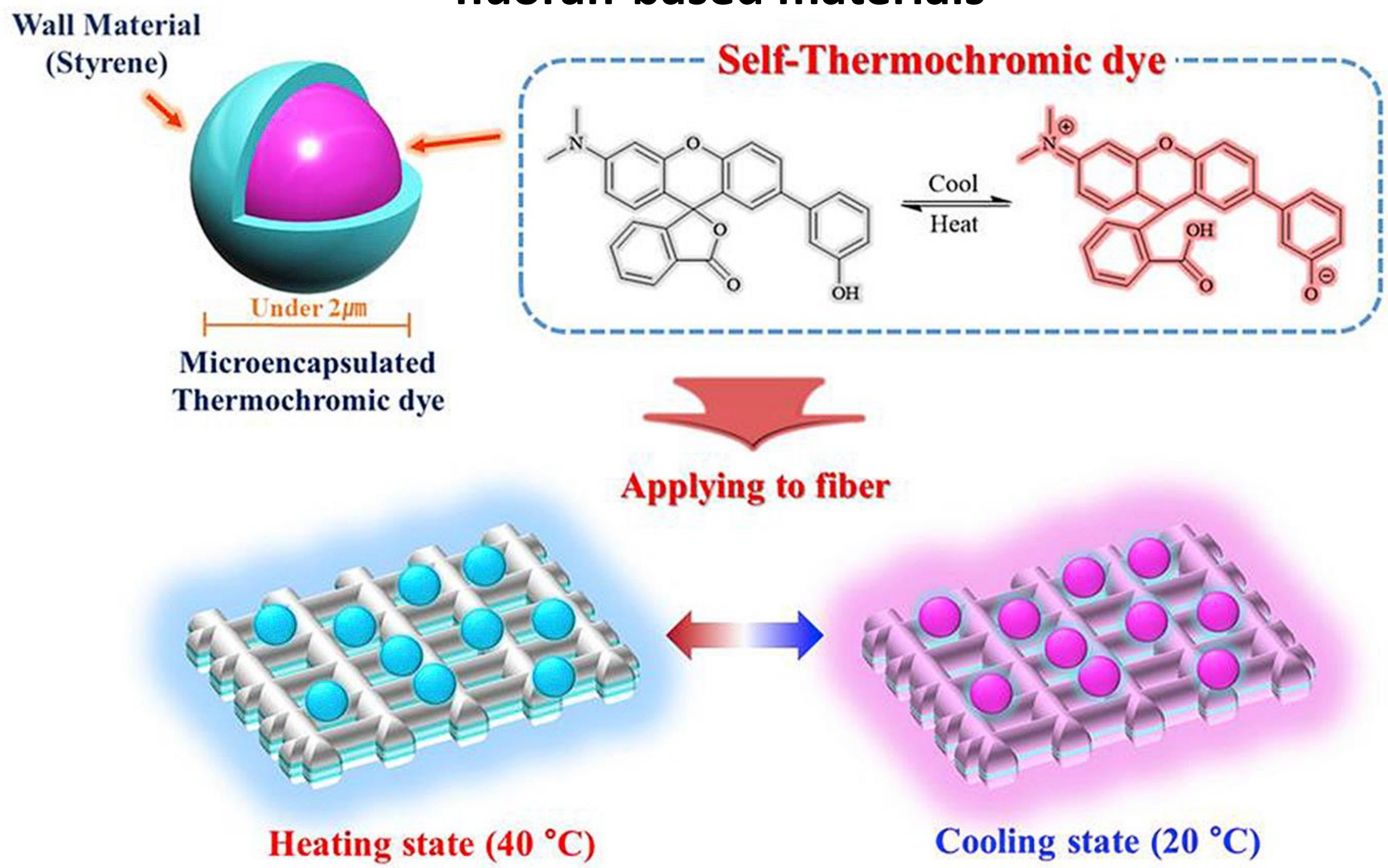
Leuco Dyes : *Iso*-Aminobenzopyranoxanthenes



Controlled by
Acid concentration
Temperature
Solvent

Thermochromic Materials

Thermochromism in microencapsulated fluoran-based materials



https://doi.org/10.1016/j.dyepig.2017.12.047

Thermochromic Materials

Thermochromic materials Applications:

1. Used as **temperature indicators** in many industrial sectors, to determine the temperature variation and reaction heat in chemical reactions.
2. **Thermometers for** room, refrigerator, aquarium, and medical use, which display different colors at different temperatures.
3. Indicators of level of **propane in tanks**, which change color depending on the temperature and pressure of the gas.
4. **Heat transfer mapping devices**, which visualize the temperature distribution and convection patterns on a surface.
5. **Artistic and educational materials**, such as mood rings, thermal cards, stickers, and toys, which change color with body heat or ambient temperature

