COLOURS IN OUR LIFE : FROM AESTHETICS TO FUNCTIONS
Society of Dyers and Colourists, India
Decennial Celebrations, Mumbai, July 28, 2016

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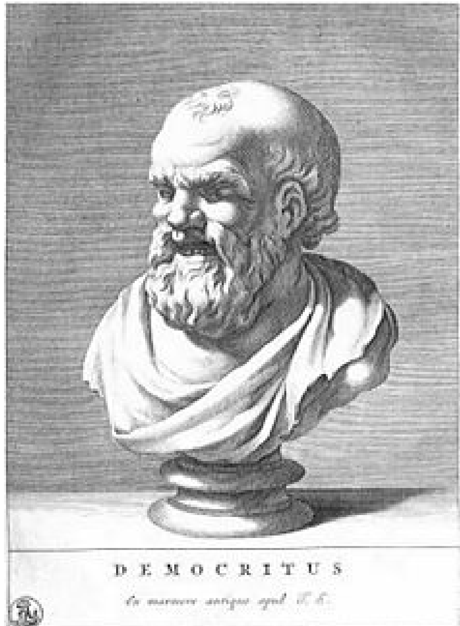
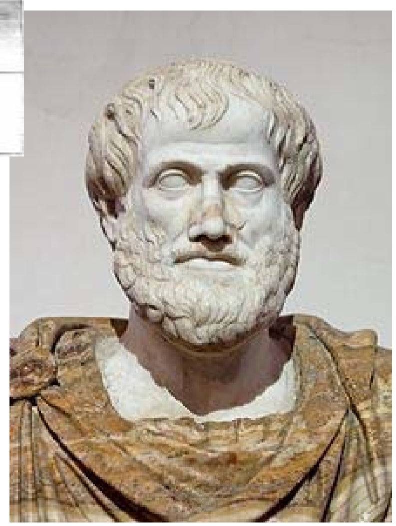
COLOURS HAVE FASCINATED HUMANS FROM TIME IMMEMORIAL



Democritus
470-370 BCE



Aristotle
384-322 BCE

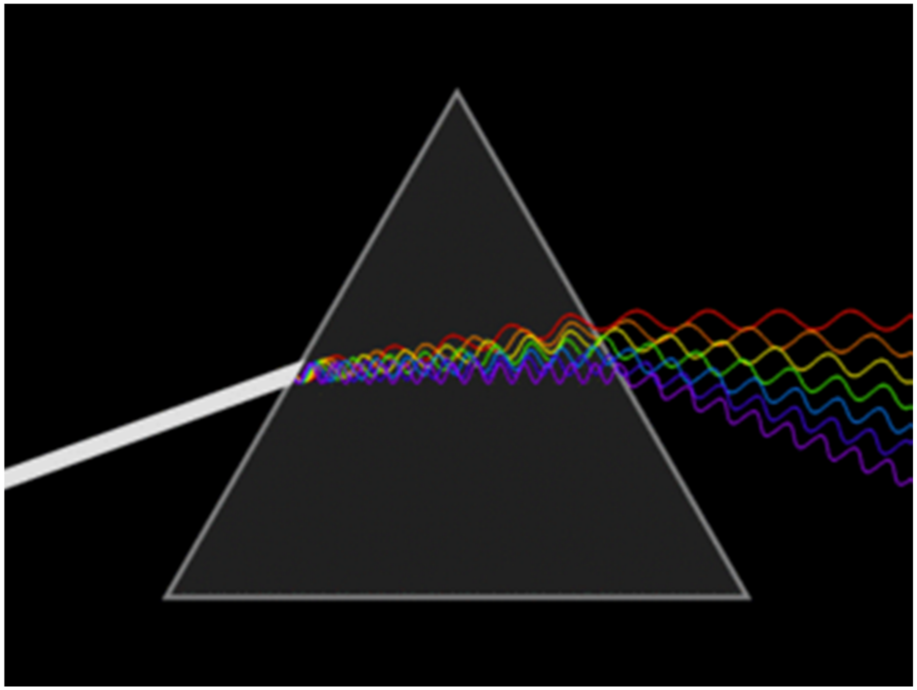
Egypt circa 1000 BCE

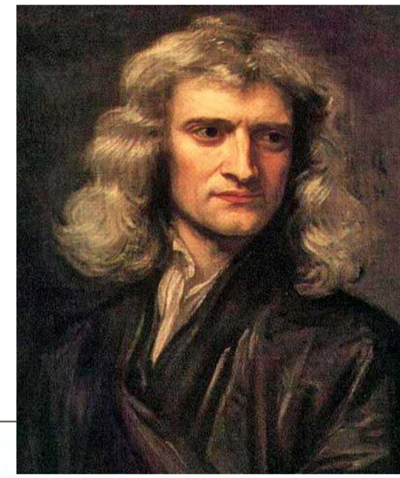
Pliny the Elder
23-79 CE

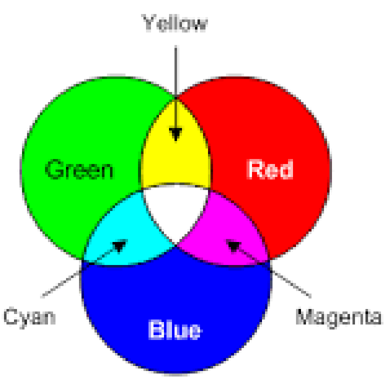
THE CAVE PAINTINGS OF AJANTA
200 BCE TO 500 CE

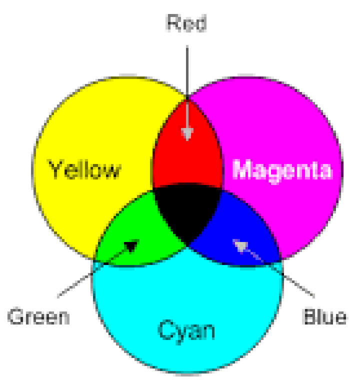
Highly refined pigments, all water soluble, were developed based on Kaolin, lamp black, Glauconite (green), ochre (yellow) and lapis lazuli (blue)

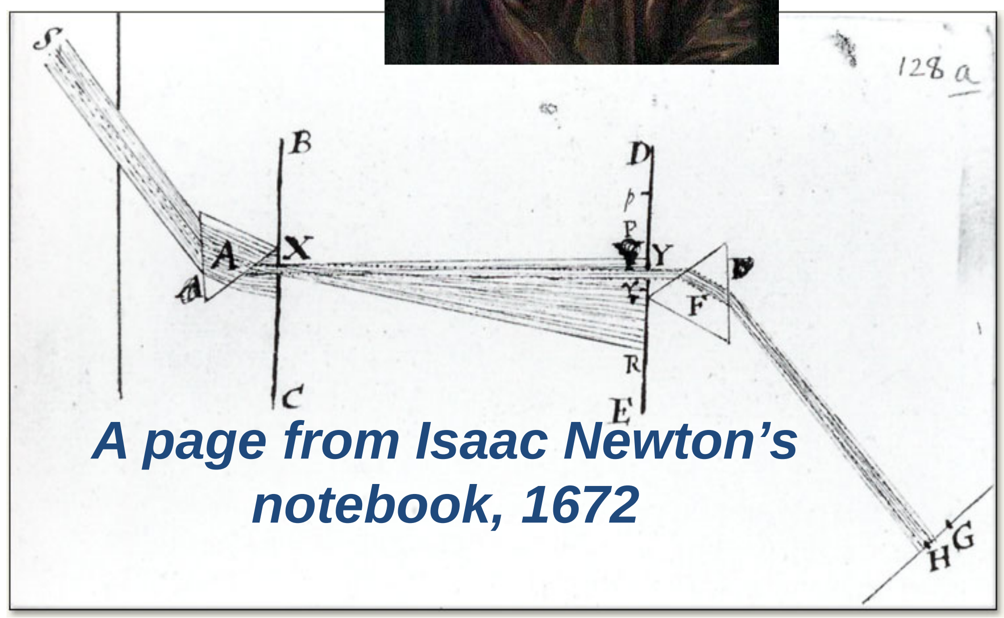
Colour results when light interacts with matter





