

## **Hands-On Sensors for the Exploration of Light Polarization**

*Marisa Michelini, Alberto Stefanel*

*Research Unit in Physics Education, University of Udine, Italy  
michelini@fisica.uniud.it, stefanel@fisica.uniud.it*

### **Introduction**

Simple systems, based upon sensors computer on-line, offer new learning opportunities. [1-4]. These are proposed for experimental interactive explorations also in informal learning contexts as a powerful extension of the senses [5-6]. In the field of optical physics they allow the exploration of optical properties, usually addressed only in advanced physical studies [1, 7-8]. Optical polarization becomes in this context a property which can be observed both in common everyday phenomena [9-12], and in phenomena that are interpretative challenges in the classic and quantum context [13-17]. Thus by nature it provides a fertile terrain for the formation of theoretical thought and in particular for the critical analysis of interpretive models of light.

In the context of our research into physics didactics, we initiated a broad study for the planning of a didactic learning path for optic polarization. This involved four research projects in physical studies (1a-1) whose rationale is explained through the following objectives: the recognition of light polarization as a property of light and the exploration of its qualitative characteristics through quantitative experiments in everyday contexts. In particular we attempt to develop Moduli di Lavoro Esemplari (MLE) (Exemplary Working Models) and Procedures, using relative didactic and experimental material in order to recognise polarization in phenomena of light interaction (reflection, diffusion, transmission) with different materials; to determine the principal macroscopic phenomenological laws; to identify its nature in order to compare macroscopic and microscopic meaning of the results of various processes; to utilise it to comprehend certain basic assumptions of quantum mechanics and to lay the foundations of formalised thought.

In this work we focus our attention upon the proposal of informal education based upon experimental exploration in the context of a hands-on exhibit 'Games, Experiments, Ideas' (GEI) [6, 18]. The method of realisation is qualified both in operative and methodological terms through the apparatus devised for the hands-on activity and through the cultural and learning environment, of which light polarization becomes a vehicle. In this way we must:

1. recognise polarization as a property of the explorable light through its intensity, but not coinciding with it;
2. connect qualitative sensorial information with quantitative sensorial information in the same operative context.

The definition and the characteristics of the proposal synthesized here were experimented in 2004 and 2005 using the material described, involving: 800 primary school children in the informal context of cognitive laboratories associated with the GEI exhibit and the MIUR initiatives related to L6/2000 for 2004 and 2005 in Udine; 700 secondary school pupils in Palermo on the occasion of demonstrations organized for WYP-2005; 24 students of final year secondary school in Udine, in a pilot experiment on the introduction of quantum physics.

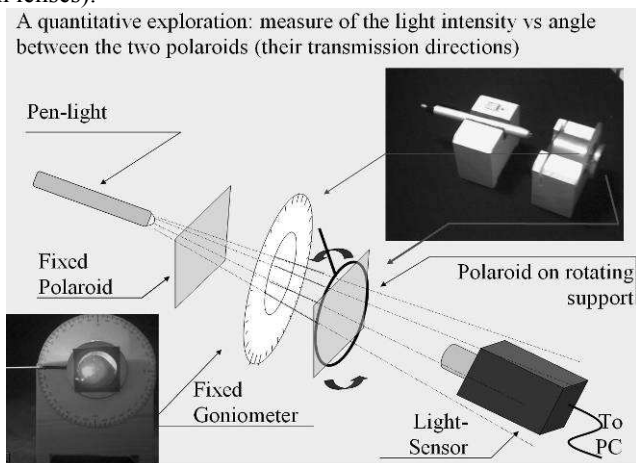
## The characteristics of materials and strategies for usage

A series of 20 hands-on experiments using poor and common materials such as: 1) calcite crystals (Iceland Spar), bought in mineral shops, to recognize and characterize polarization by bi-refraction; 2) refracting surfaces such as acetate, glass or plexiglas sheets where it is possible to study polarization through reflection and transmission; 3) glass or plexiglas containers, to study polarization by diffusion, and optical activity in sugar solutions. Basic apparatus was assembled in wood or plexiglas, easily obtained and utilised, according to the characteristics of the GEI exhibit for organizing optical support systems for the aforementioned materials. [6-18].

To produce and analyze polarized light one can use rectangular cut-outs of polaroid sheeting, available in optical shops. A rectangular shape was chosen for a macroscopic representation of the two right-angled directions associated with the anisotropy of the structure of the polaroid, which determines its polarizing property. In this way we placed the basis of a formal representation of light polarization through a vector.

