Liquid Crystals in the Classroom

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Liquid crystal displays are a context for exploring many different physics phenomena. In the contribution few experiments related to liquid crystal displays are presented. The focus is on liquid crystals, its role in liquid crystal displays and on experiments that illustrate the key liquid crystals properties.

Introduction

Physics education community deals with the fact that there is lack of interest for studying physics [1,2]. The reason that school physics seems uninteresting, not useful and boring might be topics they meet are old [3]. An attempt was made to partly solve the problem with the introduction of interdisciplinary modern science contents into teaching of physics. When thinking about physics topics, which are interesting, related to daily life and enable students to identify the connection with current academic research and applied science liquid crystals immediately come to the front. Why to teach and learn about liquid crystals? Liquid crystals can be directly put into the context of liquid crystals displays, which students handle every day. Another important fact is that liquid crystals research field is active [4,5]. Liquid crystals are interdisciplinary topic intertwining chemistry, physics, computer sciences, biology, math, etc. Various experiments can be carried out with liquid crystals. The content of experiments covers aims from the curricula. One can also find number of publication about liquid crystals on different level of difficulties as some researchers, besides an academic research, try to present their work also to wider audience [4,5].

What are we staring at every day?

We cannot imagine life without laptops, ipods, mobile phones, etc. All those have something in common – the liquid crystal display (LCD). Have you ever observed the display through a drop of water on it? Try it. Water droplet acts like a lens and one can easily see pixels. Curiosity might leads us further to the question how does the LCD work. One can find explanation on web which is important source of information. If we write into *google* "LCD*" we get billion of hits. It seems that people have interest in LCDs. Since physics should present the bridge between physical innovations and applications as well as physical correct information physics teacher have to follow to the development.

If we simplify the LCD monitor has a power supply, an electronic circuit and a screen. Typical parts of LCD monitor screen are fluorescent lamp, light guide plate, first diffusive foil, prism foil, second diffusive foil and LCD panel with part of the electronics [6]. In the contribution we focus on LCD panel, more specifically on LCD picture element (pixel). Pixel has tree parts – red, blue, green. Each part of the pixel (the cell) is composed of crossed polarizers with twisted nematic liquid crystal between and colour filter (red, blue or green). In the described case the cell transmits light and the state is bright. When electric field is applied the electric dipole is induced in a nonpolar liquid crystals' molecules. Electric torque tends to arrange molecules in the direction parallel or perpendicular to the external field, depending on the molecular properties [7]. The greater the dipole is (at constant electric field) the greater is the torque and the consequent average rotation of molecule. The arrangement of molecules in cells used in displays is shown on Figure 1 [4,8].

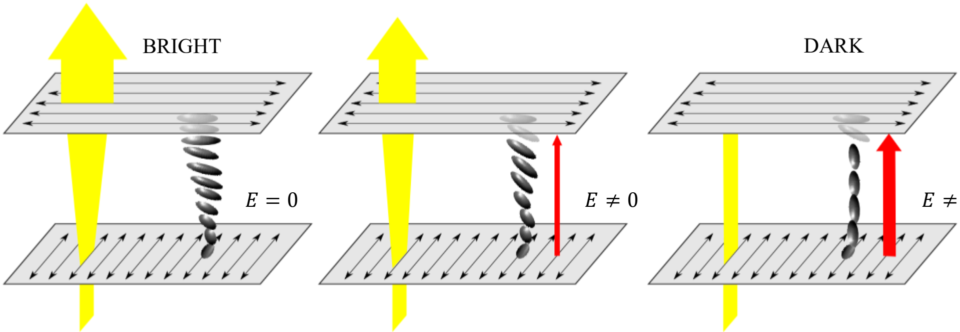

Figure 1: The arrangement of molecules in cells used for displays. (a) The 'bright state' is achieved without an applied electric field (the cell transmits light); (b) when voltage is applied to the two glass plates molecules rearrange and the cell partly transmits light; (c) the 'dark state' is achieved when high voltage is applied and molecules rearrange in the direction of E-field (the cell does not transmit light) [9]

Activities presented in continuation are related to exploration of LCD and to more detailed presentation of liquid crystals on qualitative level.

(1) Observing of LCD with USB microscope

We suggest that students explore the LCD screen by themselves by using USB microscope. Focus of students' attention is achieved by observing of figure with the primary and secondary colours and white. They find out why primary colours are primary and how the primary colours are combined into the secondary colours and white (Figure 2a). From observing few random parts of the screen it is seen that the pattern repeats. The smallest element of pattern is called pixel. It has three parts, one for each colour. From observations it can be also concluded that intensity of each part can be manipulated (Figure 2b).

