Ivan ČERNUŠÁK - Danica ČERNUŠÁKOVÁ

NARRATION ABOUT COLOUR:
Indigo story *

Oh, what do you know about living in Turbulent Indigo?*

Colours. For the majority of us they are life-long companions. Modern man perceives colours as self-evident fact and only rarely asks the question: Where do they come from? In the past, only natural dyes were part of our colourful world. Today, many of colours around us are synthetic or "electronic". This is very short story about one of the them. Story of the colour that is probably as old as the human civilization. Indigo.

Botany, beauty and craft

Nature is multicoloured during the whole year. All these colours have plethora of functions – to attract the attention, to hide or to distinguish from the environment, sometimes also to threaten. Colour of the body is certainly important in animal world, e.g., it can help to attract the opposite sex. In the plant kingdom the multi coloured flowers draw attention of the insects.

In both cases it is important for the preservation of the species. In this context, man has not detached himself from the nature, one can hardly imagine that we would wear the clothes of the same colour. In the society, colour played significant role because it often distinguished people from different social background.

Ancient people in neolithic age coloured their dress with natural dyes obtained from various plants. A large variety of plants were used in the past for colouring textiles, leather or hair.

Some of them are quite common also nowadays: onion shell, walnut leaves, bark of yew-tree, berries of elder or blueberry, flowers of Klamath weed, but also the whole plants, e.g. mignonette, sorrel and many others. Only few plants were cultivated for use in colour industry in the past.

Figure 1

Probably one of the oldest dye plant used for colouring fabrics was Indigofera tinctoria (Figure 1), source of dark-blue dye indigo. Today we know up to 350 different indigo plants. One large group that comes from tropical Africa belongs to the Fabacae family. These plants have pinnate leaves and long clusters of red or purple flowers.

Figure 2

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** Joni Mittchel, TURBULENT INDIGO, 1994, Reprise Records.

In temperate climate (central Europe, Mediterranean and Mid-East Asia) it was Isatis tinctoria (Figure 2), from family Brassicaceae, that served as a source of indigo dye. In east Asia, Polygonum tinctorium (Figure 3) from family Polygonaceae, also known as japanese indigo, was used for indigo production. The dye was obtained from the leaves of these plants1. Leaves were cut and stored in water in big tanks. The subsequent hydrolysis took 10-15 hours. Key part of this process was the decomposition of the glycoside indican, contained in these plants, into sugar compo-nent and indoxyle. After its oxidization the beautiful blue dye is produced.

Figure 3

Physics – waves and colours

Historically, the first decomposition of the white light to its component colours is attributed to Isaac Newton, but people observed the relation between rainbow and light or light effects during sunrise/sunset, long time before.

White light emerges from *additive* mixing of three primary colours (shining three primary colored lights on a white surface), opposite process is the decomposition of the light passing through prism. Similarly, additive mixing of one primary colour and one component colour gives also white, like do blue and yellow. Subtractive mixing takes place when colour media (e.g., paints or inks) absorb certain colours. Any colour that is not absorbed (subtracted) from the light reflected off the mixture gives the mixedcolour that we see. For instance, blue filter contains material that suppresses partially green and fully red components while enhancing blue one. This type of mixing is present in colour grains (miniature colour filters) on painter's palette and is accompanied by the diffuse picture that we percept. For example, if the light passes through many red and yellow grains in the mixture, they enhance red and yellow. As a results, we see orange.

Chemistry – molecules and orbitals

Molecule are composed of atoms. For our story it suffices to say that building blocks of atoms are nuclei and electrons. The latter sit in molecules at well defined energy levels called shells. Why there is that well defined? Because the world of atoms and due to its "wave/corpuscular" duality it is distributed in quanta. Their energy is product of Planck's constant and frequency of the radiation, e=hn . For the visible light the range of frequencies corresponds to wave lengths from 400 to 780 nm. Only appropriate quanta can stimulate electronic transitions between molecular energy levels. These processes are very fast and usually are limited to small region in the molecule, e.g., group of atoms or even just the bond between two atoms. This entity is called chromophore.

