

# Chromic Dyes for SMART Textile: A Review

Ahmed G. Hassabo <sup>1,\*</sup> , Mai Bakr <sup>2</sup>, Menna Zayed <sup>2</sup> , Hanan A. Othman <sup>2</sup>

<sup>1</sup> National Research Centre, Textile Research and Technology Institute, Pretreatment and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O. 12622, Giza, Egypt; aga.hassabo@hotmail.com (A.G.H.);

<sup>2</sup> Benha University, Faculty of Applied Arts, Printing, Dyeing and Finishing Department, Benha, Egypt; maiabakr@yahoo.com (M.B.); mennazaied525@gmail.com (M.Z.); hanan.othman@gmail.com (H.A.O.);

\* Correspondence: aga.hassabo@hotmail.com (A.G.H.);

Scopus Author ID 55909104700

Received: 15.06.2022; Accepted: 11.08.2022; Published: 21.11.2022

**Abstract:** SMART fabrics with various 'self-functioning' characteristics are being developed at an increasing rate, opening up new opportunities for inventive and technical applications. Chromic materials are one type of SMART textile. Chromism is a reversible color shift produced by various reasons (temperature, pH, etc.). The numerous chemical classes, mechanisms, and applications of chromic colorants are discussed in this article.

**Keywords:** SMART fabrics; chromic dyes; chemical classes; mechanisms and applications.

© 2022 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

The fabric of the future must be smart. Functional textiles serve a specific purpose, such as preserving the environment, whereas SMART textiles may respond to their environment. Technological textiles are defined as usable and SMART fabrics [1]. Three subcategories of SMART textiles may be distinguished [2-4]: a) Only on sensors, passive SMART textiles are able to perceive the surroundings and the user, (b) Active SMART textiles react quickly to environmental stimuli and combine an actuator function with a sensor device, and (c) Ultra-SMART fabrics are able to detect their environment, respond, and adjust their behavior accordingly. SMART fabrics are the requirement of the future.

Several approaches for developing SMART and functional textiles begin with the fiber stage and continue through the dyeing and finishing stages. Among these strategies, using SMART and functional dyes is thought to be the most cost-effective way to create SMART and functional textiles [1].

SMART dyes can detect their surroundings and adjust their behavior appropriately. Chromogenic materials are dyes that change color and are classified as chameleonic because they change color reversibly in response to changes in temperature, light, stress, pH, and other environmental factors, as well as artificially created stimuli [5].

The word "chromo" comes from the Greek language and refers to the color of something. A chromogen is a colorful chemical that contains a chromophore that causes the color to appear. A chromophore is a collection of atoms inside a larger molecule that absorb some wavelengths of visible light while transmitting wavelengths that are not absorbed [6]. This includes alterations at the molecular level, such as chemical bond breakage and molecular conformation changes. Most of the time, chromism is caused by changes inside the molecule,

namely between electrons. This includes the 'pi' and 'de' electron locations, implying that the phenomena are triggered by various stimuli capable of altering the electronic density of the molecule or material [4,5,7].

Many natural substances contain chromism, and manufactured compounds with specialized chromic characteristics have recently been produced. Chromic materials have the unique capacity to change color in response to external stimuli [5].

## 2. Classes of SMART Dyes

Depending on the environmental stimulation, there are several forms of chromism [5,7-9]. Table 1 lists the various chromism kinds and the associated stimuli. [10].

**Table 1.** Classes of Chromism types.

Chromism type	External stimulus
Photochromic	Light
Halochromic	Ph
Thermochromic	Heat
Electrochromic	Electric current
Mechanochromic	Mechanical deformation
Piezochromic	Mechanical pressure
Tribochromic	Mechanical friction
Solvatochromic	Solvent polarity
Hygrochromic	interaction with bulk water or humidity
Chemochromic	Chemical agents
Ionochromic	Ions
Chronochromic	Time
Gasochromic	a gas—hydrogen/ oxygen redox.
Carsolchromic	Electron beam
Vapochromic	the vapor of an organic compound due to chemical polarity/polarization
Biochromic	Biological agents
Aggregachromic	dimerization/aggregation of chromophores.
Crystallochromic	Crystal structure change of a colorant
Magneto chromic	Magnetic field
Cathodochromic	Electron beam irradiation
Radiochromic	Ionizing radiation

Additionally, there are chromisms that combine two or more stimuli. Examples of this [5] are photoelectrochromism, photovoltachromism, bioelectrochromism, solvatophotochromism, thermosolvatochromism, halosolvatochromism, and electromechanochromism.

### 2.1. Thermochromic dye.

Thermochromic materials, such as thermochromic dyes that may change color at specific temperatures, change color when the temperature changes [11,12].

#### 2.1.1. Classification of thermochromic.

In general, thermochromic materials are divided into two groups based on their discoloration mechanisms: inorganic reversible (metal complexes, chelate compounds, composite salts, and rare-earth, for example) and organic reversible (reversible organic materials) (liquid crystals and pigments, etc.) [13]. Organic reversible materials are the most often utilized thermochromic materials.

### 2.1.2. Mechanism of organic thermochromic.

Organic materials' discoloration is primarily caused by electron transfer, proton transfer, pH value, dimension structure, electron spin, and other factors [14].

#### 2.1.2.1. Crystal transition mechanism.

Both organic and inorganic reversible thermochromic compounds use the same process. Previous studies have shown that the 2,3(phenyle-thenyl)-5,6 dicyanopyrazine crystal's - interaction can improve at high temperatures, where the molecule undergoes a reversible color shift from yellow to red at 174.5°C.

