Groupe international
de recherche sur
l'enseignement de la physique

# Physics Teaching and Learning

girep book of selected papers

## dedicated to the memory of professor Arturo Loria

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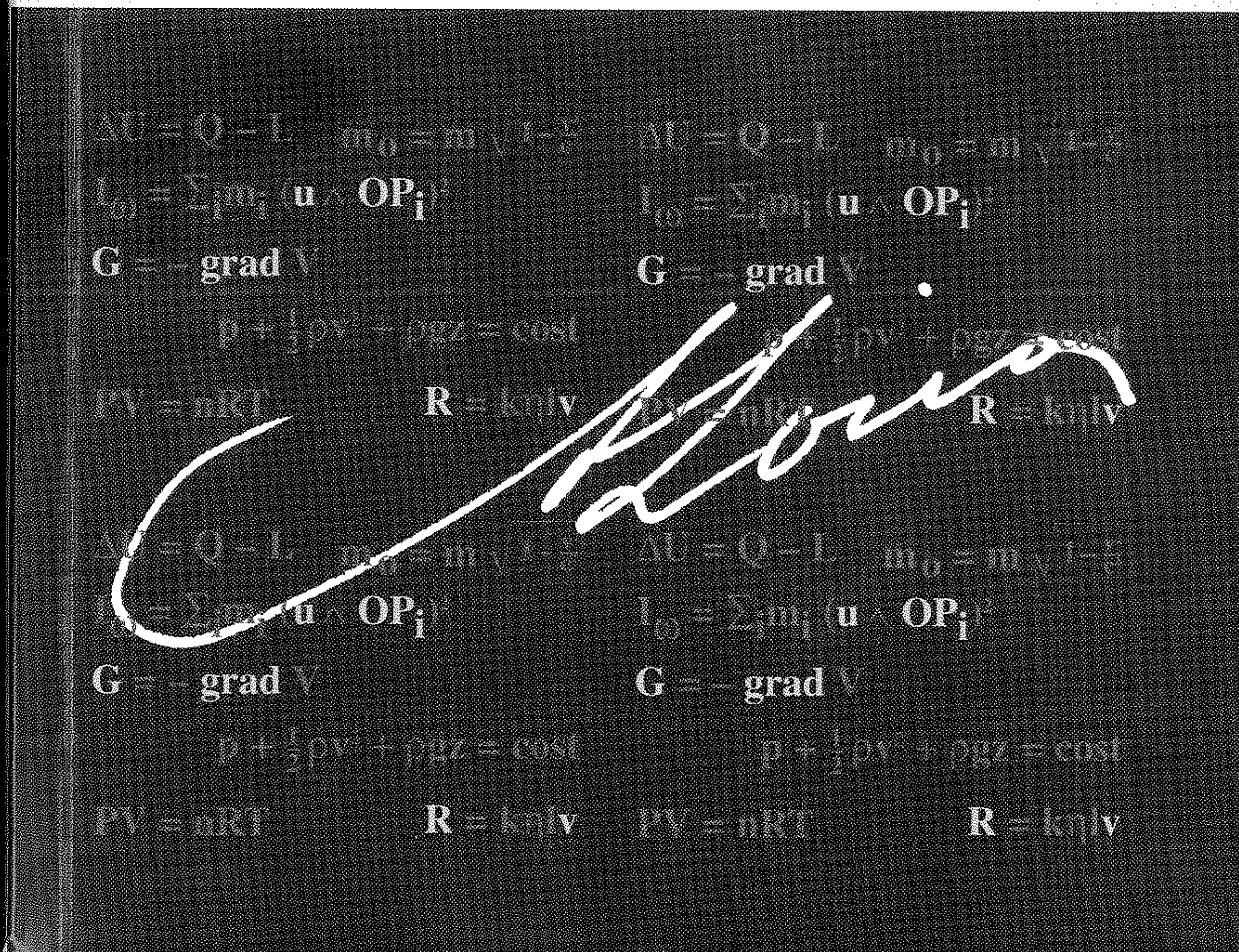

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# PHYSICS AND ART: INTRODUCING TO LIGHT-MATTER INTERACTION BY LOOKING AT FAMOUS PAINTINGS

**Federico Corni, Giampiero Ottaviani,** *Physics Department, University of Modena and Reggio Emilia, Italy*

The colour of an object is a subjective sensation produced by a series of phenomena connected to the interaction between matter and electromagnetic waves. Our eyes incessantly convey images and information to us, but hardly ever do we stop to consider their physical origin. We are enchanted by the colours of spring, we marvel at the beauty of a butterfly's wings, we are carried away by the sight of a picture and yet we ignore that these sights are the result of the interaction between light in the environment and the material of the bodies' surface. Such an attitude originates spontaneous explanatory hypotheses which tend to take root, such as those of colour being one of the properties of an object and light being a neutral entity which gives luminosity to objects. This position does not allow a scientific approach to reality and therefore it does not allow quantification of the phenomena. Unfortunately scientific models of phenomena often require mathematical or geometrical formalism, and therefore they are often seen by the students as being an end in themselves, having no evidence in reality and no practical use; for this reason, they may not be considered to represent an actual advance in learning.