Thermochromic Materials

Electrochromic Materials

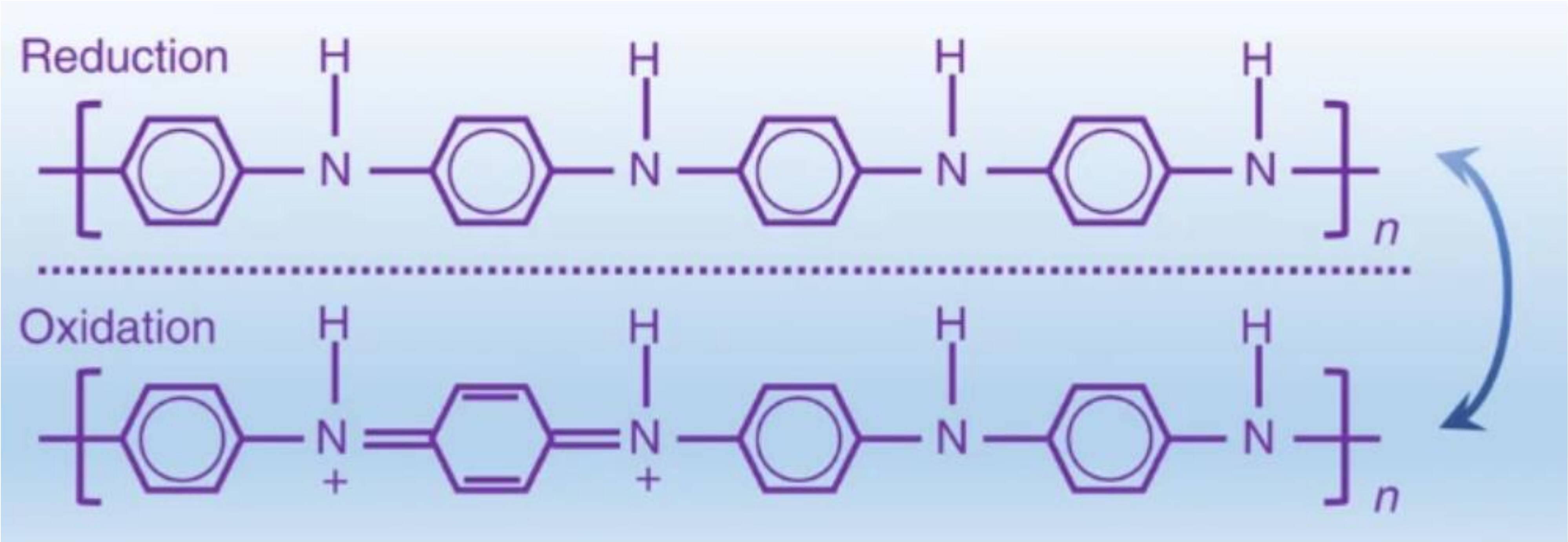
- Electrochromic materials are able to vary their coloration and transparency to solar radiation, in a reversible manner, when they are subjected to a small electric field (1–5 V).
- Electrochromic material changes colour in a persistent but reversible manner by an electrochemical reaction and the phenomenon is called electrochromism.

- Electrochromism is the reversible and visible change in transmittance and/or reflectance that is associated with an electrochemically induced oxidation-reduction reaction. It results from the generation of different visible region electronic absorption bands on switching between redox states.

- The main materials with electrochromic properties are metal oxides of transition, in particular WO_3, MoO_3, IrO_2, NiO, and V_2O_5.