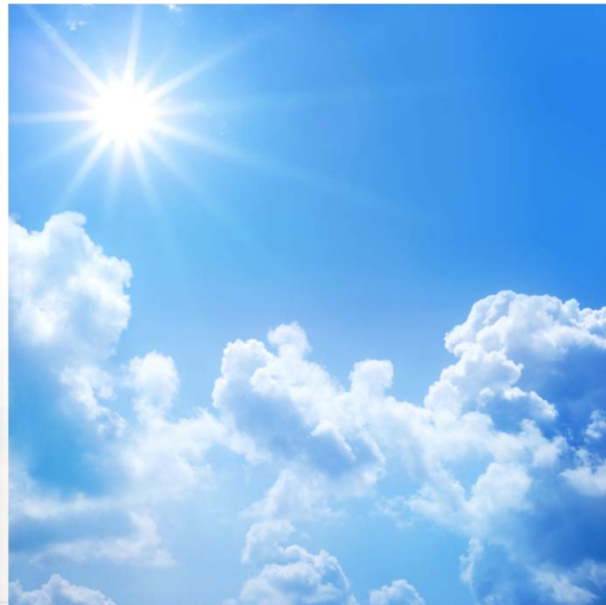


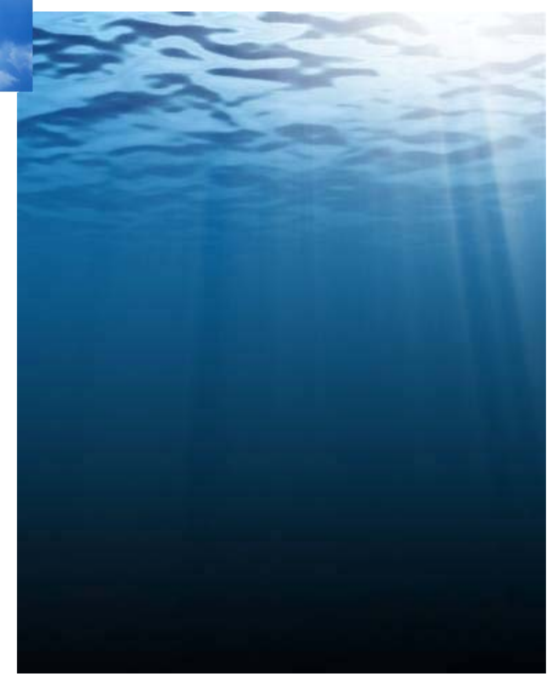


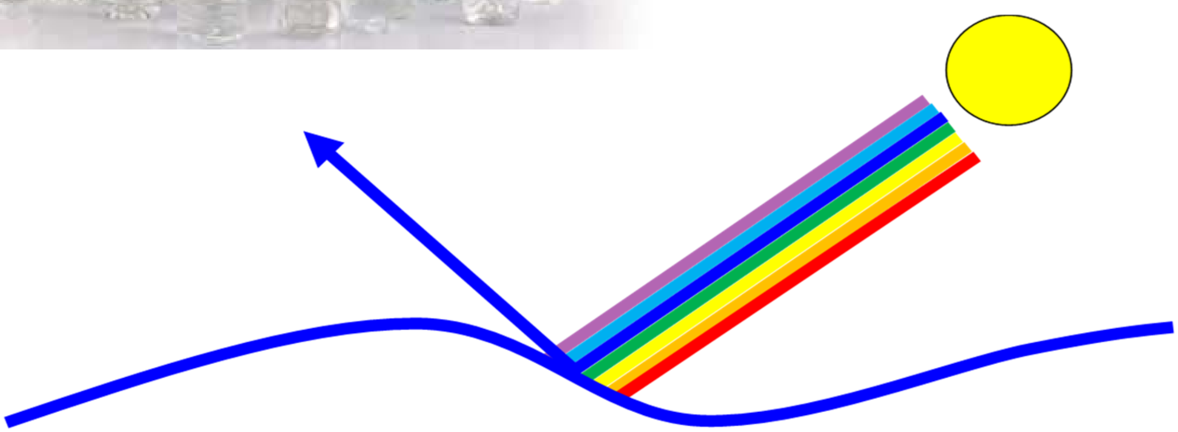


A page from Isaac Newton's notebook, 1672

WHY ARE THE OCEAN AND SKY BLUE AND WATER COLORLESS ?



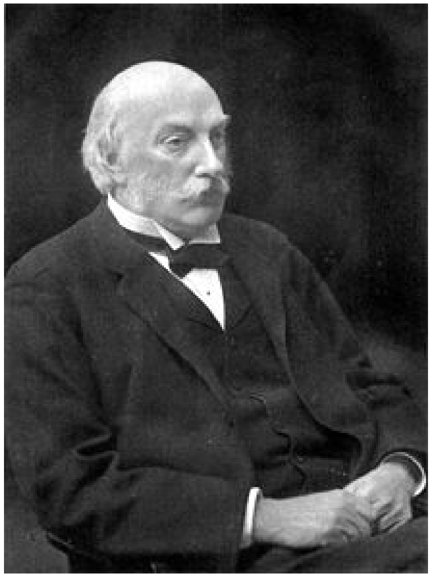




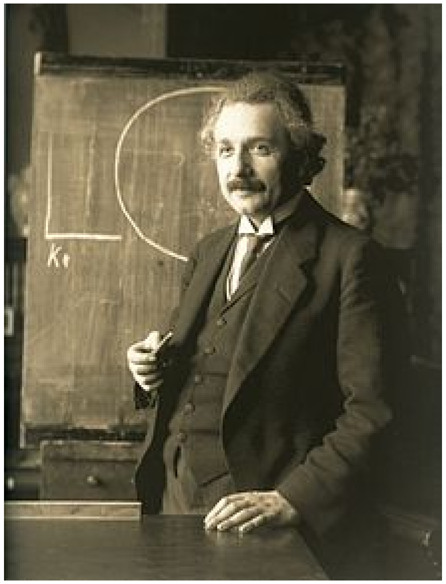
WHY DO THE SKY AND SEA APPEAR BLUE ?

- Of the colours in the visible spectrum of light, blue has a very short wavelength, while red has the longest wavelength. When sunlight passes through the atmosphere, the blue wavelengths are scattered more widely by the oxygen and nitrogen molecules, and more blue comes to our eyes. This effect is called Rayleigh scattering after Lord Rayleigh, the British physicist who discovered it. It was confirmed by Albert Einstein in 1911
- Near sunrise and sunset, most of the light we see comes in nearly tangent to the Earth's surface, so that the light's path through the atmosphere is so long that much of the blue and even green light is scattered out, leaving the sun rays and the clouds it illuminates red. Therefore, when looking at the sunset and sunrise, you will see the colour red more than any of the other colours
- The sea is seen as blue for largely the same reason: the water absorbs the longer wavelengths of red and reflects and scatters the blue, which comes to the eye of the viewer. The colour of the sea is also affected by the colour of the sky, reflected by particles in the water; and by algae and plant life in the water, which can make it look green; or by sediment, which can make it look brown

THE SCIENCE BEHIND COLORS : ABSORPTION AND SCATTERING OF LIGHT



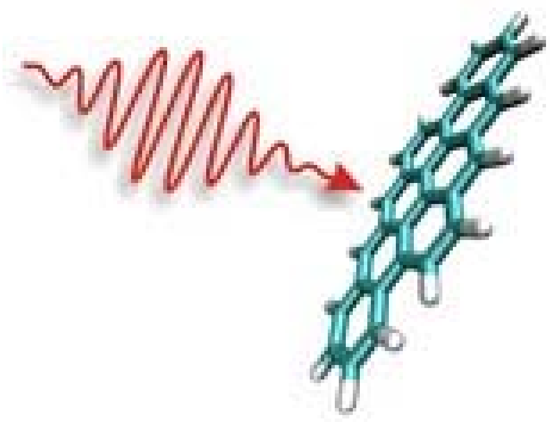
Lord Rayleigh
1842-1919
NL 1904

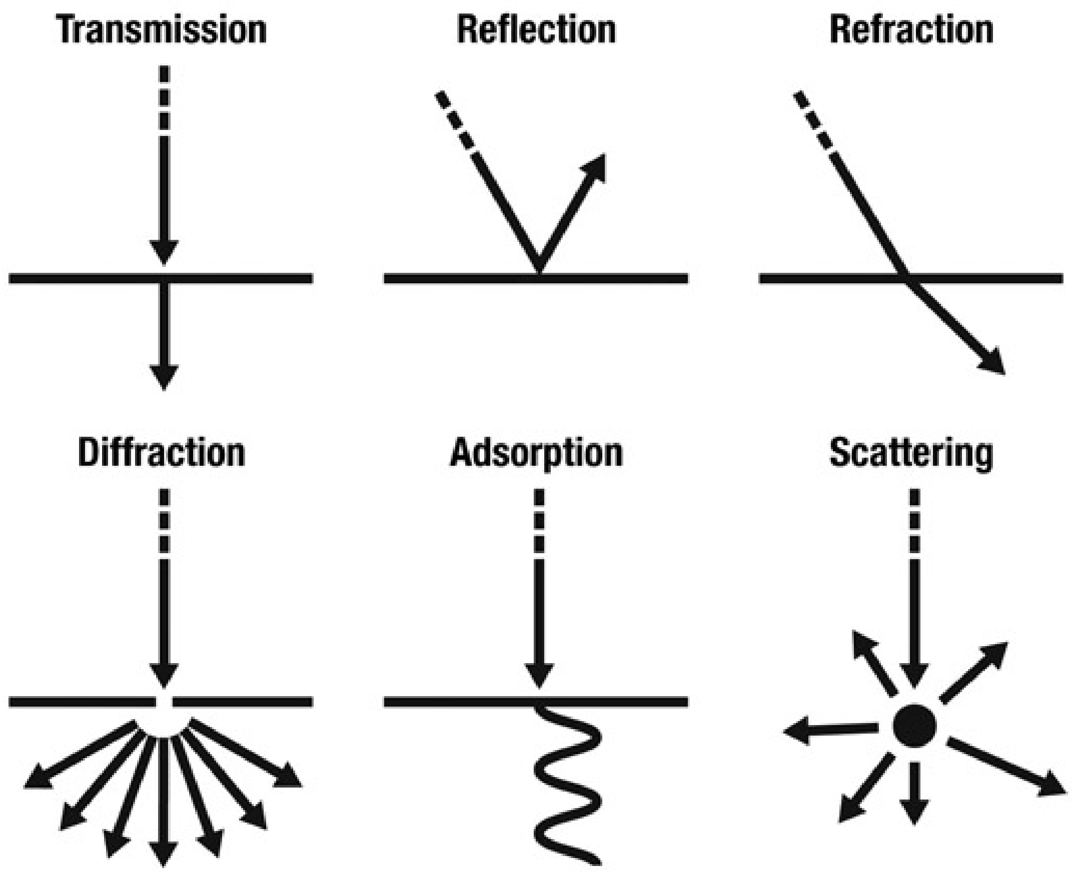


Albert Einstein
1879-1955
NL 1921

C.V.Raman
1888-1970
NL 1930

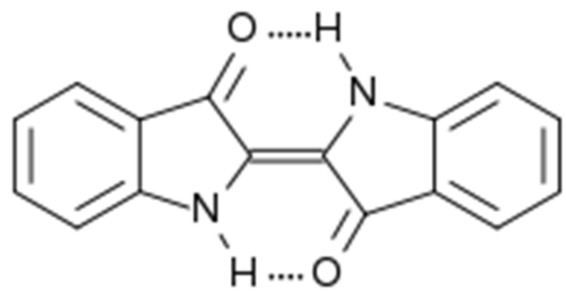
ORIGIN OF COLOURS : INTERACTION OF LIGHT WITH MATTER