The sources of light (both polarized or non-polarized) used in this context were chosen with same criteria of simplicity and low cost: a) pen-light, using a 3V battery which generates sufficiently intense and regular non-polarized light beams ( $\approx 0.2 \text{ W rad}^{-1}$ ); b) low-powered laser lights ( $\leq 1 \text{ mW}$ ) using flat batteries, that produce an almost totally polarized light that is sufficiently monochromatic and regular (less than 1%).

The qualitative phenomenological explorations take place before to the naked eye. Measurements of relative light intensity are made with medium sensibility commercial light sensors [19-20]. A preliminary preparation phase is always necessary to calibrate the system according to the actual conditions of operation, involving a simple set-up toward in the linearity range of the sensor (e.g.: screening of high intensity light source, focalization of weak beams with lenses).



**Figure 1:** Home-made apparatus for measuring Malus' law

The apparatus for measuring the law of Malus (fig.1) is representative of the technical choices carried out for all exhibit apparatuses: small blocks of wood shaped accordingly function as supports for light sources and polaroid sheets; the various elements are aligned using the laser light beam; it is not necessary to use an optics bench; it is not essential to darken the working area. The apparatus is made up of two Polaroid sheets: the first is fixed on the wooden support; the second is attached to a rotating support made of two cylindrical

bronze sleeves, one inserted inside the other to obtain a stable rotation around an axis. The external cylinder is fixed into a groove on the wooden support. The internal cylinder is given an index for the manual measuring of the angle of rotation of fixed polaroid sheet. The light beam produced by a pen-light or a laser incides on the first fixed polaroid. An on-line sensor shows the intensity of the light transmitted by the second rotating polaroid. For a consistent result it is important that relative position of source and sensor remain fixed.

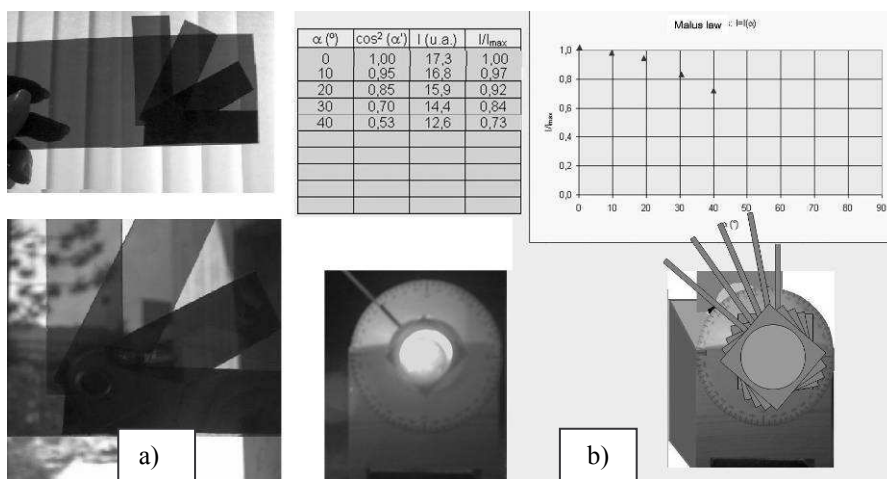
The modularity and flexibility of the apparatus are a pivot in the approach to phenomenology, as each step toward a conceptual understanding is accompanied by a step toward formalization of learning concepts. In an operative context what is obtained through an analytical cycle of hypotheses is then confronted with phenomenology, an understanding of which emerges from experimental exploration dictated by the very same hypotheses. In this sense previsions of the significant variables of the experiment are particularly challenged, requiring graph projections to determine relationship between variables. For each problem explored it is required to produce analogies and differences between previsions and obtained results.

### From phenomenological exploration to measurement

Light sensors constitute a natural extension of the human eye in the path from qualitative level to the quantitative level in the informal context. In the first qualitative phase we explore light intensity from the same source with the naked eye, when observed through several polaroids with variations in the angle formed on the long edge of the polaroid (fig. 2a). We used both light sources available and/or a over head projector.