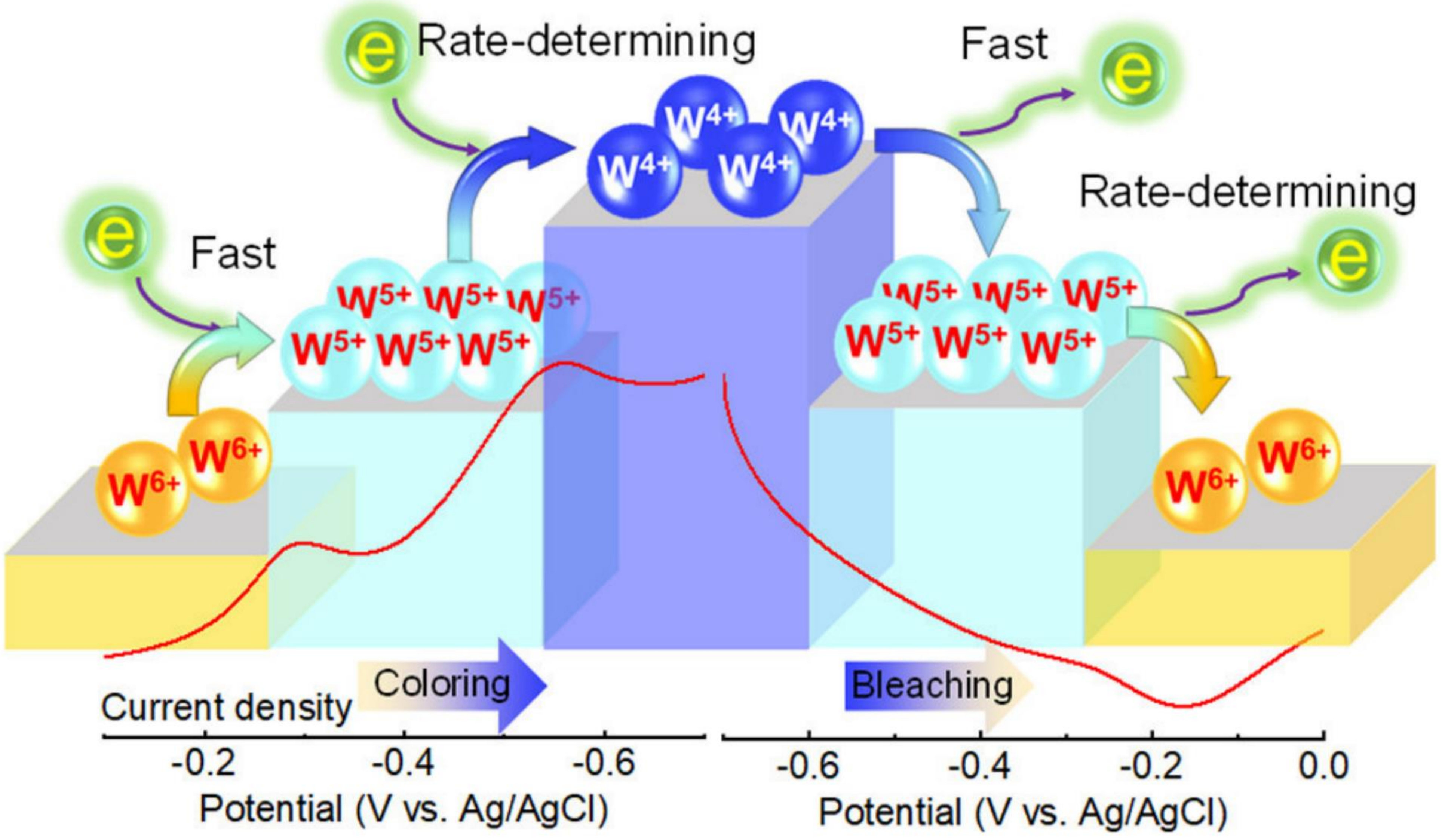
Electrochromic Materials

- **Polyaniline (PANI),** is one of the most used organic electrochromic material. As shown in Figure, when the voltage is applied, the REDOX reaction of PANI is induced, and the material changes gradually from yellow reducing state to green oxidation state. It may show a distinct color differentiation from blue or black when electrolyte is changed