When the molecule's chromophore absorbs energy quantum, certain wavelengths disappear from the spectrum, so originally white light becomes coloured because of changes in additive mixing. Some chemical substances, like many organic molecules present in plants, or transition-metal containing inorganic salts posses beautiful colour because they absorb light in visible part of the spectrum. How does it work for the molecule of indigo (Figure 4)?[2-4]

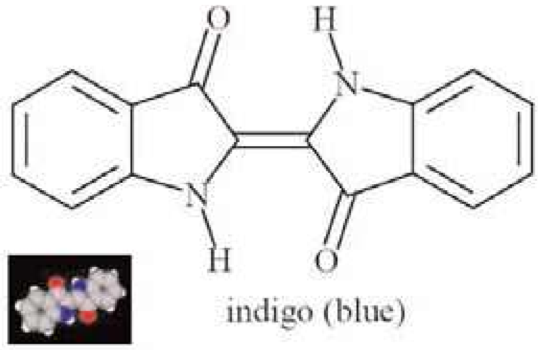
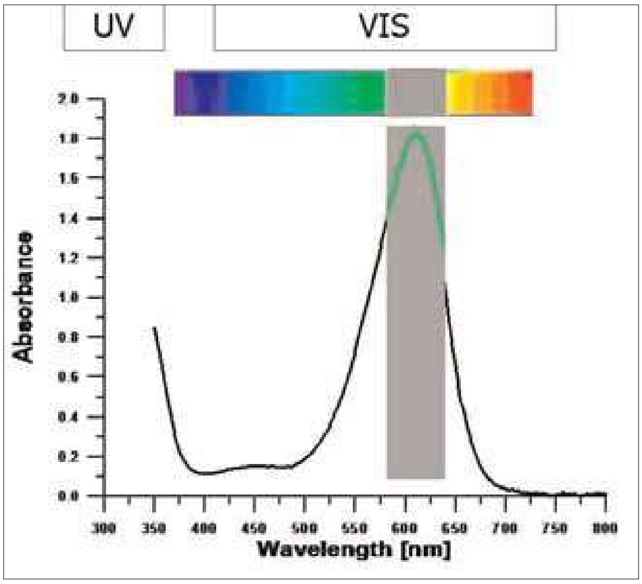


Figure 4

The lowest electronic transition observed in indigo dye spectrum corresponds to peak around 620 nm (Figure 5). If we convert this wavelength to energy scale, it is 2 eV. Translated to layman terms,

Figure 5



this wavelength has “yellow/orange colour” and its component colour is exactly the beautiful indigo blue. This the colour of jeans or of popular folk textile *blue-and-white.*

We can visualize this electronic transition also on molecular level, using quantum chemistry concepts - highest occupied molecular orbital (HOMO, Figure 6a) and lowest unoccupied molecular orbital (LUMO, Figure 6b) of indigo molecule. From the electronic transition’s standpoint, the central part of the structure is the most important region of the molecule.

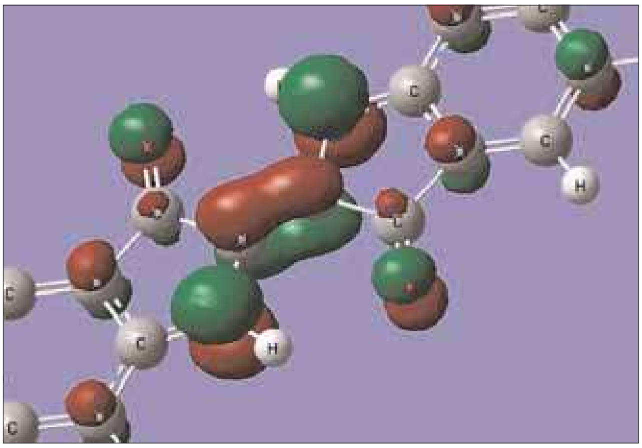
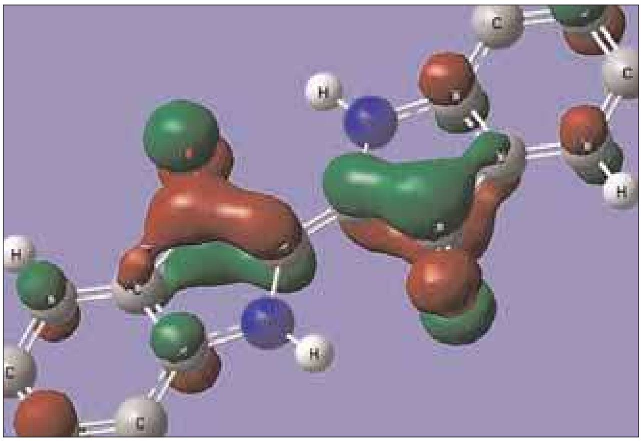