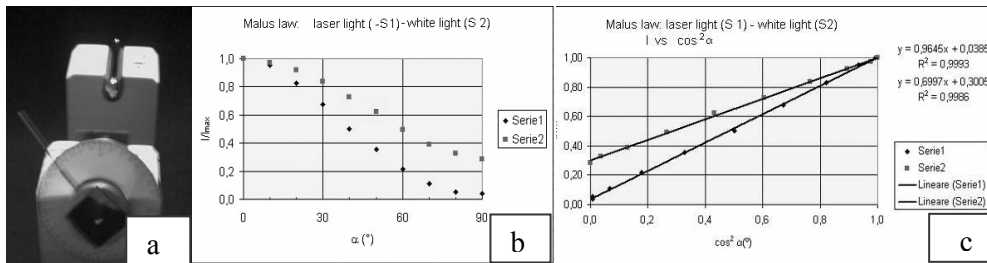
The basic apparatus used allows not only exploration but also good quality results with minimal effort. It is suitable for use in a didactic laboratory setting, as in an informal context, where the speed of execution and immediate results are the key elements.

Therefore we must compare the graph projection with what comes into being in real time on the computer, when we acquire the intensity  $I$  for each angle  $\theta$ , in which the polaroid under analysis rotates (fig. 2b) with the light sensor [19].



**Figure 2:** a) 4 polaroids, rotated 30° with respect to each other, are placed on a single polaroid sheet. b) Simulation of real time a graph  $I = I(\theta)$  construction.

In figure 3 we see the sample results acquired with the non-polarized white light and with the polarized laser, in a typical activity of the GEI exhibit. With only around ten measuring points we obtain a linear correlation between  $I$  and  $\cos^2 \Theta$ , i.e. less than 1%. For the laser light we obtain a minimum which is practically zero [11] and we thus recognise the law of Malus in its usual form:  $I = I_{\max} \cos^2 \Theta$ .

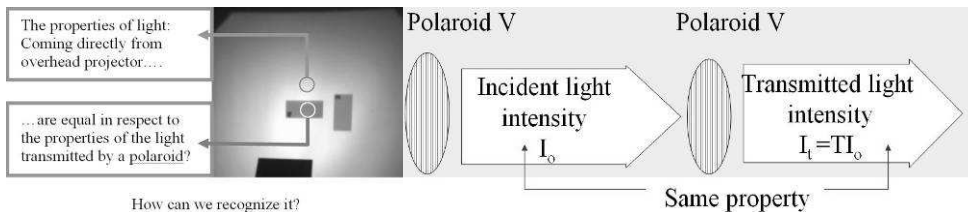


**Figure 3:** a) Apparatus utilized with a laser as light source. b) Graphics  $I = I(\Theta)$  and c)  $I = I(\cos^2 \Theta)$ , for the white light (series 2) and laser light (series 1).

### Polarization: a property of light

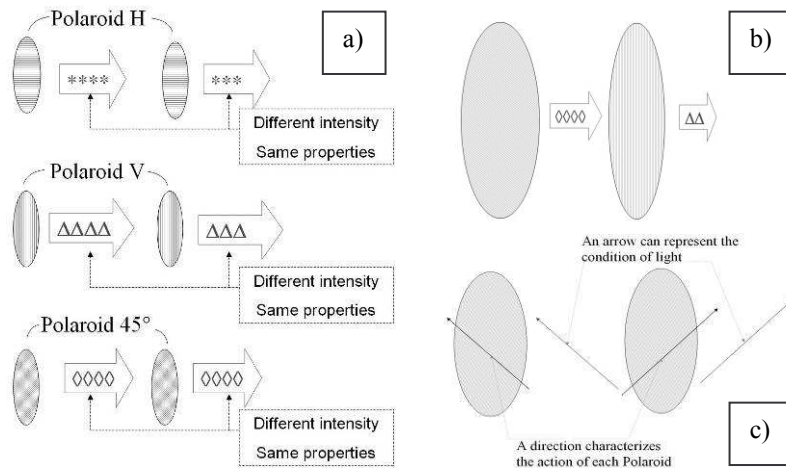
The following strategy of an operative characterization of polarization as a property of light was devised after a series of cognitive investigations of spontaneous interpretations of the elementary phenomenology observed.

We examined the polaroids placed on the overhead projector (OHP) (fig.4a). We asked ourselves whether the light coming from the source and that shining through the polaroid sheet had the same properties.



**Figure 4:** a) On the left: Polaroid placed on OHP. b) On the right: the intensity of the light transmitted from parallel polaroids decreases, but the polarization is the same.