https://www.nature.com/articles/ncomms10479

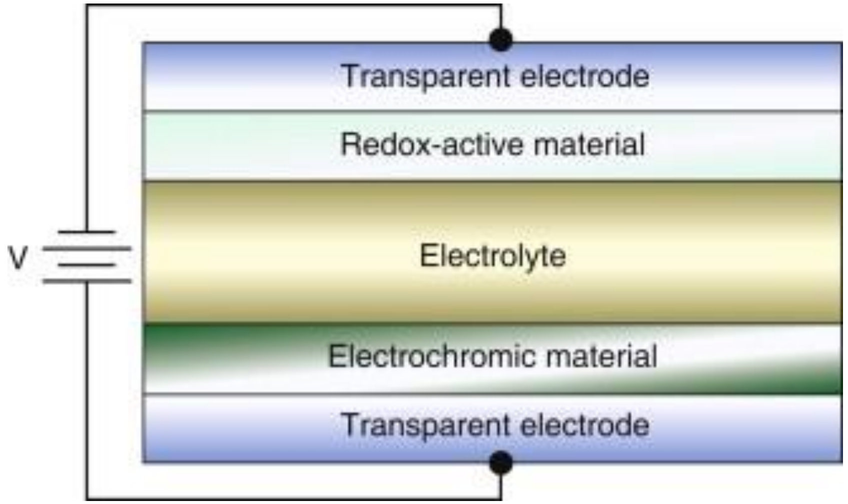
Electrochromic Materials



Electrochromic Materials

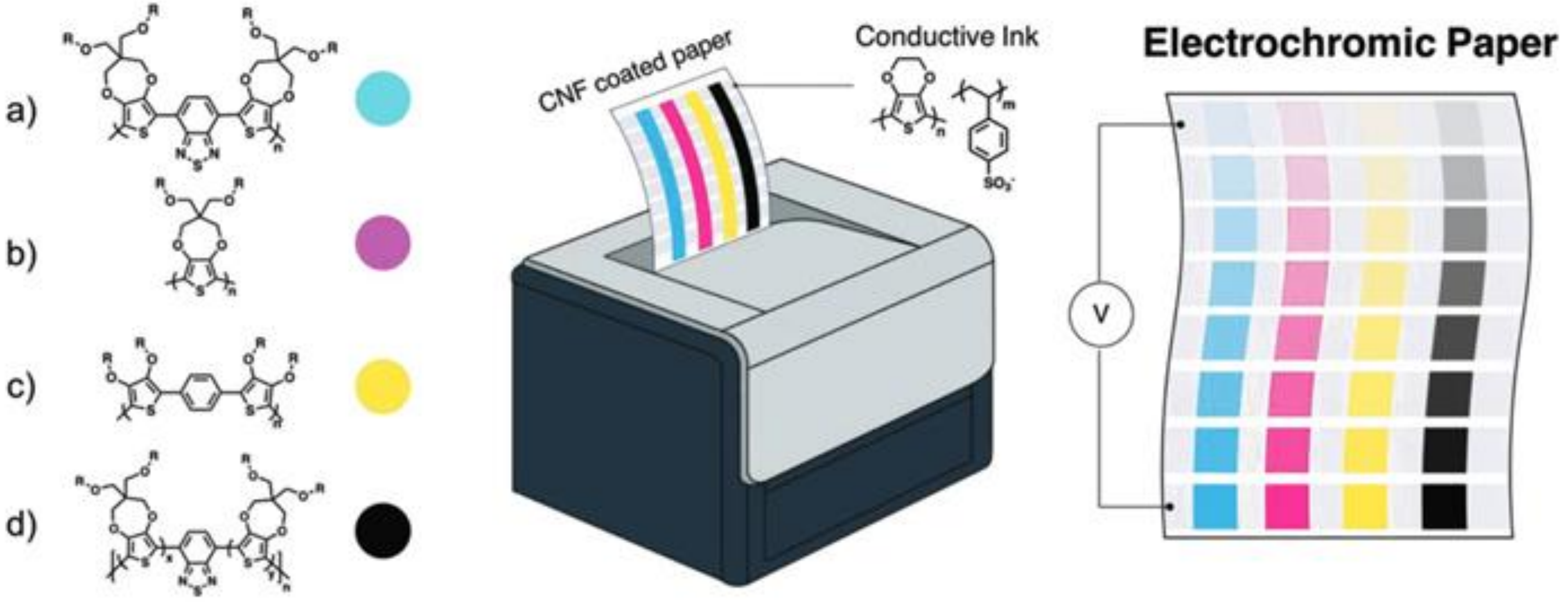
The basic architecture of an ECD is shown in fig. An electrochromic material is located between an electrolytic layer and an electrode, both of which must be optically transparent. The electrolytic layer provides the ionic transport necessary for electrochemical oxidation and reduction of the electrochromic material, and should accordingly possess high ion conductivity. Most ECDs utilize solid-state polymers intercalated with mobile ions, such as poly(ethylene oxide) saturated with lithium chlorate as the electrolytic layer. A secondary redox-active layer, capable of supporting an electrochemical reaction opposing that of the first electrochromic layer, is positioned on the reverse side of the electrolyte and capped with an additional optically transparent electrode.

Schematic of an electrochromic device ECDs.



Electrochromic Materials

The ability to inkjet print color-neutral, low resistance electrodes on paper from PEDOT:PSS ink and develop a path towards high throughput fabrication of readouts for disposable electronics. The PEDOT:PSS/cellulose nanofiber paper supports the reversible oxidation of 3 electrochromic polymers with differing colors (cyan, magenta, and yellow) which generates the possibility for a fully printed color display.