Art is probably the most suitable context to introduce the phenomena connected to light-matter interaction, since painters know well - at least from a practical point of view - that the final result of their work is given by their capability to control these phenomena. Thus they are very skilful at using the most varied materials in as many varied ways in order to give their paintings certain characteristics, and to convey sensations. Though it is extremely difficult to use scientific terms in an art context - since we are used to dealing with art using specific terminology, language, and logic - this paper means to deal with works of art using the rigorous and accurate approach which is typical of science. The observation of a painting depends not only on the observer, but on light, and on the nature of the painting itself.

Light, or rather, the intensity of its components, affects the observer's perception of colours. If a painting is observed in the sunlight its colours will look completely different from the colours that an observer would perceive if the same painting were observed in the light of a lamp having only one chromatic component - for example, red: in this second case the colour shades, intensity and contrasts would look completely distorted.

Not only does light affect our perception of colours, but unexpected results may be obtained by illuminating a painting with electromagnetic waves (components) that cannot be perceived by the human eye, and by "observing" the images in the painting by means of suitable instruments.

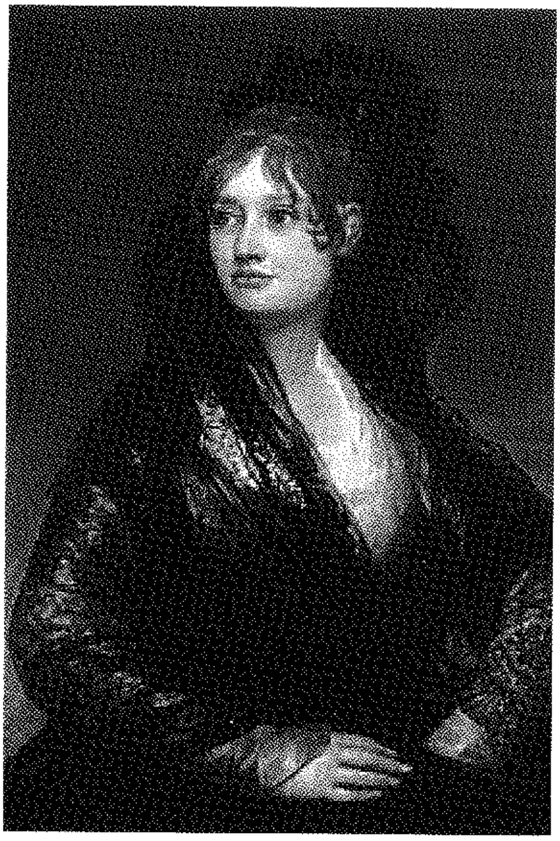
Infrared light "observation" of Goya's *Dona Isabel de Porcel* shows an eye appearing underneath the woman's chin, belonging to a former underlying portrait. This happens because the eye was painted with pigments which interact with this kind of radiation, whereas the pigments above interact to a very limited extent.

X-ray observation of *The triumph of Henry IV* by Deruet reveals the portrait of a woman in a formal dress hidden underneath Henry IV's chariot. In this case, radiations are extremely penetrating and they interact only with heavy chemical elements such as lead and mercury, used in certain white and red pigments.

These examples show how different the same painting may look depending on the wavelength of the incident ray and on the kind of detector used, thus helping to overcome the misconception of light as a neutral entity.

The last factor - the nature of the painting - is worth a more complex and exhaustive treatment.

As far as natural visible light is concerned, the physical phenomena underlying its interaction with matter are reflection, refraction, and absorption, and it is the interplay among these three phenome-



Dona Isabel de Porcel
Francesco Goya
Oli on canvas.

na which originates the sensations of colour, light and shade that we feel when looking at a painting.

The works of the Panza modern art collection "Monochromatic Light" are particularly suitable to describe these three phenomena. They are monochromatic paintings which fill seven rooms of the "Palazzo Ducale" in Sassuolo (Modena, Italy). These works are the object of guided didactical visits by children and students from nursery school to secondary school.

First of all it is necessary to state that the quantity and quality of light conveyed to our eyes after interacting with the surface of the object being observed are controlled by the phenomenon of reflection. The components of the incident light being equal, a surface may look brighter or darker depending on the material it is made of.