By eye we see that the intensity of the light produced from the OHP and that transmitted through the polaroid are different. The first remains constant, although this is reduced when we observe this with eye through a second polaroid, (the analysing device), rotated in the direction of the observer. We recognise that the light transmitted from a polaroid possesses a property (polarization) which is not possessed by that coming from the whiteboard where it is placed. This property depends entirely on the orientation of the polaroid, as one may easily recognize by analyzing the light transmitted by several parallel polaroids (fig. 4b).



**Figure 5:** Iconographic representation of light polarization. a) light passes through several polaroids placed in order to achieve maximum transmission. It possesses a property that is characteristic of the specific orientation of the polaroids and can be represented by an equal number of symbols of the same type. b) light polarized at  $45^\circ$ , with properties represented by the symbol  $\diamond$ , strikes a vertical polaroid. The transmitted light acquires a new property, represented by:  $\Delta$ .  
c) Representation of polarization with an arrow/vector.

The association of iconic symbols, already at this level of qualitative description of phenomena, allows us to build representations (models) that convey the articulated enumeration of situations in which light is polarized not only by selective transmission, but also by bi-refraction, reflection and diffusion. In our experience with students the following two representations occurred spontaneously:

- Vectorial (fig. 5c), where the principal direction of polarization is represented with an arrow (vector) parallel to the longest side of the polaroid;
- Iconographical, whereby one attributes an icon to each type (and direction) of polarization, as in fig. 5a (2), suggesting the possibility that two parallel polaroids transmit light with the same polarization (or the same property), in spite of decreasing intensity.

The vectorial representation immediately poffers the interpretation of the law of Malus. Representation by icon defines the active role of the polaroid filter in its interaction with the light: this determines the properties of polarization of the light passing through it (in iconography terms it fixes the symbol representing light polarization after it has passed fig. 5b).

The passive role of all filters in diminishing intensity by absorption and reflection, highlights the problem\_of intensity, given its role of representing the state of the polarization. The students found two ways to \_represent intensity in relation to the state of polarization, emerging from informal discussion: 1) a continuous role where the symbol representing the state of polarization is shown by dimensions in proportion to the intensity of the polarized light, as though this intensity were concerned with polarization alone and no other properties of light; 2) a discret role where the symbol that represents the state of polarization possesses a multiplicity (a number of discret iconic elements) which is proportional to the intensity.

## Conclusions

We were able to define a proposal for activities in the informal context concerning light polarization, which is based upon an operative approach which can be proposed at various levels.

It requires simple apparatus made from readily available materials and uses solutions that utilize the potential of the human eye in exploring light intensity, which characterizes the state of light polarization. It proposes the use of on-line sensors as extensions of the senses, to build a path from a qualitative dimension to a quantitative dimension of the phenomenology. Assembly is simple due to the versatile solutions provided by the apparatus. The experimental explorations do not require technical systems of alignment. It proposes the analysis on a conceptual level of observation and actual experiments, carried out in an informal context and therefore favouring the imaginative reduction of concepts, in order to developing formal thinking.

This path foresees the construction of polarization as a property of light, which is operatively isolated through the study of its intensity, to be then recognised in an everyday context characterized by simple phenomenological laws. Interpretation is an autonomous phase where the students produce spontaneous representations, which constitute the basis for a reading of polarization as a quantum property of the state of the system. Vectorial representations, useful for the formal description of phenomenological laws in a classical framework, in fact provide the tools for recognising in a quantum framework the status autovector of a property whose character (autovalue) may be represented also iconographically at the first level. In this way the representation of the intensity of light polarization acquires differentiations, which carry out a problematic role with respect to the nature of light and to the properties of polarization associated with it.

The operative context indicated how it is possible to work with the intensity and polarization of light, which appear to be indistinguishable in reality, through hands-on activities. The representation of polarization through a vector pays tribute to the law of Malus, while an iconographic representation highlights the active role of the polaroid. The representation of intensity as a parameter of iconic magnification amplifies the arrow or symbol used to characterize the specific polarization, remaining purely on a descriptive level.

The experiments carried out allowed us to highlight the worthiness of these proposals in the development of formal thought, rendered more effective through the informal manner used in experimental exploration.