Electrochromic Materials

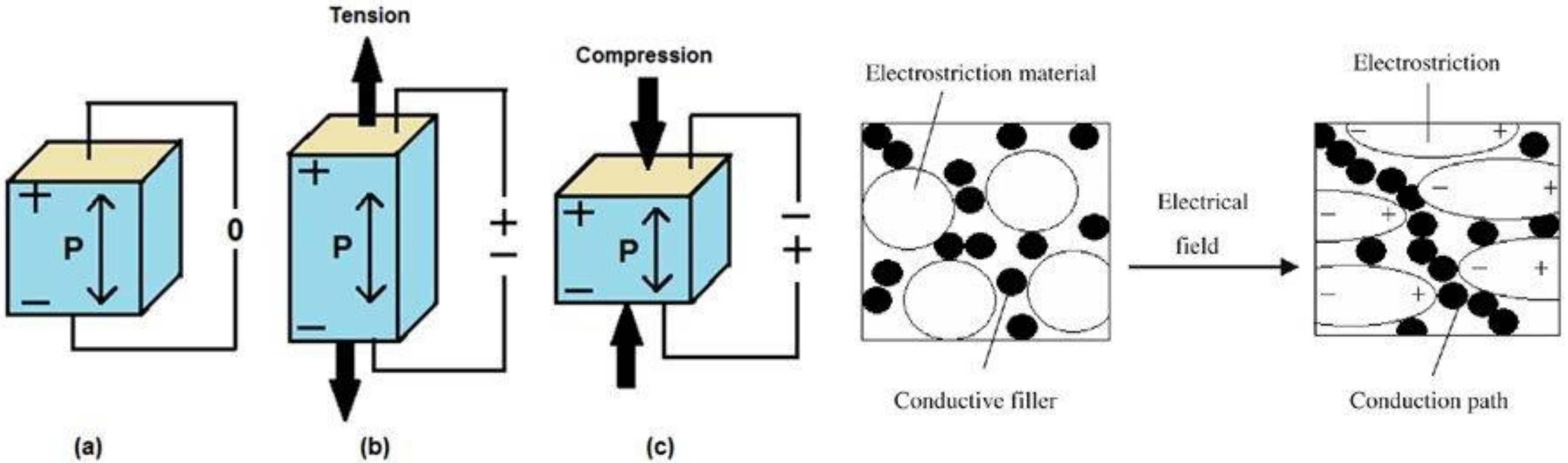
Electrochromic Materials

Applications:

- Smart windows.
- OLEDS display devices
- **Electrochromic displays** that can show information with low power consumption.
- **Electrochromic supercapacitors:**Integrating electrochromic functions into supercapacitor energy storage devices can also realize the intelligent characteristics of visual monitoring of energy storage status while converting electrical energy.
- **Electrochromic battery :** When the voltage of the wearable energy storage device goes to be 0 V in the process of wearing, that is, in the short-circuit state, the PPy electrode can respond quickly and immediately by turning yellow to provide visual energy storage information
- Sensors, optical shutters or optical modulators which controls the transmission or reflection of light.

Electro-strictive Materials

Electrostriction (converse piezoelectric effect**)** is a property of all electrical non-conductors, or dielectrics, that causes them to change their shape under the application of an electric field. [A *dielectric material* is defined as an electrical insulator that can be polarized by an applied electric field.]



Electro-strictive Materials

Electrostriction materials are used in the industry and research as **transducers in low dimensional systems such as micro-pumps and micro-electromechanical systems (MEMS)**

Micro Electromechanical Systems (MEMS)

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BiCMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices. They are often fabricated using silicon electronic chip technology, including nanometer-scale etching and photolithography

Micro Electromechanical Systems (MEMS)

Miniaturization is driving the development of MEMS, or micro electromechanical systems. They are now widely used in consumer electronics, wearable devices, medical instruments, and other applications. MEMS have numerous advantages over traditional electronic components including:

- low power consumption
- small size
- high accuracy

Unlike traditional electronic components, MEMS devices are inexpensive, highly reliable, and can be soldered directly onto a circuit board. These advantages make the technology an attractive choice for small and high-volume applications.

MEMS can act on real-time information about our physical environment. By developing these sensors, we can improve our lives, our understanding of the world, and our productivity. This research is supported by the director of our college, the professor at ADCET, and R. A. Jadhav, and the technical assistance at ADCET. The researchers thank their mentors and instructors for their support of their work. Listed below are some examples of applications of MEMS.

Micro Electromechanical Systems (MEMS)