#### 2.1.2.2. Dimensional structure change.

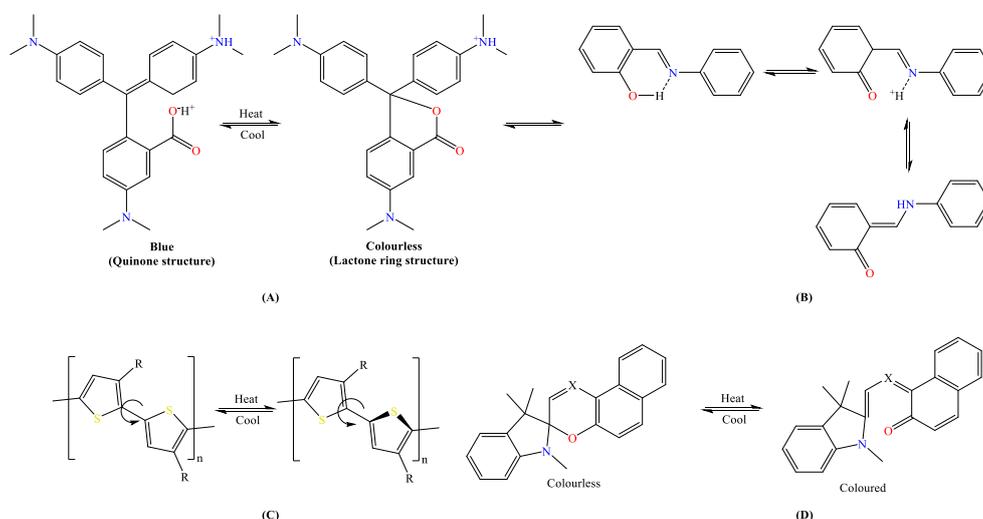
The structure and size of the chemical may change when heated. Because of five-membered heterocyclic rings, the polythiophene is naturally coplanar at low temperatures. Because the C-S bonds are twisted as the temperature rises, the structure changes from having a planar to a spatial shape, as seen in Figure 1.

#### 2.1.2.3. Intermolecular proton transfer.

A proton transfer occurs when the temperature of a substance rises, resulting in a change in the material's molecular structure. As illustrated in Figure 1B, At higher temperatures, rapid proton transfer from oxygen to nitrogen atoms is made possible by the intermolecular hydrogen bond that may be formed by the salicylaldehyde acetaminide containing -O-H. [13].

#### 2.1.2.4. Intermolecular electron transfer.

Based on the electron's ability to discriminate between the following, this technique: electron acceptor, electron donor, and solvent chemical [1]: (a) Solvent compound: it controls the temperature at which alcohols and esters get discolored; (b) Fluoran, indole phthalide, and spiro-pyran are examples of electron donors that determine color; and (c) Electron acceptor: substances like phenols, sulfonic acids, and carboxylic acids use this to determine the color chroma.



**Figure 1.** Molecule structural alterations include (A) the crystal violet alctone's electron transfer procedure, (B) N-keto-enol salicylideneaniline's tautomerization, (C) polythiophene's conformational shift, and (D) spiropyrane's ring opening mechanism.

Reversible thermochromic organic compounds typically contain at least three components: a color former, a color developer, and a solvent. Color formers are dyes that are colorless and operate as electron donors. These compounds are halochromic, meaning their color changes when the pH varies. The location of the longest wavelength absorption that causes the response of the electron-accepting developer determines coloring or decolorization. When the solvent is solid at lower temperatures, it generates a colorful dye developer complex; the solvent developer interaction takes primacy when it melts at higher temperatures. The melting point of the solvent, which controls the temperature at which decolorization/coloration takes place, is a typical way to represent the activation temperature (TA). Too far, the most important systems for generating thermochromic characteristics with organic materials are leuco dye developer–solvent composites [15, 16].

Commercially available reversible thermochromic colorants have activation temperatures ranging from  $-15$  to  $65$  °C, even though the majority of applications are limited to three temperature ranges: cold ( $10$ °C), body-heat induced ( $31$ °C), and warm ( $43$ °C).[16].

### 2.1.3. Applications of thermochromic.

There are various issues with thermochromic materials in textile applications, such as water insolubility and insufficient affinity for the fibers. Furthermore, PCMs, which are the solvent component of leuco dye-based ternary TS, have a problem flowing on fabric structures at temperatures above their melting point. Microencapsulation was used to overcome the difficulties [17].

Manufacturers recognized the potential in the following application fields: permanent fragrance insect repellents, cosmetics, dyes, antimicrobials, phase-change materials, fire retardants, anti-counterfeiting, polychromic and thermochromic effects, technical textiles, and specific medicinal applications [7].

## 2.2. Photochromic dye.

When a material is irradiated with UV or white light, it can undergo a reversible color shift between two separate chemical species with different absorption spectra. When the light source is removed, the color change process can be reversed to the original color or colorless condition [10].

Photochromic characteristics may be found in a wide range of organic and inorganic materials [18]: Inorganic photochromic materials include metal oxides, titanates, copper components, mercury components, and transition metal oxides; Organic photochromic materials include spiropyranes, spirooxazines, chromenes, fulgides, flumigides, and diarylethenes (see Figure 2) [19-21].