Figure 6 a

Figure 6 b



We have mentioned chromophore when talking about the spectra. In fact, it is possible to reduce the complex physical phenomenon large organic molecule - indigo to just very simple model with minimum number of atoms. This is the essence of molecular modelling (Figure 7). It can give us the right answer for the right reason despite significant reduction of the quantum chemical model we are using for the explanation of the observed spectrum. In chemistry and physics, with the aid of molecular modelling we are able to visualize highly abstract ideas and concepts in a very instructive manner, often with startling effects.

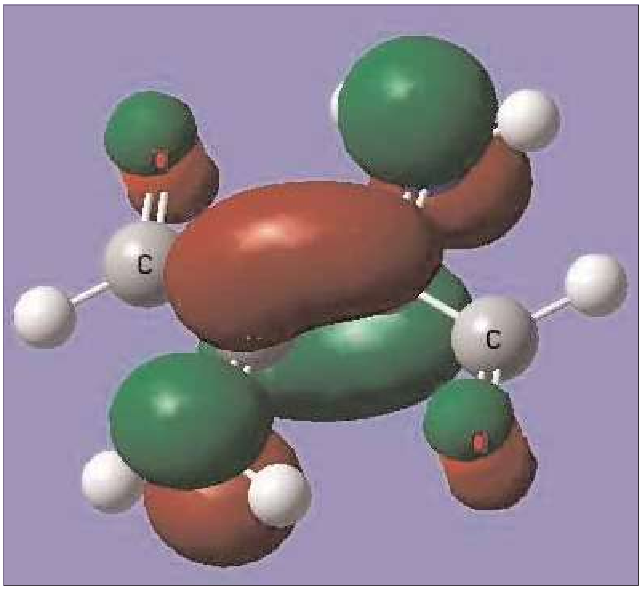
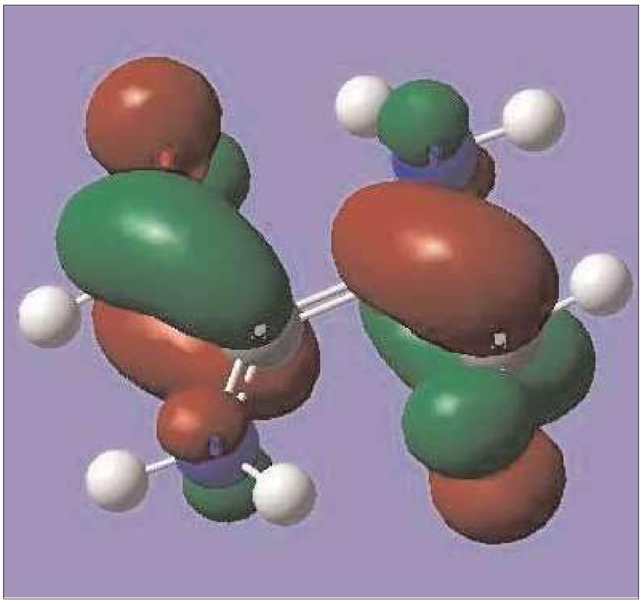


Figure 7 a

Figure 7 b



Seemingly boring science brings sometimes surprise of simplicity and beauty.

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Figure captions

Figure 1 Indigofera tinctoria
Figure 2 Isatis tinctoria
Figure 3 Polygonum tinctorium
Figure 4 Molecular models of indigo. Top – chemical structure, lower left inset – overlapping van der Waals spheres.
Figure 5 Observed electron spectrum of indigo in near-ultraviolet and visible region.
Figure 6 Models of: a) highest occupied molecular orbital (HOMO), b) lowest unoccupied molecular orbital (LUMO) of indigo molecule.
Figure 7 Models of: a) highest occupied molecular orbital (HOMO), b) lowest unoccupied molecular orbital (LUMO) of indigo chromophore.