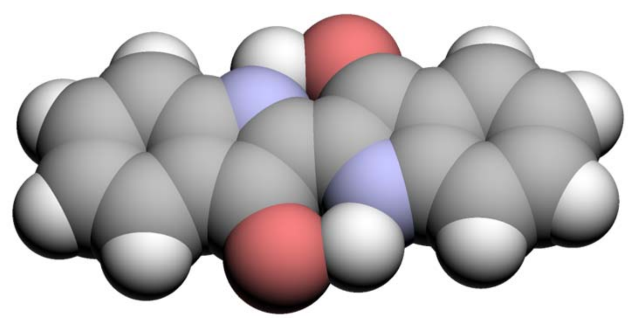


BEGINNING OF INDUSTRIAL CHEMISTRY : THE INDIGO SYNTHESIS

Adolf von Baeyer (1835-1917)

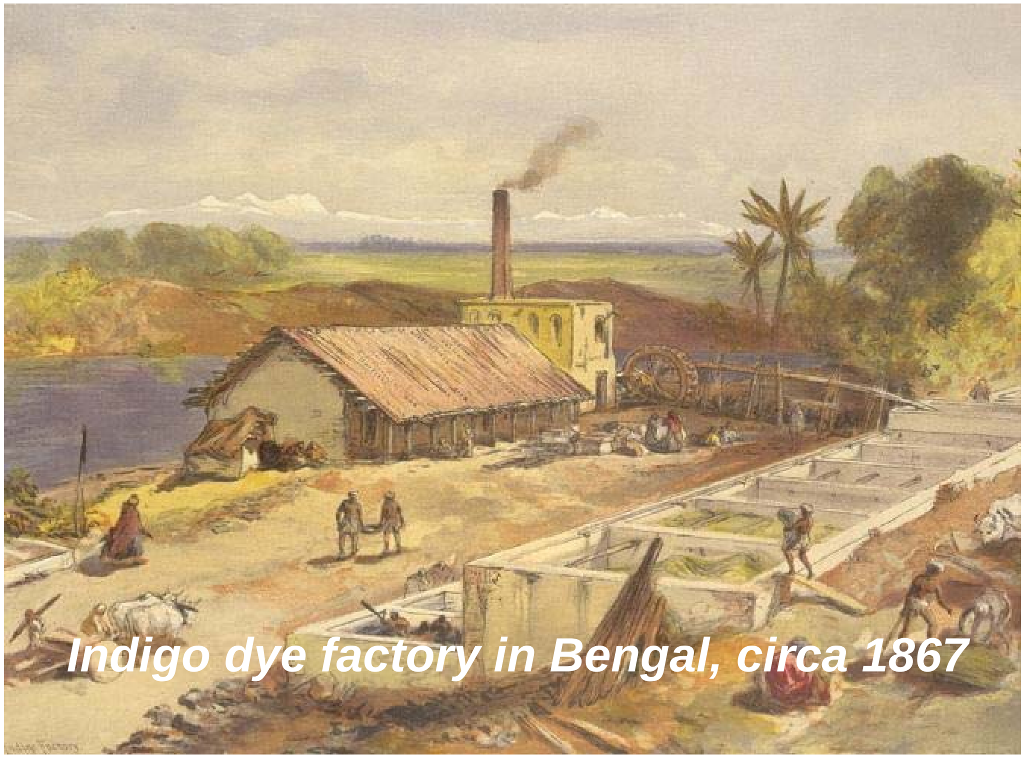


Synthesis of a plant derived natural product, from Isatin and 2- nitrobenzaldehyde (1878-80)

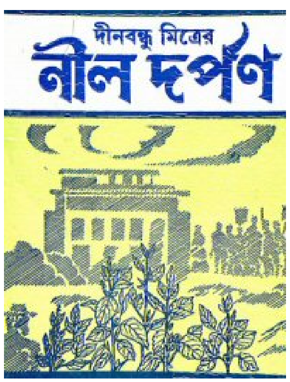


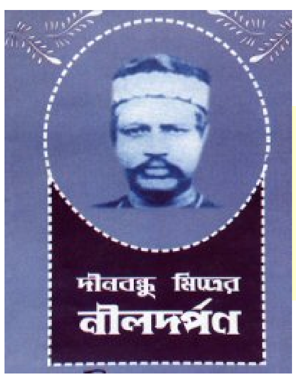
Nobel Prize , 1905

THE DAWN OF THE CHEMICAL INDUSTRY: THE BENGAL CONNECTION



Indigo dye factory in Bengal, circa 1867





Nil Darpan by Dinabandhu Mitra (1860)

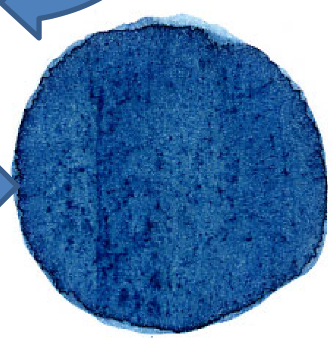
- Indigo plantation in Bengal dates back to 1777
- The Indigo Riots (Nil Bidroho) began in Nadia in 1859, an uprising of the farmers against the exploitation by the planters and later spread to Champaran in Bihar in 1868
- There was an anger against the British traders, fresh after the Sepoy Mutiny of 1857
- Regarded as the first non violent passive resistance in Indian history
- India's exports of over 20,000 tons of Indigo to Europe ceases; by 1914 synthetic Indigo completely replaces natural Indigo

THE DAWN OF THE CHEMICAL INDUSTRY: THE MANUFACTURE OF INDIGO

BASF commences manufacture of synthetic Indigo (1897)

BASF develops a more economic route based on N-2-carboxyphenyl glycine, derived from aniline, which had become just then available from coal tar distillation