The five Panza Collection paintings by the artist Phil Sims represent five colours: red, green, yellow, blue, and purple. If they are observed from different points of view and in different lighting conditions, their appearance does not change. These paintings are homogeneous, uniform, still. On the contrary, the ten blue paintings by Anne Appleby are luminous and lively: it seems as if the author has copied the sky in a clear, cloudless day. The difference between the two examples is that the first group of pictures are oil-painted on a linen substrate which gives roughness to the picture surface, so that light is diffused, and therefore its intensity is nearly unchanged since it is reflected in every direction. The second group of pictures, on the contrary, are painted in oils and polished wax on canvas. In this case, light is reflected very effectively, and this gives animation to the paintings and causes a higher percentage of light to reach the observer.

The colour of a painting does not depend on the direction where it reflects light but on the fact that light interacts with the painting itself. The sensation of colour is therefore affected by a deeper penetration of light with the painting surface. This fact was well-known to Jan van Eyck, who is considered to be a great developer of oil-painting. If one observes *The Annunciation*, one marvels at the brightness and liveliness of its colours. The artist made good use of the optical properties of enamels and used to apply several transparent-coloured layers on a white background so that light could penetrate into them, strike the background and be reflected towards the observer.

Light shed on a painting must penetrate into the paint in order to interact and be reflected by the substrate or even by the paint itself - if it is opaque; it is the phenomenon of transmission and refraction. The lesser the difference between the refractive indexes of the two media - air and paint - the more the fraction of light going through the separation surface between them. The binders in which the colour pigments are suspended generally act as light propagation media in order to facilitate interaction with the pigment particles. For example, oil colours are much more intense owing to the binder which is left after exsiccation, unlike watercolours, in which only bare pigments are left.

The triumph of Henry IV - Claude Deruet

Another interesting example is Rubens's *Holy Women at the Sepulchre*. The artist painted the picture in such a way as to give the idea that light coming from the sepulchre is shed on the women, thus highlighting their faces and figures against the dark background. This effect was obtained thanks to a particular technique: a layer of transparent enamel was deposited on the painting in order to connect the refractive index of air with that of paint, thus causing light to penetrate into the painting and enhancing the intensity of the colours.

The last phenomenon can be highlighted by observing the effects of the illumination of Phil Sims's red picture – or of any surface coloured in saturated red - by white, red, and blue light. White light and red light have an illuminating effect on the painting, which appears to be "lit up", unlike blue light which seems to make it even darker. If one tries the same experiment on Phil Sims's blue picture, one will find that white and blue light give brightness to the painting, unlike red light. Further to the previous statements, in the first two cases light is reflected, whereas in the third case it is absorbed by the coloured surface. The light-pigment interaction phenomenon which has not yet been identified is just absorption: the fraction of the spectrum of the incident light which is not absorbed and is reflected towards the observer is the origin of the colour that one may observe.

Absorption may happen on an atomic level, by the interaction of light with the electrons of the pigments, as well as on a nanoscopic level, through the interaction with ordered structures having dimensions smaller than the visible light wavelengths.

The pigments of most conventional colours are powders of chemicals, which absorb - on an atomic or molecular level – certain wavelengths, so modifying the intensities of the reflected components of the incident radiation.

Holy Women at the Sepulcher – Peter Paul Rubens
Oil on Pane 1611-1614

As regards the more interesting case of absorption caused by the structure of the paint, an interesting hint is given by David Simpson's works in the Panza collection. They are four monochromatic paintings of a pinkish colour which is hardly describable, with reflections and iridescent glows. The absence of suitable terms to describe these colours is due to the fact that the artist created colours which had never been seen before, through the interplay created by the absorption of light by metal nanoparticles suspended in a binder. These are particle-made paints which exploit the interplay of light with ordered nanoscopic-sized structures.
The same phenomenon had already been exploited in the Renaissance period, to produce the golden and red colours of the Gubbio and Deruta (Italy) lusters. In that case, the effect was due to ordered suspensions of copper and/or silver nanoparticles whose interplay with light caused the absorption of certain wavelengths and originated colours so ravishing that the ancients thought they had something to do with alchemy.
These last aspects may contribute to open a discussion on what colour is and which properties of matter cause its definition.
In conclusion, an introduction has been outlined to the phenomena of light-matter interaction, which are responsible for the image formation of objects as they are seen in terms of colour and brightness. Reference to paintings by well-known painters helps contextualize the subjects and the physical phenomena being dealt with, thus contributing to the formation of a scientific approach to reality and to a greater awareness of one's culture in physics.