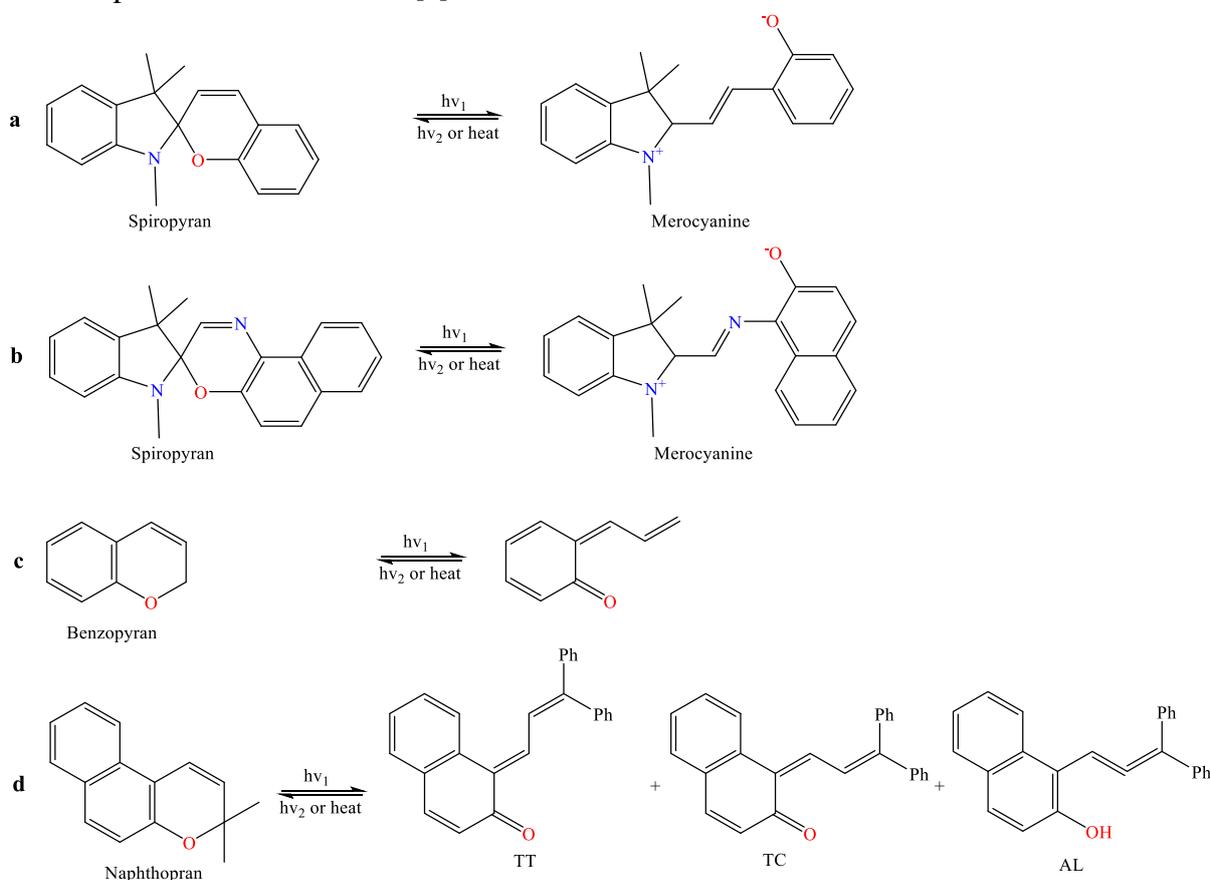
### 2.2.1. Types of photochromism.

#### 2.2.1.1. Positive photochromism.

When exposed to UV light, the photochromic compound, which is, in this case, decolorized until it is exposed to UV radiation, becomes colored [9].

### 2.2.1.1.1. Negative photochromism.

Because the photoproducts absorb at shorter wavelengths than the original compound, the photochromic compound, which is colored until it is subjected to UV light, decolorizes when exposed to UV radiation. [9]



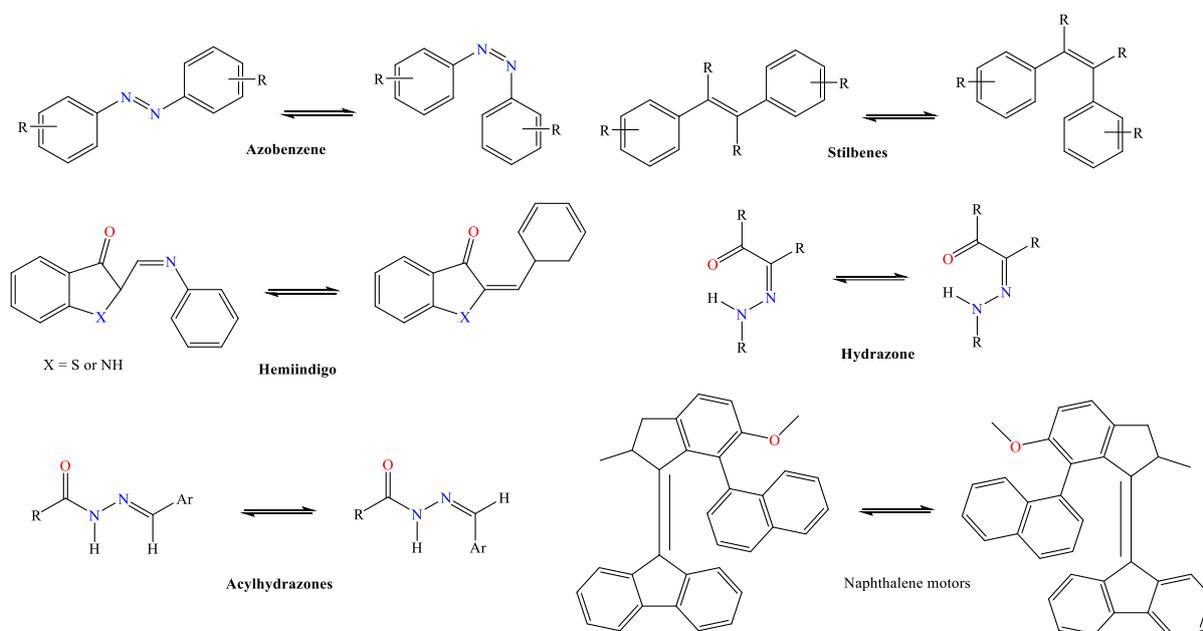
**Figure 2.** Photochromism of (a) spiropyran, (b) spirooxazine, (c) benzopyran, and (d) naphthopyran.