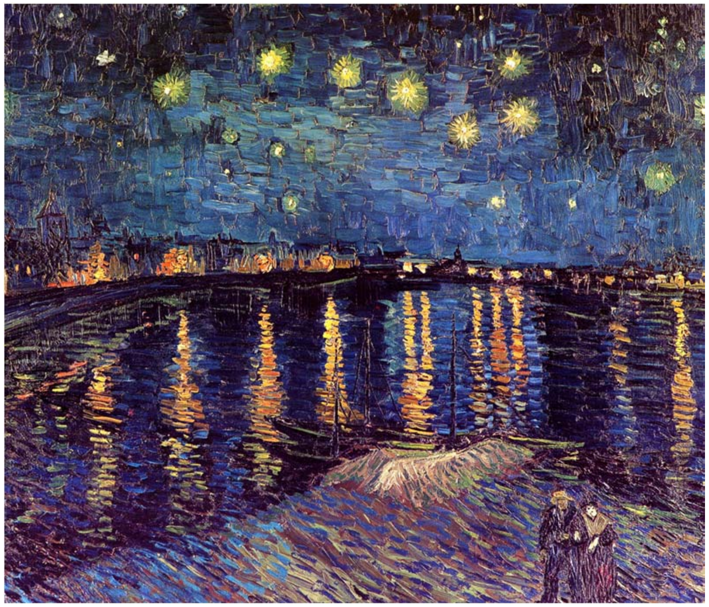
Indigofera Tinctoria



Indigo dye

Blue denim

BLUE IN ART



Van Gogh
Cobalt Blue
1880

Bellini, 1480
Ultramarine Blue

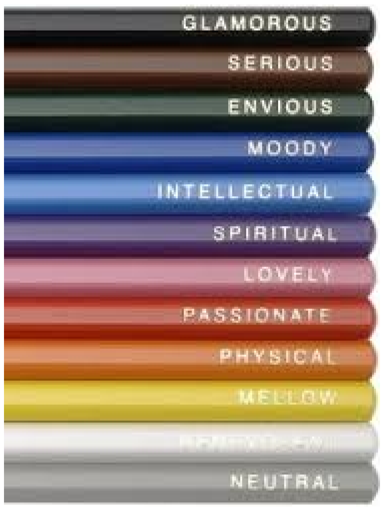
Prussian Blue

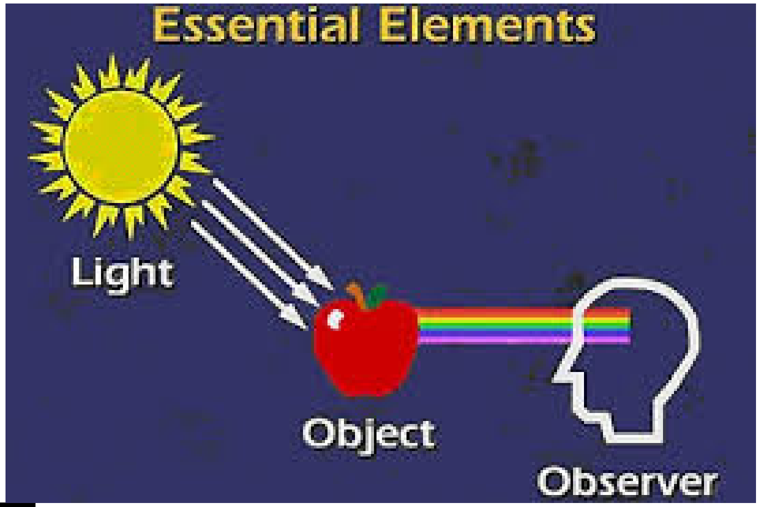
SCIENCE LEADING ART: NINETEENTH CENTURY PAINTING

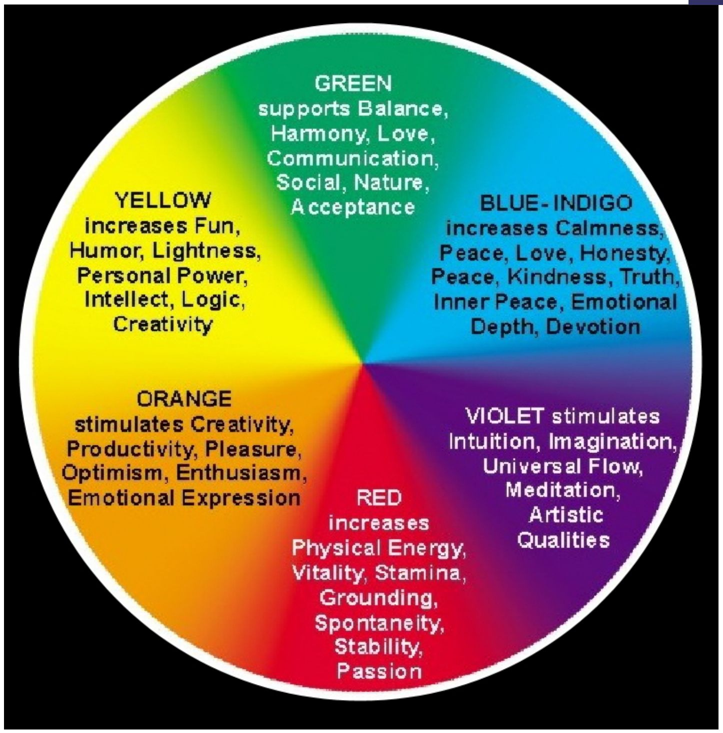
Van Gogh, 1890
Cobalt Blue

Renoir, 1881
Ultramarine blue

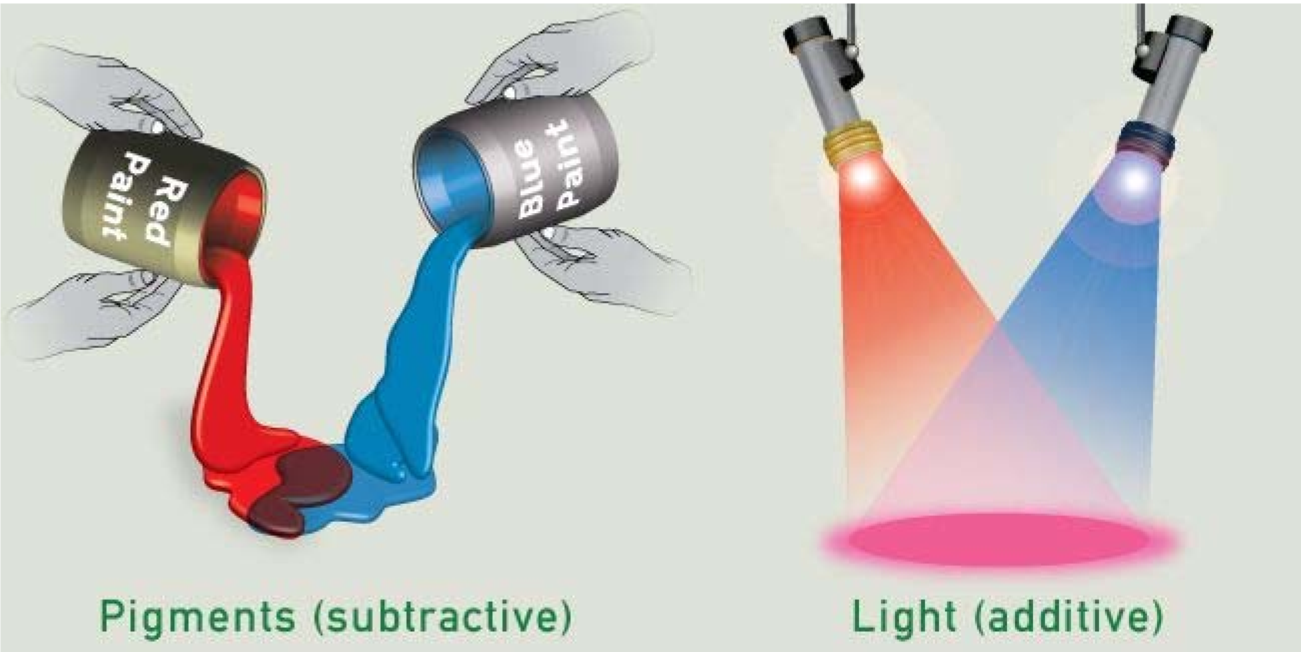
COLOURS AND MOODS







DIFFERENCE BETWEEN PIGMENTS AND LIGHT



THE EXPANDING WORLD OF COLOUR APPLICATIONS

- Textile (natural and synthetic) : Dyes
- Surface Coatings : Surface protection, texture, decor
- Foods and pharmaceuticals : organic colourants
- Display and lighting systems : OLED materials
- Energy harvesting devices(Solar Cells) : Light absorption
- Printing Inks (ink jet, laser)
- Biomedical and imaging applications

DYES AND COLOURS

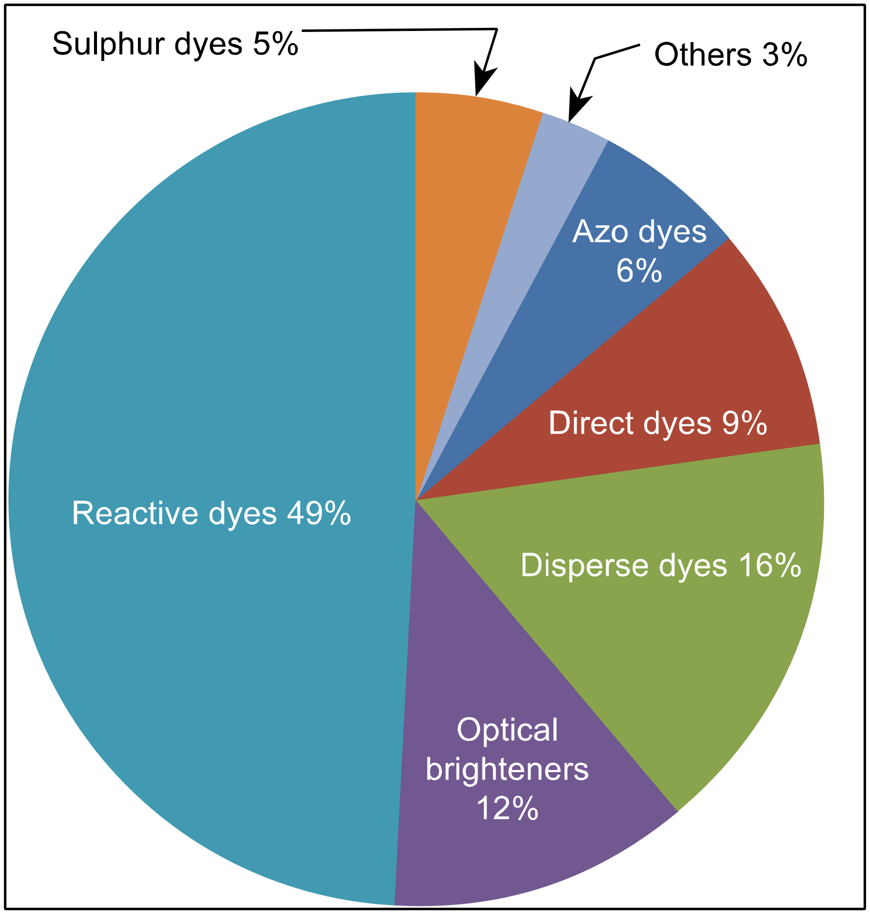


Fig. 2: Production of dyes [FY15: 184-kt]

US $ 4 billion (2012)
Expected to double by 2020
Domestic market : 60 % textiles
Export: reactive dyes : 60%; organic colours : 13 %, OBA : 13 %

Industry fragmented; R&D intensity low

Challenges
Raw Material availability and environmental issues

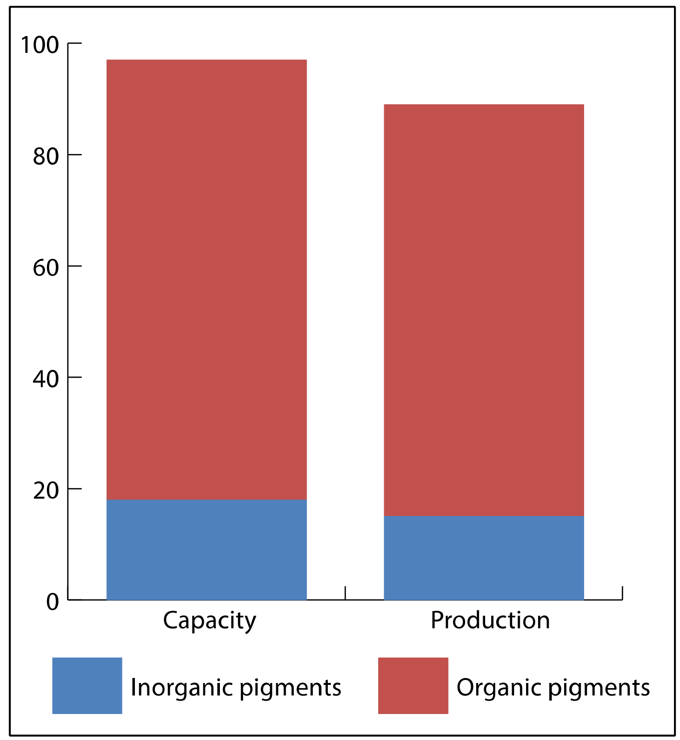


Fig. 3: Capacity & production for pigments, ktpa [FY15]