## Notes

(1) In the course of the Progetto SeCiF (Spiegare e Capire in Fisica/Explaining and Understanding in Physics), PRIN-MIUR 1999-2000, a didactic proposal on polarization was developed for high school. During the Progetto NOAI (Nuove occasioni di apprendimento informale/New cases of informal learning), L6/2000-MIUR 2004, working prototypes for most of the experiments were devised and refined. During the Progetto Interreg III – Italia - Slovenia, 2004-2006, working models in the informal context were developed and tested, and the results were recorded on work-sheets in order to be used in hands-on demonstrations. We are also developing work-sheets for teachers illustrating single experiments and work-sheets for class activities to be proposed as Moduli di Lavoro Esemplari/Exemplary Work Modules (MRE), in the ambit of the Progetto Fis21, PRIN-MIUR 2004-2006.

(2) Iconographic representation was introduced to characterize the quantum state of polarization of photons in previous experiments [16, 17].

## References

- [1] Hirata K 1986 How can we use microcomputers effectively in teaching and learning physics? *Communicating Physics, ICPE (IUPAP)* 132
- [2] Riel M 1998 Educational Change in a technology-rich environment *Journal of Res. In Computing in Education*, 26, 31-39
- [3] Swan K, Miltrani M 1998 The changing nature of teaching and learning in computer-based classrooms, *Journal of Res. In Computing in Education*, 25, 121-127
- [4] Michelini M, Pugliese Jona S 1999 Computers for Learning Physics, *Wirescript* (at: [www.wirescript.com](http://www.wirescript.com)).
- [5] Bosio S, Capocchiani V, Michelini M, Santi L 1996 Computer on-line to explore thermal properties of matter *Teaching the Science of Condensed Matter and New Materials* ed M Michelini et al., GIREP-ICPE Book (Udine: Forum-Girep) 351-355
- [6] Bosio S, Ceccolin D, Michelini M, Sartori C, Stefanel A 1998 Games Experiments Ideas from low cost materials to the computer on-line, *Hands on experiments in physics education* Ed G Born et al (Duisburg: ICPE, GIREP, Duisburg University)
- [7] Corni F, Mascellani V, Mazzega E, Michelini M, Ottaviani G 1993 A simple on-line system employed in diffraction experiments, *Light and Information*, Girep book, ed L C Pereira, J A Ferreira, H A Lopes Editors (Braga: Univ. do Minho-GIREP) 381-388
- [8] Bosio S, Michelini M, Santi L 1996 From an incandescent lamp to the electrical properties of tungsten, *Teaching the Science of Condensed Matter and New Materials*, ed M Michelini et al. GIREP-ICPE Book (Udine: Forum-GIREP) p 216-220
- [9] O'Connell J 1999 Optics Experiments Using a Laser Pointer, *The Phys. Teach.* 37, 445-446
- [10] Benenson R E 2000 Light Polarization Experiments with Diode Laser Pointer, *The Physics Teacher*, 38, 44-46
- [11] Easton D 2001 Transmission through Crossed Polaroid Filters, *The Phys. Teach*, 39, 231-233
- [12] Ouseph P J, Driver K and Conklin J 2001 Polarization of light by reflection and the Brewster angle, *Am. J. Phys.* 69 (11) 1166-1168
- [13] French A P 1975 Experimental Bases for Quantum Ideas, in A.Loria, P.Thomsen, ed., *Seminar on the Teaching of Physics in Schools 2* (Gyldendal: Girep) 258-272
- [14] Cobal M, Corni F, Michelini M, Santi L, Stefanel A 2002 A resource environment to learn optical polarization, in Physics in new fields, *Girep Int. Conference proceedings* (Lund: Girep)
- [15] Cobal M, Corni F, Michelini M 2002 Thinking on vectors and formal description of the light polarization for a new educational approach, in M Michelini, M Cobal eds, *Developing Formal Thinking in Physics* (Udine: Girep-Forum) 310-319
- [16] Ghirardi GC, Grassi R, Michelini M 1995 A Fundamental Concept in Quantum Theory: The superposition Principle, in C Bernardini et al Eds *Thinking Physics for Teaching* (New York: Plenum Press) 329-334
- [17] Michelini M, Ragazzon R, Santi L, Stefanel A 2000 Proposal for quantum physics in secondary school, *Physics Education*, 35 (6) 406-410
- [18] Michelini M ed. 1996 *Games, Experiments, Ideas - From low cost materials to computer on-line* (Udine: Forum)
- [19] Pasco scientific at [www.pasco.com](http://www.pasco.com)
- [20] Vernier Software and Hardware at [www.vernier.com](http://www.vernier.com)
- [21] Meyer-Arendt J R 1972 *Introduction to classical and modern optics* (Englewood: Prentice-Hall) cap 3.5