### 2.2.1.1.2. Photo responsive materials.

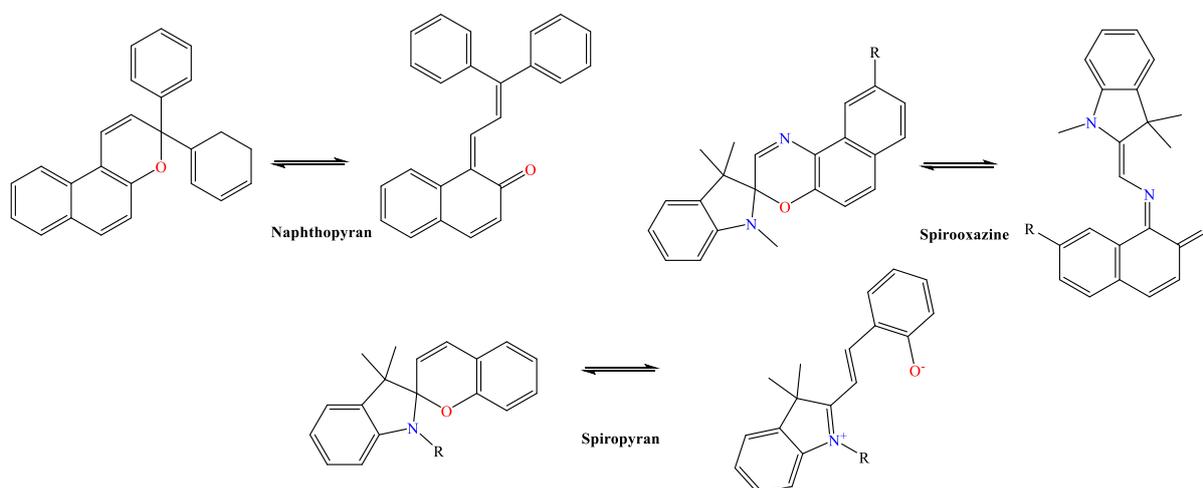
When the photochromic reaction occurs (at the molecular level), the structure of the photochromic compound undergoes a conformational change. Differences in physical and chemical characteristics between the two types of photochromic molecules can be transmitted to the microenvironment or supramolecular structure, resulting in photo-responsive materials with light-induced property changes.

### 2.2.2. Mechanism of photochromic.

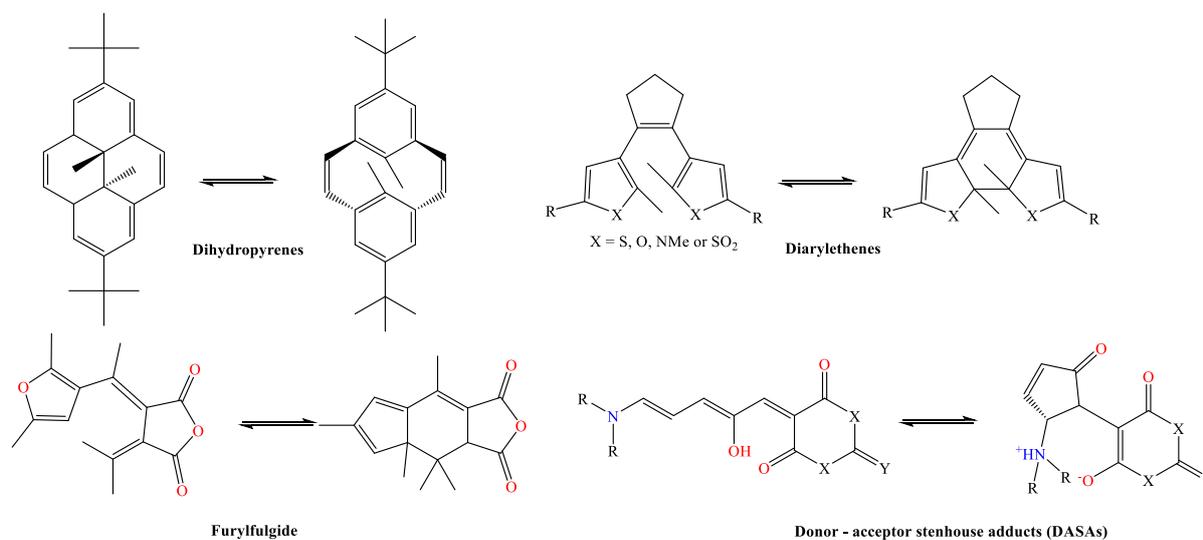
Traditional photochromism dyes (PDs) are divided into two groups based on the photogenerated species' thermal stability: T-type (thermally reversible type): photogenerated isomers return thermally to their initial forms; P-type (photochemically reversible type): photogenerated isomers do not revert to their initial forms even at high temperatures. Over the years, several different families of PDs have been produced, with the key difference being the sort of photochemical reaction that causes the color shift. As a result, PDs may be classified according to their photoreaction route, they follow: Trans-cis isomerization (see Figure 3); Photocleavage of bonds (see Figure 4); Electrocyclization and cycloreversion reactions (see Figure 5); Intermolecular cycloaddition and cycloreversion reactions (see Figure 6) [22].