Chem. Weekly, May 31, 2016

ORGANIC COLOURS : CAROTENOIDS

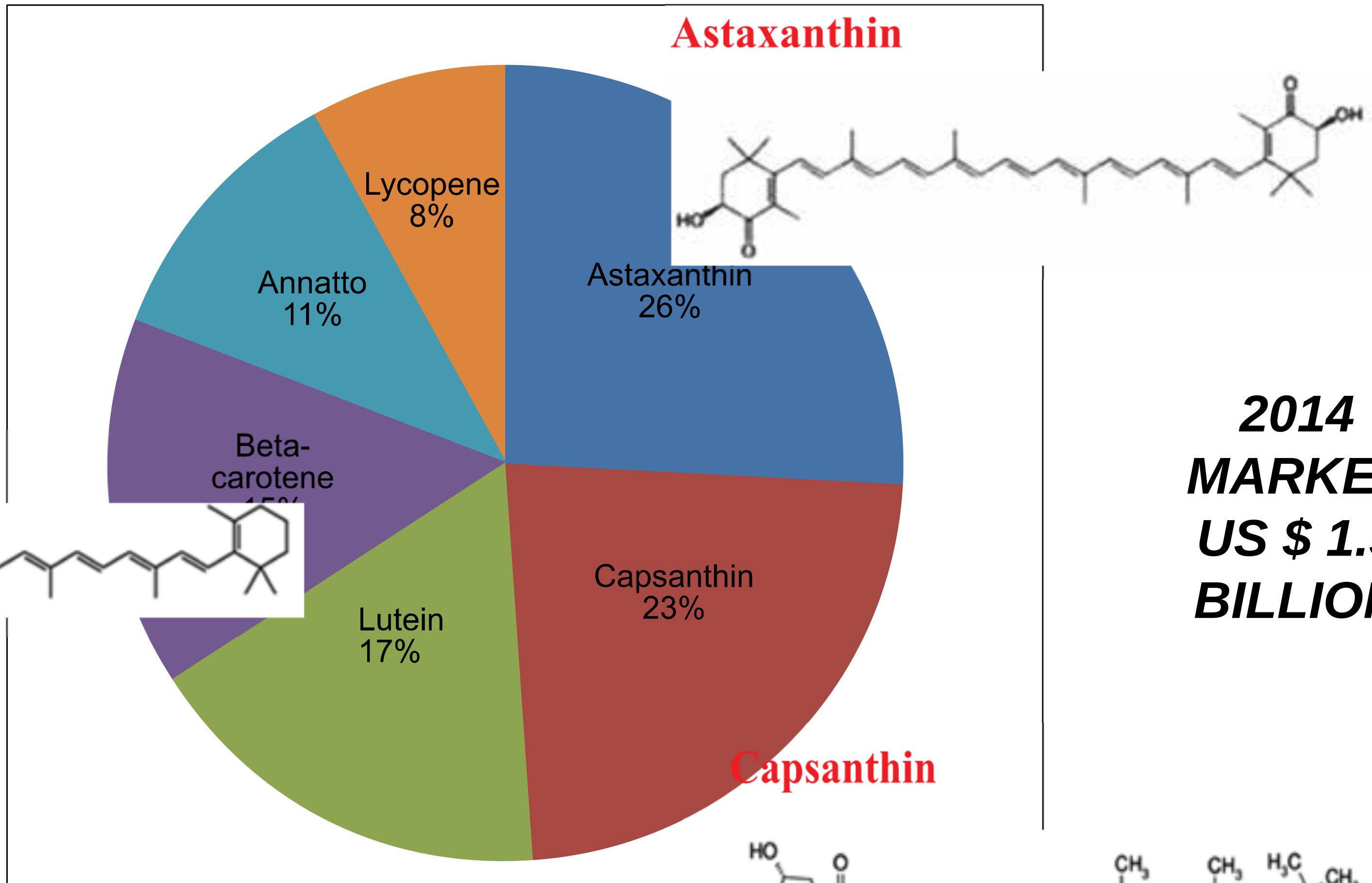
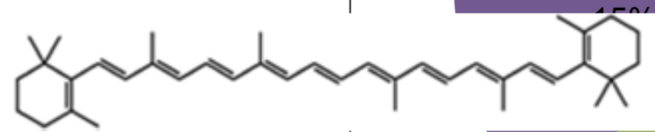


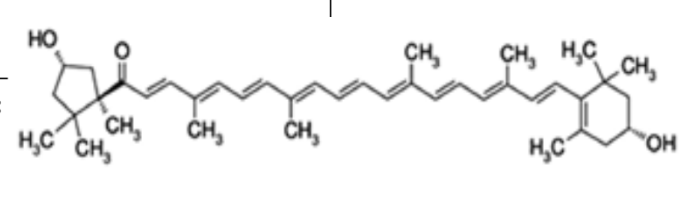
Fig. 1: Global market for carotenoids (2019):

Astaxanthin

Beta-carotene



Capsanthin

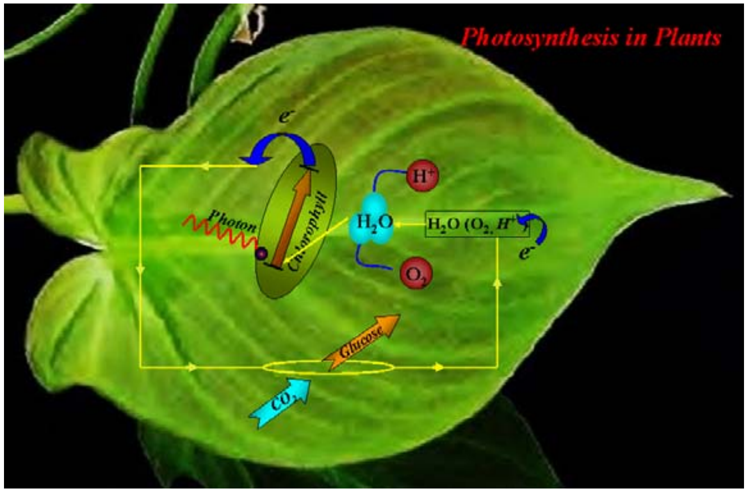


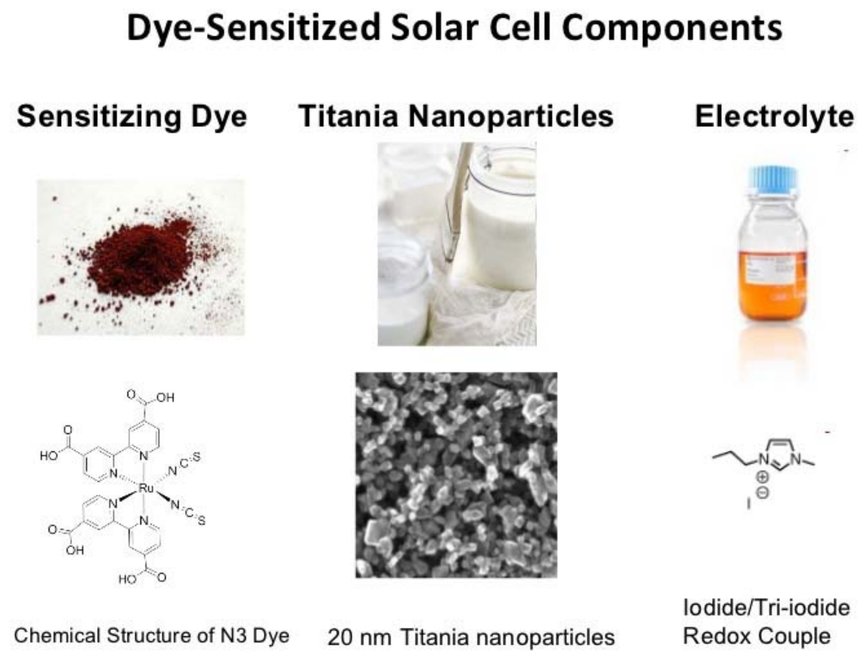
2014 MARKET US $ 1.5 BILLION

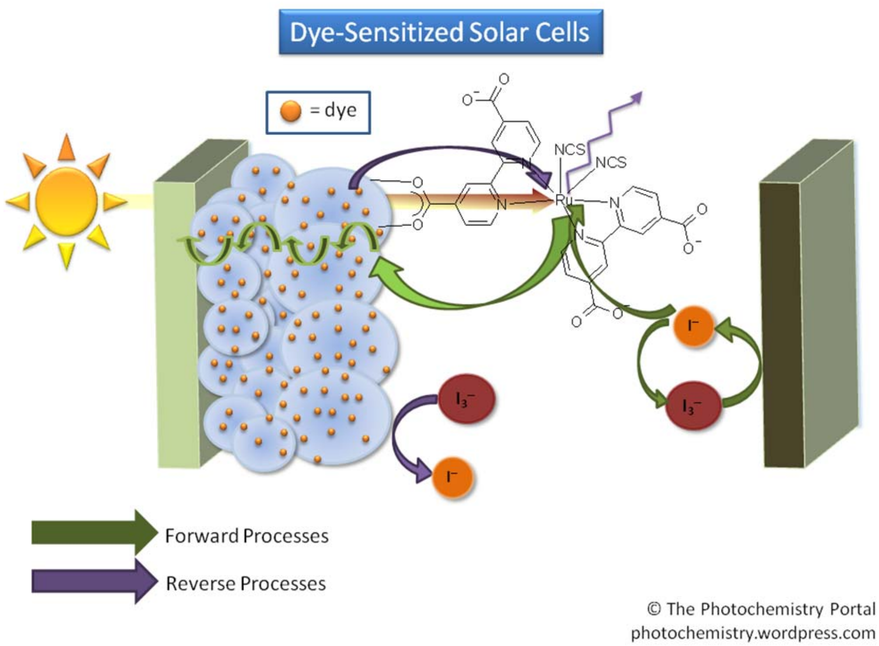
Chem Weekly, June 7, 2016

Interaction of light with matter is one of the most profound concepts in science; The colours in our material world , both, nature made and man made is an exquisite manifestation of this science. Our ability to create energy out of light also exploits the same phenomenon.