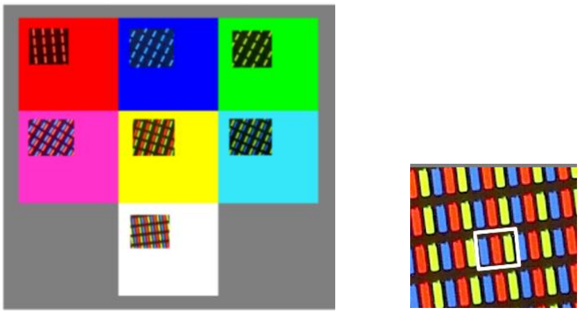

Figure 2. (a) Colour scheme for observing with USB microscope, on each colour is presented the image observed under the USB microscope; (b) Pixel

PowerPoint can be used for the preparation of colour scheme (Figure 3). Tasks for the students after observing the screen with USB microscope are (1) explore colours during setting different coloured backgrounds in PowerPoint and (2) find the area on the figure where the presented image seen under the USB microscope was taken (Figure 4).

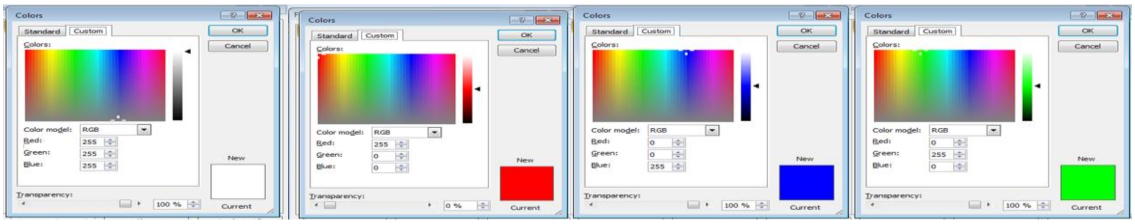

Figure 3. Settings for white, red, blue and green background in PowerPoint

Figure 4: (a) Part of the figure on the right under the USB microscope; (b) The observed figure; the presented part seen under the microscope is a border between magenta flower and orange background

(2) Showing the existence of liquid crystalline phase

Intensity of each part of the pixel can be manipulated. The substance which orientation is manipulated in LCD by electric field is a liquid crystal [10]. By name liquid crystals are meant materials that have at least one additional phase between liquid and solid. This phase is called the liquid crystalline phase and it has properties from both the liquid and crystalline phases: it flows like a liquid and it is anisotropic. Anisotropy is a property of crystals that physics properties differ in different directions [11,12]. In the most of the LCDs are used mixtures of nematic liquid crystals. Nematic phase has the simplest type of long-range ordering. Molecules in nematic phase are in general oriented in the same direction. The molecular order in the crystalline phase, the nematic liquid crystalline phase and in the isotropic liquid phase is shown schematically in Figure 5 [8].

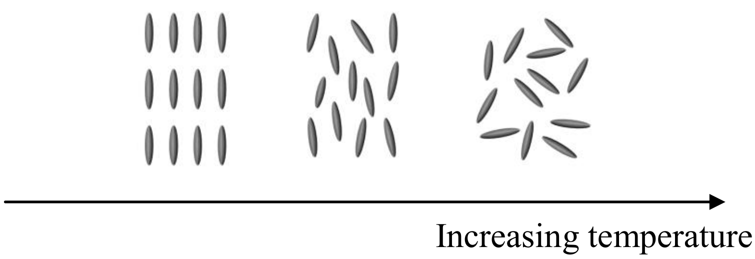

Figure 5. (a) Molecules of crystal have a long-range positional and orientational order; (b) In nematic phase exists some orientational order of long molecular axes; (c) Isotropic liquid

For getting experiences how liquid crystals look like in different phases students heat the test tube with liquid crystal in water bath, measure temperature and precisely observe what happens (Figure 6). When crystalline liquid crystal is heated it melts at the melting point and changes to liquid crystalline phase. An opaque liquid is observed. If the liquid crystal in the liquid crystalline phase is heated further the opaque liquid starts clearing and it becomes translucent at clearing point. The phase transition from liquid crystalline phase to isotropic liquid phase appears. When the temperature of liquid crystal is higher than the clearing point it is in an isotropic liquid phase.

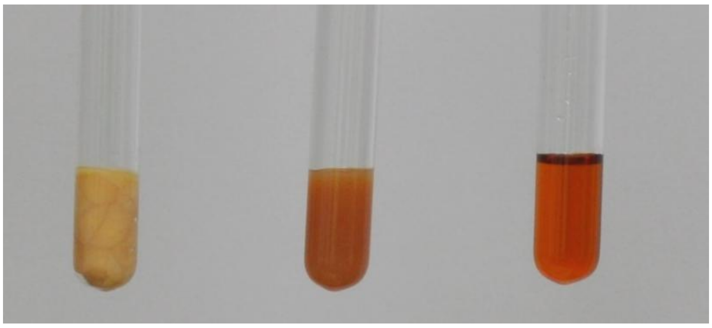

Figure 6. Liquid crystal MBBA in different phases: (a) Crystalline; (b) Liquid crystalline (nematic) and (c) Liquid. Liquid crystal MBBA has a melting point 20 °C and a clearing point 41 °C [13,14].