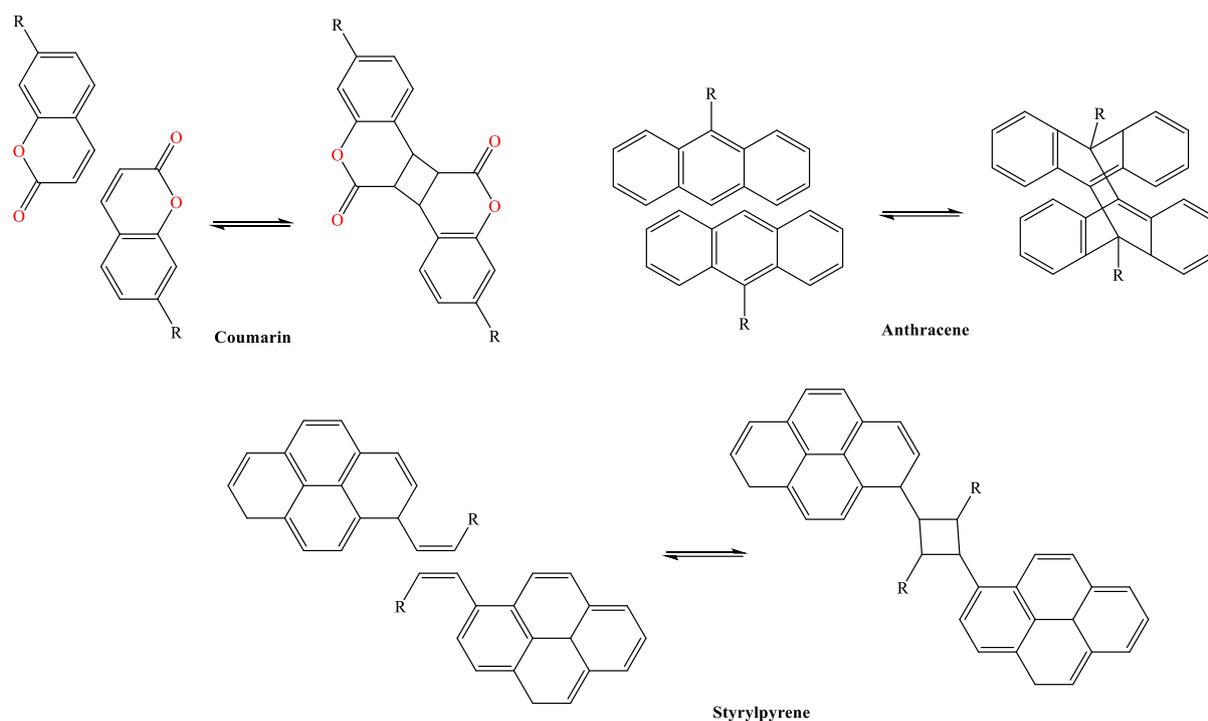
**Figure 3.** Trans-cis isomerization type photo dyes.



**Figure 4.** C<sub>sp3</sub>-pyranAO bond photocleavage type of photochromic dyes.



**Figure 5.** Electrocyclization and cycloreversion reaction type of photochromic dyes.



**Figure 6.** Intermolecular cycloaddition and cycloreversion reactions type of photochromic dyes.

Binder film production is often used to adhere photochromic molecules to the surface of textiles. Mateja *et al.*, for example, described a class of photochromic cotton textiles made by covering them with photochromic microcapsules. He *et al.* used polydimethylsiloxane to adhere a type of pre-prepared photochromic microcapsules to the surface of cotton fabric. However, due to the use of additional binders, printing photochromic compounds for textiles has experienced several issues, including poor washability and a stiff hand feel. Chemical linkages between textiles and photochromic molecules can be used to circumvent these flaws. For example, Bao *et al.*, and Fan *et al.*, described techniques for creating durable and photochromic cotton-based materials using click chemistry to form covalent connections between photochromic chemicals and cotton fibers [23].

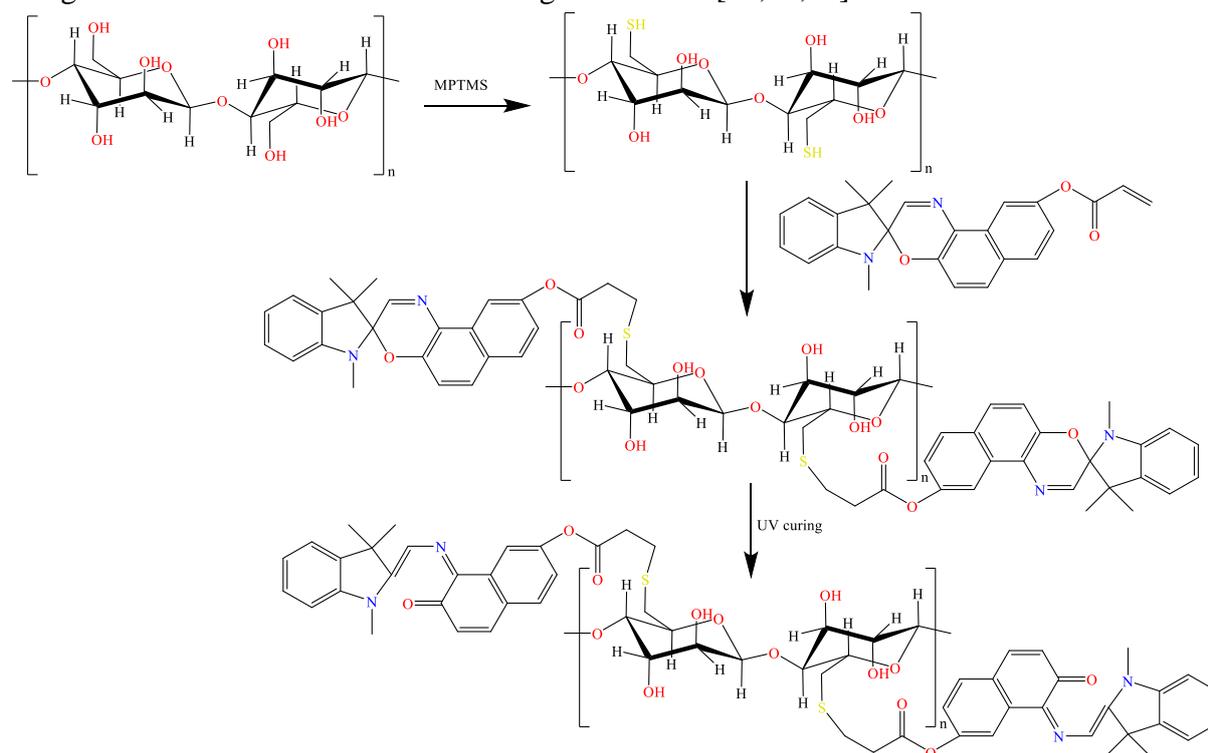
### 2.2.3. Applications of photochromic.