DYE SENSITIZED SOLAR CELL : TAKING A LEAF OUT OF NATURE





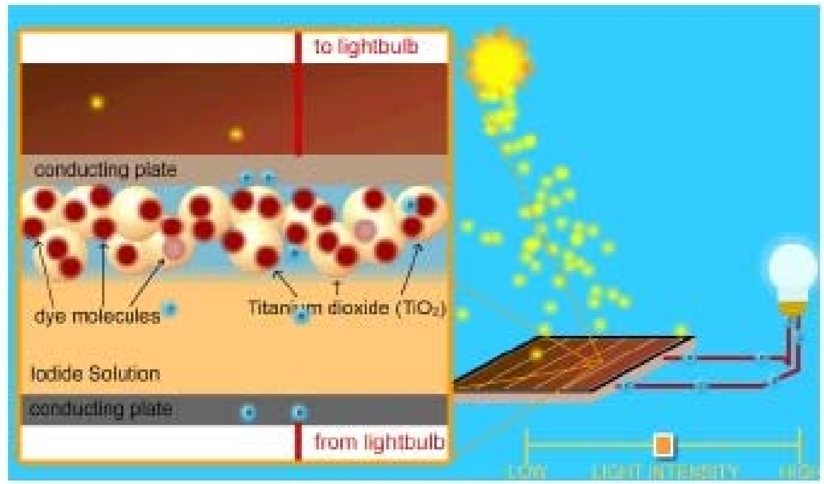


Max. Certified Efficiency : 11.9 %

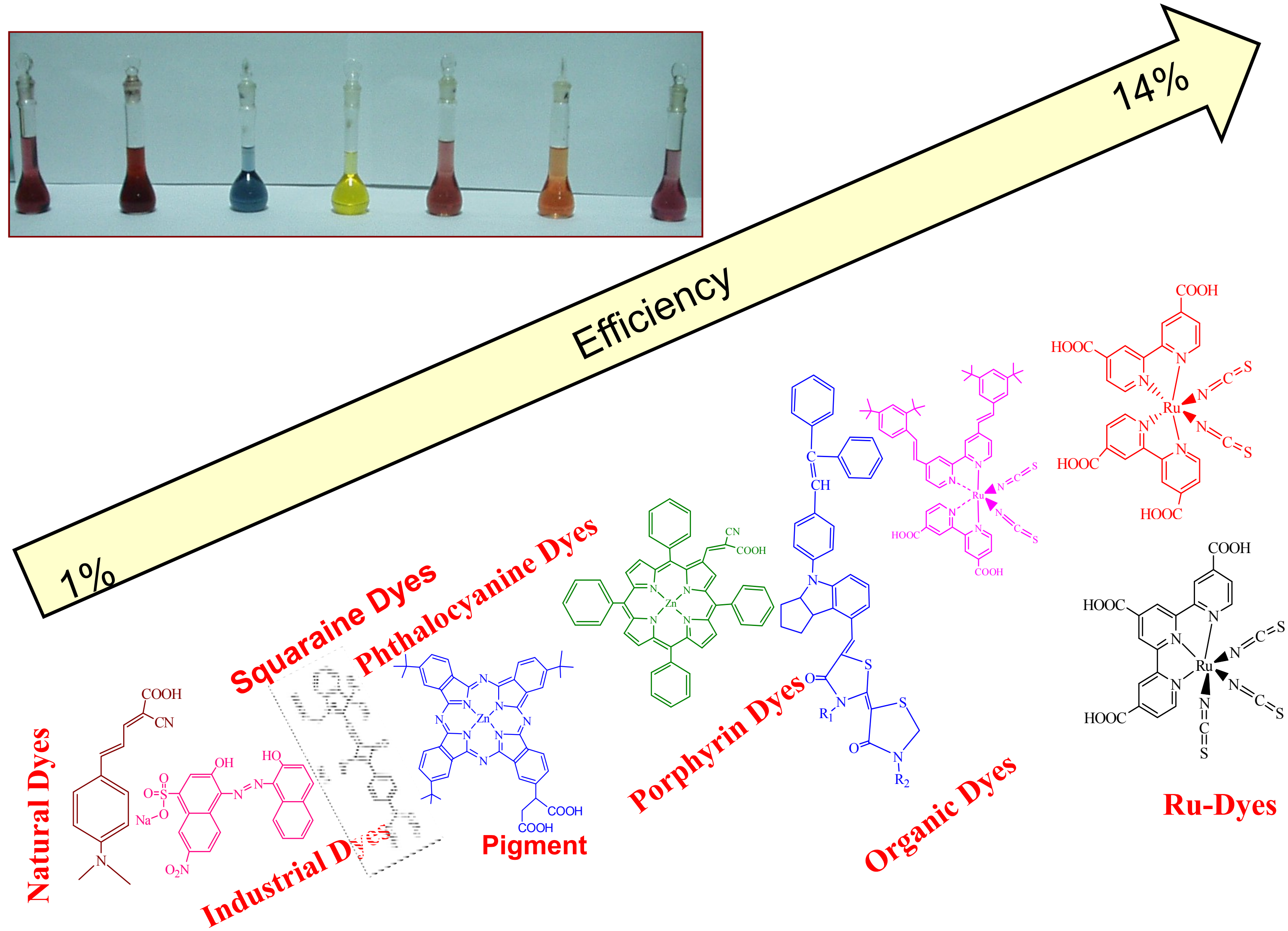
Gratzel and O'Regan, Nature, 353, 737 (1991)(cited over 10,000 times); US Patent, 1988 (a patent classic)

How a Dye-Sensitized Cell Works

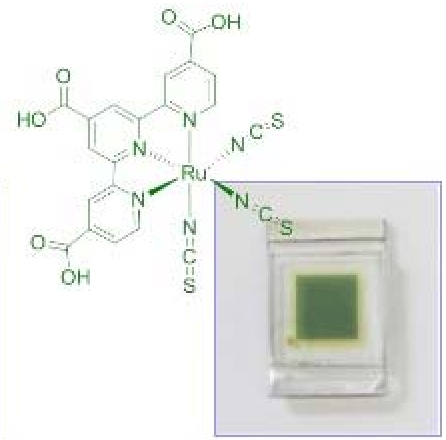
- **Light with high enough energy excites electrons in dye molecules**
- **Excited electrons infused into semiconducting TiO_2, transported out of cell**
- **Positive "holes" left in dye molecules**
- **Separation of excited electrons and "holes" creates a voltage**

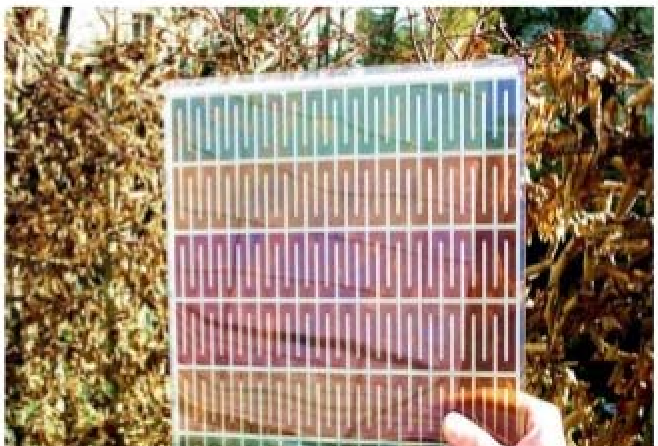


Click image to launch animation
(requires web access)



14%
Efficiency
1%
Natural Dyes
Industrial Dyes
Squaraine Dyes
Phthalocyanine Dyes
Pigment
Porphyrin Dyes
Organic Dyes
Ru-Dyes





Various colors in a series-connected dye solar cell module courtesy Dr. Andreas Hinsch, FHI, ISE Freiburg Germany.

Leaf-shaped transparent DSC with four colors courtesy AISIN SEIKI CO.,LTD.

Applications of DSSC

(a) 200 m^2 of DSSC panels installed in Newcastle (Australia)– the first commercial DSSC module

60

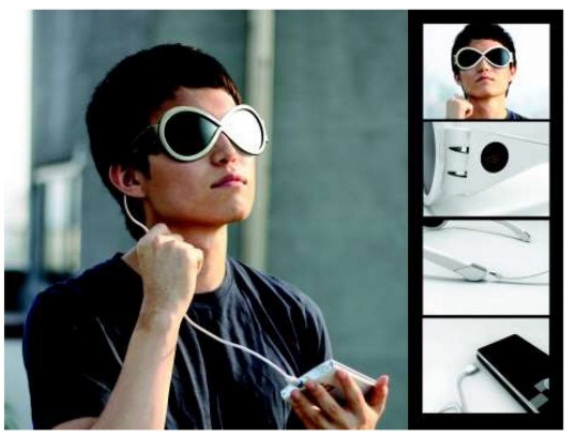
- Flexible
- Wearable
- Paintable
- Can harvest diffuse light

G24, UK, Donjin Semichem, Korea
3G Solar, Israel, Dyetec Solar, USA
Fukikura and Nissha Corp, Japan

Building Integrated Photovoltaics
IOT applications

Solar Powered Solar Panel Sun Glasses

The SIG, or "Self-Energy Converting Sunglasses" are quite simple. The lenses of the glasses have **dye solar cells,** collecting energy and making it able to power your small devices through the power jack at the back of the frame. "Infinite Energy: SIG"



Courtesy: Sony Corp.