(3) Exploring how polarizers work

Light transmitted through the polarizer is linearly polarized. The polarizers are anisotropic since light polarized in certain direction is absorbed more than light polarized perpendicular to this direction. Two polarizers with perpendicular transmission directions do not transmit light and for parallel do. Optical anisotropic material placed between two crossed polarizers transmits light [15,16].

Students use two polarizers and compare the transmitted intensity of light as a function of the angle between the polarizer axes (Figure 7).With one polarizer students also check whether light from the screen is polarized (Figure 8). They put a drop of liquid crystal MBBA between two crossed polarizers and observe the behaviour of anisotropic material, as liquid crystals are, between (Figure 9).

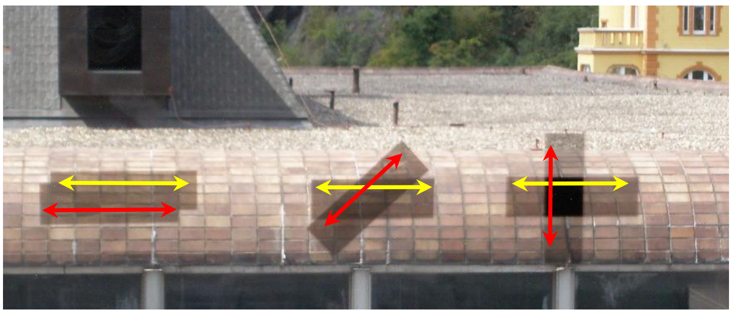

Figure 7. The intensity of transmitted light in dependence of the angle between the polarizer axes. Polarizers do not transmit light if the axes of the polarizers are perpendicular.

Figure 8. Different position of the polarizer on the screen. One can conclude that light from the screen is polarized.

Figure 9. (a) A drop of liquid crystal MBBA (anisotropic) and (b) a drop of water (isotropic) between two polarizers with perpendicular polarizer axes [10]

(5) Mechanical ordering of liquid crystals' molecules

Ordering of liquid crystals' molecules on polymeric and other surfaces is important technologic procedure at manufacturing LCDs. Surfaces applied with polymer are rubbed. Molecules orient with their long axes parallel to the surface in the rubbing direction. The quality of ordering can be observed under the polarizing microscope [4].

Students fabricate a planar cell (Figure 10). They rub the microscope slide with velvet. After the rubbing of microscope slide a drop of liquid crystal is put on it and covered with a cover glass. The fabricated cell is placed the between two crossed polarizer. Students observe it under the microscope.

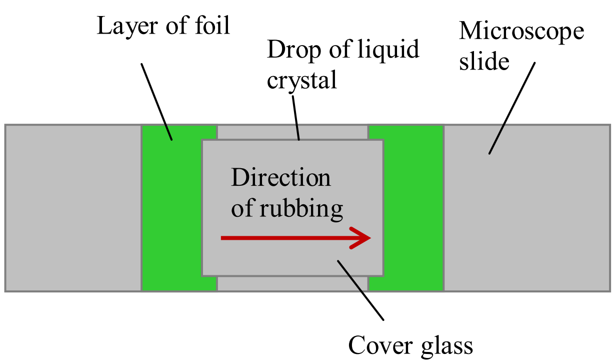

Figure 10. Schematic presentation of the planar cell

(6) Illustrating anisotropy of liquid crystals – double refraction

Liquid crystals are birefringent. The most easily observed and striking optical property of transparent birefringent materials is a double refraction. The double refraction is usually demonstrated by observing the doubling of a text observed through the calcite [16]. When a polarizer is placed behind the calcite (or in front of it), one of the figures disappear if the polarizer's transmission direction coincides with the polarization of the transmitted light. By using a wedge liquid crystalline cell one can carry a more straightforward experiment which demonstrates the splitting of the unpolarised incident light ray into two rays of linearly polarized light [18].

Students direct laser pointer light on the wedge liquid crystalline cell and find the area of the cell where the laser beam splits into two beams (figure 11). The verification of light polarization in the two beams is done by rotating the polarizer between the cell and the distant screen.

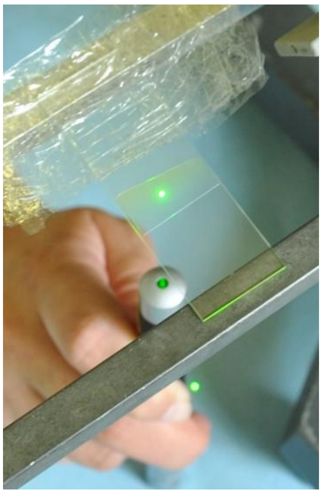

Figure 11: Experimental setup for demonstrating the double refraction

Conclusion

The article briefly describes the experiments which help students assimilate concepts related to liquid crystals in context of liquid crystal displays. During the experimental work students gather experiences with liquid crystals, liquid crystal displays, USB microscope, polarizers and the liquid crystalline cells.

Acknowledgment

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