Many textile applications, such as T-shirts, purses, and headgear, now use the photochromic phenomenon. For example, nightwear is white indoors but turns to blue, green, purple, or whatever color when exposed to sunlight [24].

Photochromic dyes have shown to be beneficial in the fabrication of photoswitchable biomaterials. Textiles have a wide range of applications, from daily clothing to high-tech SMART and functional textiles used in fashion and intelligent design, security and brand protection, anti-counterfeiting, camouflage, textile UV sensors, and active protective equipment. Photochromic fabrics offer the benefit of changing color fast in reaction to light while keeping the overall qualities of the material. UV sensing fabrics, for example, are more flexible, and adjustable, and need less maintenance than traditional sensor systems [4].

A novel kind of SMART photochromic fabric is created by covalently attaching 3-mercaptopropyl tri methoxy silane (MPTMS) modified cotton fabric with spirooxazine (SO). The well-known thiol-ene click chemistry approach is used to modulate the optical characteristics of cotton fabric dynamically. (See Figure 7) Under UV irradiation, the photochromic fabric may transform colorless to blue with a quick light reaction time while

displaying fine pictures. After 20 reversible color-changing cycles, it still possesses photochromic properties and reusability, which means that the prepared photochromic fabric has great value in SMART devices and light detection [22,25,26].



**Figure 7.** Schematic diagram of the preparation process and photochromic mechanism of photochromic cotton fabric.

### 2.3. Halochromic dyes.

When pH changes, halochromic fabrics change color and can be used for wound healing, protective gear, filtration, and other purposes [26]. pH-detecting SMART textiles can help determine if a situation is alkaline or acidic [4,27].

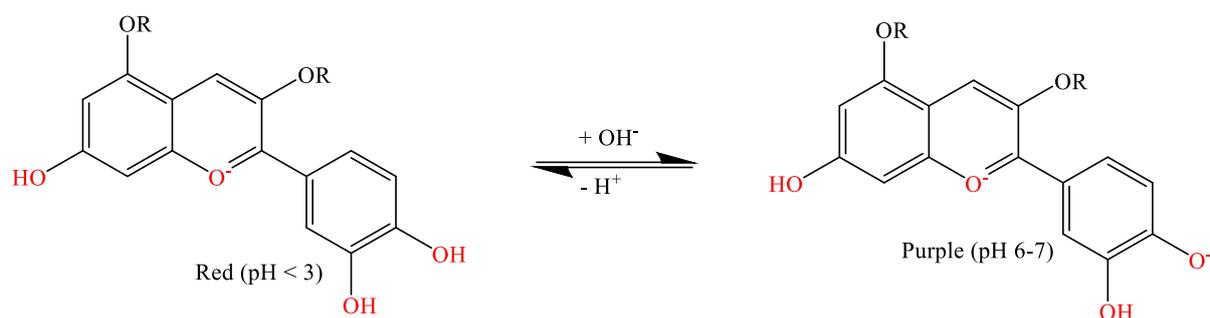
#### 2.3.1. Classification of halochromic dyes.

Halochromic dyes are available in both natural and synthetic forms. Phthalenes, triarylmethanes, fluoranes, and azo dyes are the four main categories of halochromic synthetic dyes. Thymol blue, methyl ratio, bromine cresol green, methyl red, bromine thymol blue, phenol ftalein, phenol red, alginin yellow, and other synthetic pH indicators [28]. Most synthetic dyes are halochromic, meaning they change color depending on pH. However, they have negative environmental consequences and are linked to allergic, poisonous, and other adverse reactions [26].

As a result, we'll need to utilize natural coloring. Biocompatible and biodegradable pigments derived from natural resources are predicted. However, replacing synthetic dyes with natural colorants is challenging due to the color stability of light, oxidation, temperature, and pH.[26,29].

Cyanidin is a natural chemical molecule that may be used as a dye and can also be used as an indicator. (Refer to Figure 8) It belongs to the anthocyanin family, which includes pelargonidin(C<sub>15</sub>H<sub>11</sub>O<sub>5</sub>), cyanidin(C<sub>15</sub>H<sub>11</sub>O<sub>6</sub>), delphinidin (C<sub>15</sub>H<sub>11</sub>O<sub>7</sub>), and malvidin (C<sub>17</sub>H<sub>15</sub>ClO<sub>7</sub>). Anthocyanidins are subjected to a pH-dependent reaction, with each structure displaying a distinct hue. The hue shifts from red to blue as the number of hydroxyl groups

(dotted) increases. The hydroxyl group is completely removed, resulting in a yellow hue change [29,30].



**Figure 8.** Halochromic forms of cyanidin/R = glycoside [30].

### 2.3.2. Mechanism of halochromic dyes.

A wide range of color variants is offered, ranging from one hue to another or from colorless to colored products [10]. The color change is induced by structural changes in the compounds caused by proton exchange, which causes the material to change color. Different protonation states induce color changes. They are more protonated in the acidic range than in the alkaline range. Depending on the number of transferred protons, one or more positive charges are added to the target molecule. As a result, because compounds change color when taking or releasing protons, the colorfulness may be attributed to distinct charge states at different pH levels.

### 2.3.3. Application of halochromic.

Wound healing, protective clothing, filtration, and other uses can all benefit from halochromic [26,31].