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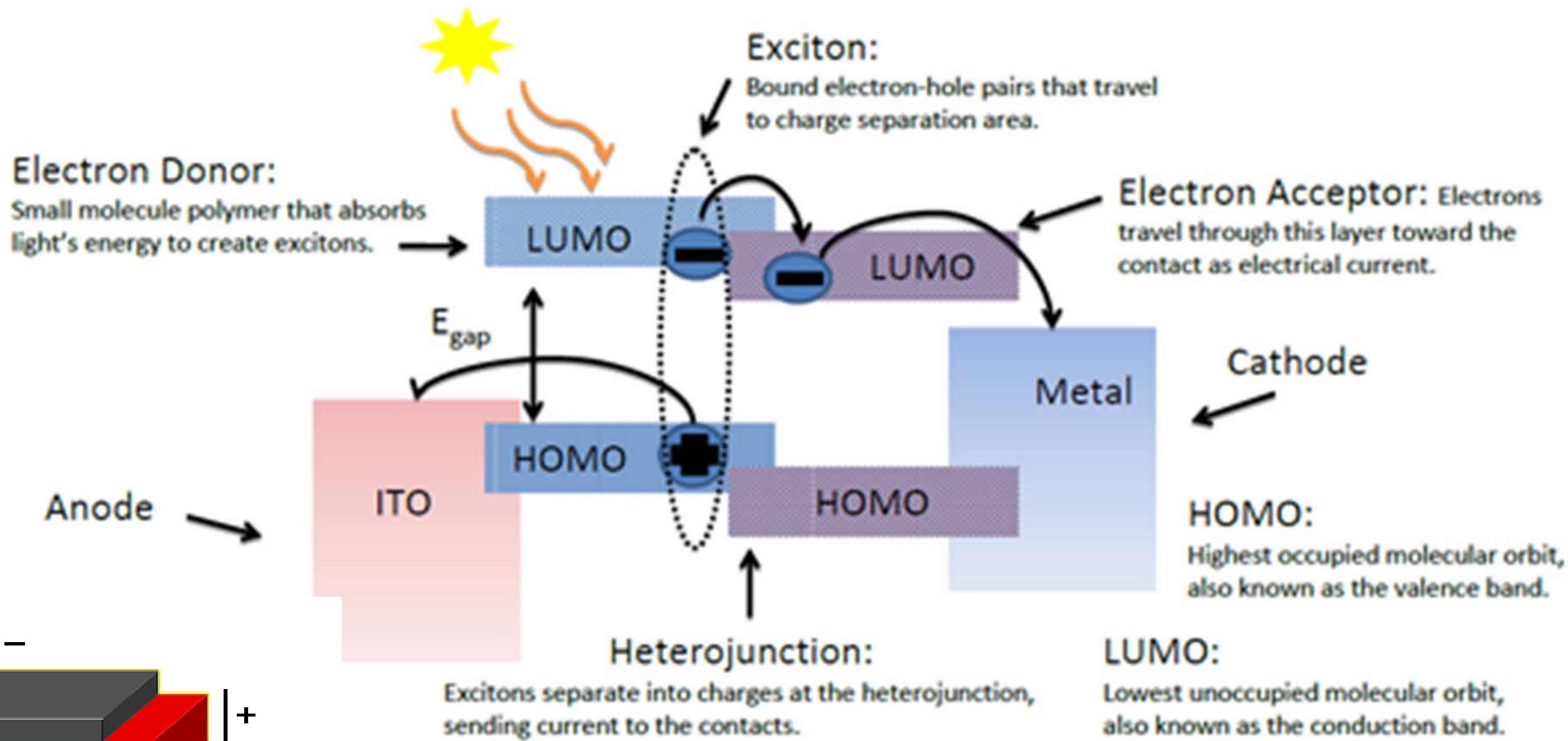
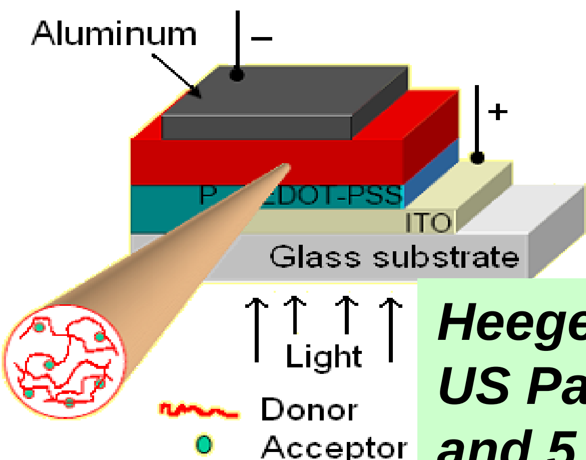
Operation of Organic Solar Cell



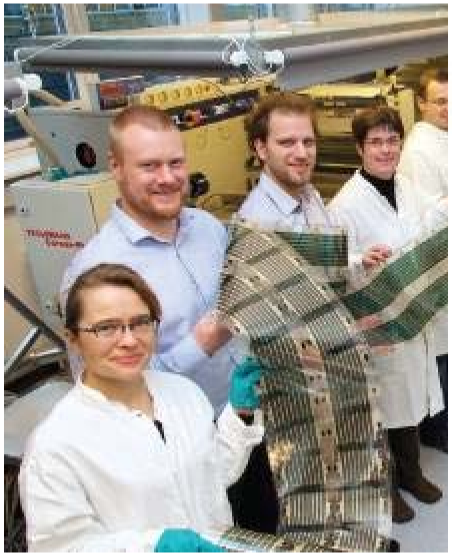


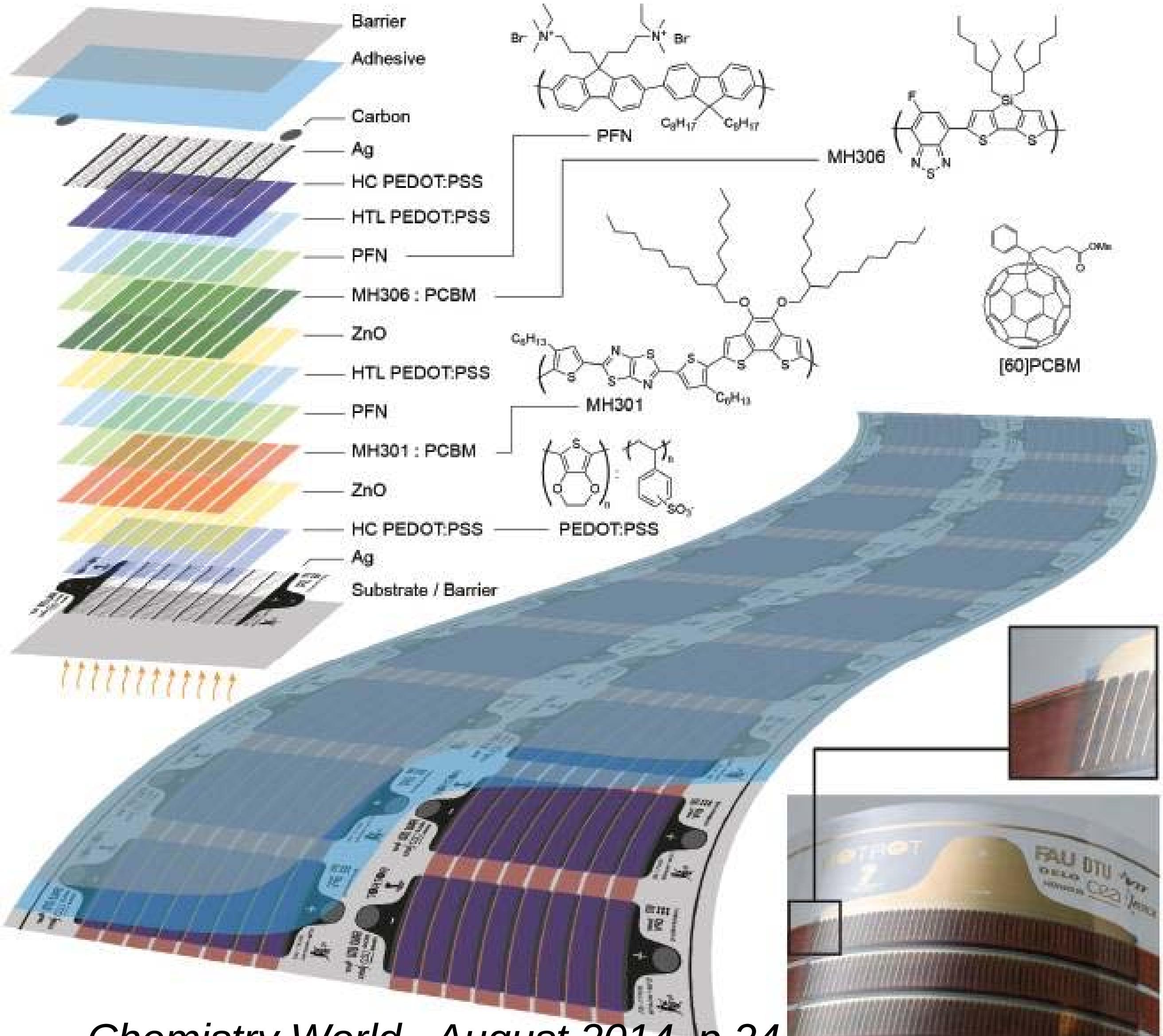
Heeger and Saricifti
US Patents 5,331, 183
and 5,454, 880;
Science,
258, 1474, 1992

Components of the device:

1. ITO coated Glass or flexible substrate (Anode)
2. Hole Transport Layer (HTL) of PEDOT:PSS /MoO3 or PFN
3. Donor and Acceptor Layer (DAL) of Polymer : PC60BM/PC70BM
4. Electron Transport Layer (ETL)
5. Cathode Electrode of Al/Ag

ORGANIC PHOTOVOLATAICS





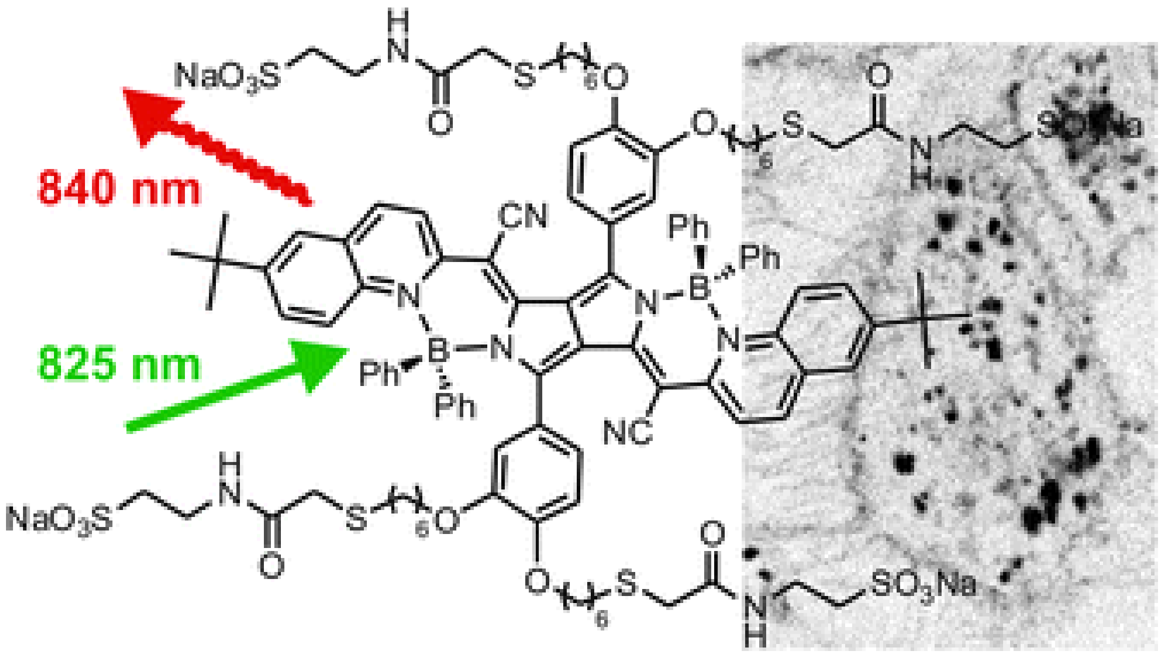
Maximum certified efficiency : 11.5 %

Konarka, USA
Heliatec, Germany
Solarmer
819, UK
Infinity PV(Denmark)
Plextronics(Solvay) : inks

Chemistry World,, August 2014, p.24

BIOMEDICAL IN VIVO IMAGING

Near Infra red absorbing dyes (700-900 nm)
Pyrrolopyrrole cyanine dyes



A NEW BLUE PIGMENT AFTER 200 YEARS

(Subramanian and coworkers, J. Amer. Chem. Soc., 131, 17084, 2009)

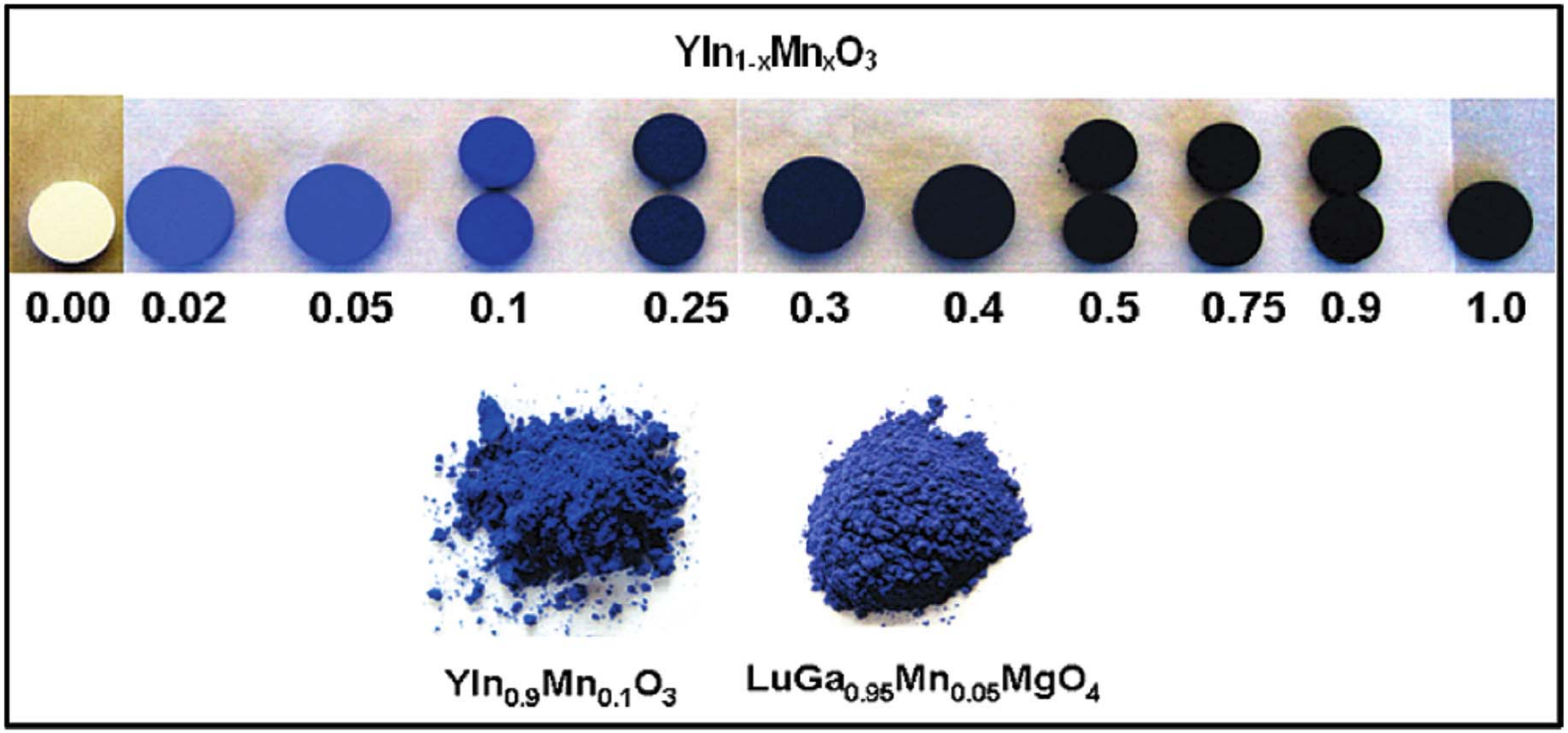
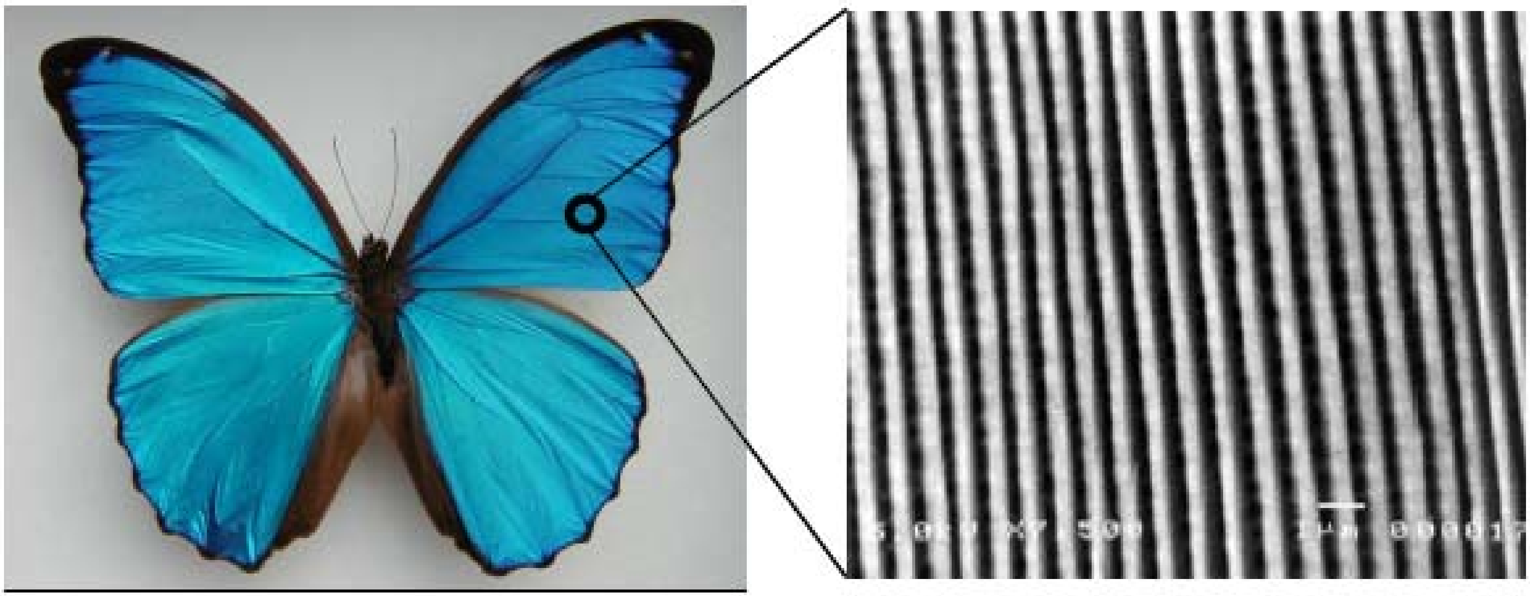


Figure 3. Colors of pellets and powders at selected compositions. The intense blue color appears at our lowest concentration of Mn doping in $YInO_3$. With increasing Mn composition, the color darkens until eventually $YMnO_3$ is found to be black (see the Supporting Information for an enlarged figure).

HOW DOES THE NATURE CREATE THE COLORS OF PEACOCK FEATHERS

Is there a bioinspired approach to create colour effects?

HOW DOES NATURE CREATE THE COLORS OF BUTTERFLY WINGS



The striking colors of butterfly wings come from light diffracting off the ordered microstructure of their scale. Synthetic surfaces with similar optical effects can be now created in the laboratory

COLOR QUOTES

"I want to know one thing. What is color?"

~Pablo Picasso

SENSATIONAL COLOR

1950 - 2010

Celebrating Sixty Years of Science

THANK YOU