In wound healing, because natural processes are often impacted by pH, halochromic textiles can be utilized to offer information about the surrounding medium. During the healing of a wound, for example, the pH of the skin changes. Chronic wounds have a pH of 7.15–8.9, which has been measured. The pH of the wound rises from neutral to acidic as it heals. A pH of 4.0 to 6.0 is found on the typical skin surface. As a result, a pH-sensitive wound dressing may be used to track the progress of the healing process without having to remove it [29].

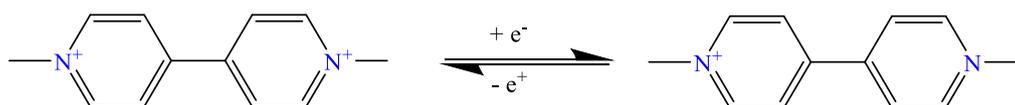
### 2.3.4. Hydrochromic dyes.

Solvatechromism is a phenomenon in which a substance's color changes when it comes into contact with a liquid, such as water. Solvent-chromic and aqua-chromic materials change color when water is exposed. This type of textile material may be utilized for various applications, including furniture covers, umbrellas, tablecloths, swimwear, sportswear, and clothing [27,32]. Hydrochromatic agents can be reversible or irreversible [32]: Irreversible ones come in various hues, including blue, black, red, yellow, and green. The chemical composition and absorption ranges of the substances are determined by the chemist; The reversible ones are the most frequent, and they usually change color from white to translucent (when wet) and then back to white when dry.

#### 2.4. Electrochromic dyes.

Electrochromic material undergoes a permanent but reversible color shift due to an electrochemical reaction known as electrochromism. An electric current can trigger electron transfer oxidation/reduction processes, which result in a reversible color shift known as electrochromism. The color transition is usually between a transparent ('bleached') and a colored state or between two colored states. When more than two redox states are electrochemically attainable, the electrochromic material can display many colors and is referred to as poly electrochromic or multicolor-electrochromism [24].

In general, inorganic-based electrochromic colorants and economically significant substances include tungsten oxide, metal phthalocyanines, and Prussian blue. Due to the partial reduction of Tungsten (VI) oxide to Tungsten(V) oxide at a cathode, pure tungsten oxide has a pale yellow hue that changes electrochemically to blue. Methyl viologen (Figure 9) is a well-known electrochromic colorant that is made up of colorless bipyridylium dication that may undergo a reduction process at a cathode to produce a blue radical cation. Other organic electrochromic colorants, such as 1,4-phenylenediamines and thiazines, are also available. Attention has also been drawn to the creation of electrochromic polymers such as polyanilines and polythiophenes. [10].



**Figure 9.** Electrochromic behavior of methyl viologen.

### 3. Conclusions

SMART materials that change color in response to one or more external stimuli have piqued scientists' curiosity, both academically and commercially. Chromic materials offer the potential for useful uses in high-performance textile-based sensing systems that change color visibly in response to external stimuli. Such textile sensors, for instance, release an early warning signal in response to ultraviolet light (photochromism), heat (thermochromism), pH (halochromism), and/or electric current (electrochromism).

#### Funding

This research received no external funding.

#### Acknowledgments

This research has no acknowledgment.

#### Conflicts of Interest

The authors declare no conflict of interest.

#### References

1. Pargai, D. Application of smart and functional dyes in textiles. In: *Dyes and Pigments*. IntechOpen: **2021**; <https://doi.org/10.5772/intechopen.96045>.
2. Farahani, M.; Shafiee, A. Wound healing: From passive to smart dressings. *Advanced Healthcare Materials* **2021**, *10*, <https://doi.org/10.1002/adhm.202100477>.

3. Fang, Y.; Chen, G.; Bick, M.; Chen, J. Smart textiles for personalized thermoregulation. *Chemical Society Reviews* **2021**, *50*, 9357-9374, <https://doi.org/10.1039/D1CS00003A>.
4. Ramlow, H.; Andrade, K.L.; Immich, A.P.S. Smart textiles: An overview of recent progress on chromic textiles. *J. Text. Inst.* **2021**, *112*, 152-171, <https://doi.org/10.1080/00405000.2020.1785071>.
5. Behera, A. *Advanced materials*. Springer Nature Switzerland AG **2022**; pp. 157-199.
6. Jeong, J.; Min, K.S.; Kumar, R.S.; Mergu, N.; Son, Y.-A. Synthesis of novel betaine dyes for multi chromic sensors. *Journal of Molecular Structure* **2019**, *1187*, 151-163, <https://doi.org/10.1016/j.molstruc.2019.03.074>.
7. Durasevic, V. Smart dyes for medical textiles. *Elsevier Ltd* **2016**, 19-55, <https://doi.org/10.1016/b978-1-78242-379-9.00002-5>.
8. Shahid, M.; Adivarekar, R. *Advances in functional finishing of textiles*. **2020**; <http://dx.doi.org/10.1007/978-981-15-3669-4>.
9. Gupta, V.K. Photochromic dyes for smart textiles. In: *Dyes and pigments-novel applications and waste treatment*. IntechOpen: **2021**; <https://doi.org/10.5772/intechopen.96055>.
10. Shahid, M.; Adivarekar, R. *Advances in functional finishing of textiles*. Springer Nature Singapore Pte Ltd **2020**.
11. Zhang, Y.; Hu, Z.; Xiang, H.; Zhai, G.; Zhu, M. Fabrication of visual textile temperature indicators based on reversible thermochromic fibers. *Dyes Pigm.* **2019**, *162*, 705-711, <https://doi.org/10.1016/j.dyepig.2018.11.007>.
12. Mohamed, M.; Abd El-AAty, M.; Moawaed, S.; Hashad, A.; Abdel-Aziz, E.; Othman, H.; Hassabo, A.G. Smart textiles via photochromic and thermochromic colorant. *J. Text. Color. Polym. Sci.* **2022**, *19*, <https://doi.org/10.21608/jtcps.2022.143466.1125>.
13. Abdellaoui, H.; Raji, M.; Chakchak, H.; Qaiss, A.E.K.; Bouhfid, R. Thermochromic composite materials: Synthesis, properties and applications. In: *Polymer nanocomposite-based smart materials*, Bouhfid, R.; Qaiss, A.E.K.; Jawaid, M., Eds. Woodhead Publishing: **2020**; pp 61-78, <https://doi.org/10.1016/b978-0-08-103013-4.00004-2>.
14. Aklujkar, P.S.; Kandasubramanian, B. A review of microencapsulated thermochromic coatings for sustainable building applications. *J. Coat. Technol. Res.* **2021**, *18*, 19-37, <https://doi.org/10.1007/s11998-020-00396-3>.
15. Zhao, Y.; Li, L. Colorimetric properties and application of temperature indicator thermochromic pigment for thermal woven textile. *Textile Research Journal* **2018**, *89*, 3098-3111, <https://doi.org/10.1177/0040517518805390>.
16. Chowdhury, M.A.; Butola, B.S.; Joshi, M. Application of thermochromic colorants on textiles: Temperature dependence of colorimetric properties. *Coloration Technology* **2013**, *129*, 232-237, <https://doi.org/10.1111/cote.12015>.
17. Tözüm, M.S.; Alay Aksoy, S.; Alkan, C. Manufacturing surface active shell and bisphenol a free thermochromic acrylic microcapsules for textile applications. *Int. J. Energ. Res.* **2020**, *45*, 7018-7037, <https://doi.org/10.1002/er.6287>.
18. Badour, Y.; Jubera, V.; Andron, I.; Frayret, C.; Gaudon, M. Photochromism in inorganic crystallised compounds. *Optical Materials: X* **2021**, *12*, <https://doi.org/10.1016/j.omx.2021.100110>.
19. Moretti, C.; Tao, X.; Koehl, L.; Koncar, V. Electrochromic textile displays for personal communication. **2016**, 539-568, <https://doi.org/10.1016/b978-0-08-100574-3.00024-2>.
20. Periyasamy, A.P.; Vikova, M.; Vik, M. A review of photochromism in textiles and its measurement. *Textile Progress* **2017**, *49*, 53-136, <https://doi.org/10.1080/00405167.2017.1305833>.
21. Morsümbül, S.; Akçakoca Kumbasar, E.P. Photochromic textile materials. *IOP Conference Series: Materials Science and Engineering* **2018**, *459*, <https://doi.org/10.1088/1757-899x/459/1/012053>.
22. Cheng, H.; Yoon, J.; Tian, H. Recent advances in the use of photochromic dyes for photocontrol in biomedicine. *Coord. Chem. Rev.* **2018**, *372*, 66-84, <https://doi.org/10.1016/j.ccr.2018.06.003>.
23. Yang, Y.; Li, M.; Fu, S. Screen-printed photochromic textiles with high fastness prepared by self-adhesive polymer latex particles. *Prog. Org. Coat.* **2021**, *158*, <https://doi.org/10.1016/j.porgcoat.2021.106348>.
24. Talvenmaa, P. Introduction to chromic materials. *The Textile Institute, CRC Press* **2006**, 193-205, <https://doi.org/10.1533/9781845691622.3.193>.
25. Qi, Y.; Fan, J.; Chang, Y.; Li, Y.; Bao, B.; Yan, B.; Li, H.; Cong, P. Smart photochromic fabric prepared via thiol-ene click chemistry for image information storage applications. *Dyes Pigm.* **2021**, *193*, <https://doi.org/10.1016/j.dyepig.2021.109507>.
26. Devarayan, K.; Kim, B.-S. Reversible and universal ph sensing cellulose nanofibers for health monitor. *Sensors and Actuators B: Chemical* **2015**, *209*, 281-286, <https://doi.org/10.1016/j.snb.2014.11.120>.
27. Atav, R.; Ergünay, U.; Akkuş, E. Producing garment based multichromic smart sensors through dyeing cotton fabrics with chromic dyes. *Cellulose* **2021**, *29*, 571-604, <https://doi.org/10.1007/s10570-021-04292-w>.
28. Taşar, Ş.; Özer, A. Production and characterization of hemicellulose-based halochromic gel pen. *Polymer Bulletin* **2021**, *78*, 6743-6760, <https://doi.org/10.1007/s00289-021-03779-7>.

29. Pakolpakçıl, A.; Osman, B.; Özer, E.T.; Şahan, Y.; Becerir, B.; Göktalay, G.; Karaca, E. Halochromic composite nanofibrous mat for wound healing monitoring. *Materials Research Express* **2020**, *6*, 1250-1253, <https://doi.org/10.1088/2053-1591/ab5dc1>.
30. Bilgin, M. Halochromic Composite Materials. In: *Encyclopedia of Materials: Composites*. Brabazon, D. Ed.; Elsevier: Oxford, **2021**; pp. 420-428, <https://doi.org/10.1016/b978-0-12-803581-8.11873-9>.
31. Van der Schueren, L.; de Clerck, K. Halochromic textile materials as innovative ph-sensors. **2012**, *80*, 47-52, <https://doi.org/10.4028/www.scientific.net/AST.80.47>.
32. Gauche, H.; Oliveira, F.R.; Merlini, C.; Hiller, A.P.; Souto, A.P.G.V.; Cabral, I.D.; Steffens, F. Screen printing of cotton fabric with hydrochromic paste: Evaluation of color uniformity, reversibility and fastness properties. *J. Nat. Fiber* **2020**, 1-12, <https://doi.org/10.1080/15440478.2020.1821288>.