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RESEARCH ARTICLE

The Element of Physical Reality Hidden in the Letter of Malus to Lancret in 1800 can Solve the EPR Paradox (Malus Thermochromatic Loophole)

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ABSTRACT

It is extremely difficult to discover an element of physical reality that might solve the "spooky action at a distance" formulated by Einstein-Podolsky-Rosen known as the EPR paradox. One very promising candidate was recently discovered in the letter of Malus addressed to Lancret in 1800. In this letter Malus (the discoverer of the polarization of light in 1808) modelled color as the composition of light and "caloric". In the modern notation we can formulate the color and heat of polarized photons as the ratio of the ordinary and extraordinary wavefronts of that polarized photon in the Descartes' model of colors caused by the rotation of spin-orbit of photons. Laser photons pass through the half waveplate where they get color and "heat content", and then in the process of the spontaneous parametric down conversion, they create two entangled photons. In the pleochroic polarizers of Alice and Bob entangled colored photons modify individually their colors and their "heat content". Pleochroism from Greek words $\pi\lambda\acute{\epsilon}\omega$ (pléon) and $\chi\rho\omega\mu\alpha$ (khrôma) means "more colors" and in the geological analysis describes dependence of color variation on the orientations of polarizer, analyzer, and the sample. This independent local color change in Alice and Bob polarizers can be mathematically described by the haversine and havercosine formulae. The havercosine describes the probability of a particle to stay on the same latitude. The haversine describes the probability of a particle to stay on the same longitude. In this model the "spooky action at a distance" is interpreted as the "local pleochroism" of entangled photons. This model can be further tested in the "Herschel-type" experiments where the polarized photons heat thermometers in the dependence of their "caloric" content. Bell four states mathematically describe the entanglement of two particles but without the physical interpretation based on the local pleochroism.

Keywords: EPR paradox, Havercosine, Haversine, Malus thermochromatic loophole.

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1. Introduction

The "spooky action at a distance" formulated by Einstein, Podolsky, and Rosen as the EPR paradox was intensively debated after the year 1935, e.g., [1]–[10]. Bell in 1964 formulated the mathematical formulae in order to experimentally compare the models with "hidden variables" with the predictions of quantum mechanics, e.g., [11]–[20]. The sophisticated experiments confirmed the mathematical predictions of quantum mechanics, e.g., [21]–[44] and excluded all local hidden-variable theories. However, there are still some attempts to discover those hidden variable models, e.g., [45]–[57].

Now, there is a generally accepted statement that all local hidden-variable theories are excluded forever. Is there an existing overlooked loophole hidden in works of Old Masters?

2. Malus Thermochromatic Polarized Photon

In 2008 Kahr and Claborn rediscovered the overlooked letter of Malus addressed to Lancret in the year 1800 [58], [59]. It was the period when many researchers measured the temperature of heated thermometers by the prismatic light [60]–[73]. The most known researcher was Herschel with his discovery of the infrared light. Malus originally interpreted the heat content of photons and their color as the composition of light with "caloric". Color depended on the relative proportion in light of caloric, as red light is more heating than violet:

$$\begin{array}{c} \textit{blues} \qquad\qquad\qquad \textit{greens} \qquad\qquad\qquad \textit{yellow}-\textit{reds} \\ a+1, a+2, a+3, a+4, a+5, a+6, a+7, a+8, a+9, a+10 \end{array}$$

where a expresses an invariant portion of light and 1, 2, 3, 4, 5 . . . the quantity of caloric as it is depicted in Fig. 1.

Recently, Stávek [74] compared the color theories of Descartes (based on the rotation energy of spin-orbit of photons) with the Newtonian model (based on the relation color = wavelength). It is now generally accepted fact that the Newtonian model cannot correctly describe the color appearance in many situations. There are many experiments when the same wavelength of photons can have different immutable colors.

We propose to use the Descartes' scenario for Malus polarized photons with a given wavelength to describe their color and heat content based on the ratio of their ordinary and extraordinary wavefronts in the dependence of the analyzer azimuth (Fig. 2).

The "heat content" and "color appearance" of polarized photons transmitted through the analyzer can be measured in the "Herschel" type experiment based on the proposed (1):

$$E_{heat}^{trans} = h\nu \cos^2\theta \tag{1}$$

where h is the Planck constant, ν is the frequency of the polarized photon and θ is the orientation of the analyzer towards the ordinary wavefront of that polarized photon.

The "heat content" and "color appearance" of polarized photons reflected or refracted on the analyzer can be measured in the "Herschel" type experiment based on the proposed (2):

$$E_{heat}^{ref} = h\nu \sin^2\theta \tag{2}$$

We can model the action of the analyzer on the polarized photon as the "pleochroic action" modifying locally the "heat content" and "color appearance" of that photon. (Pleochroism from Greek words $\pi\lambda\acute{\epsilon}\omega$ (pléon) and $\chi\rho\omega\mu\alpha$ (khrôma) means "more colors" and in the geological analysis describes dependence of color variation on the orientations of polarizer, analyzer, and the sample, e.g., [75]). Fig. 3 shows schematically the "pleochroic analyzer".

Fig. 1. Malus interpretation of colors as the composition of light and "caloric".

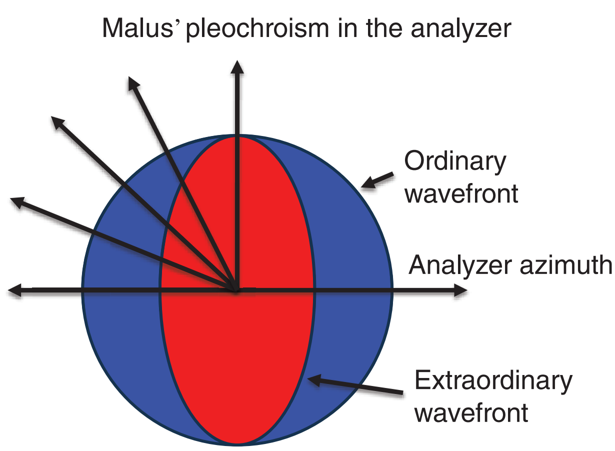

Fig. 2. The hypothesis of the Malus' polarized photons: the color and heat content depend on the orientation of the analyzer.

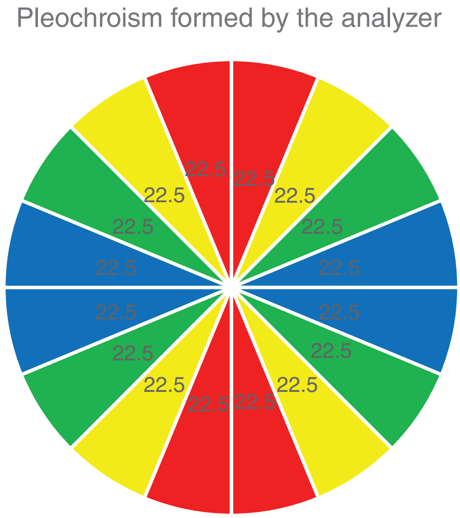

Fig. 3. The pleochroic action of the analyzer to modify locally the heat content and the color of the polarized photon.

3. Bell's "Black and White" Schema and Malus' "Pleochroic" Schema

In 1964 Bell derived his famous conditions for unknown local hidden variables and predictions of quantum mechanics. Fig. 4 depicts the Bell's schema in the "black and white" colors because there are not defined hidden variables. This schema in Fig. 4 is familiar to all scholars in quantum mechanics. Fig. 5 describes the Malus' "pleochroic" schema.

Fig. 6 shows the spontaneous parametric down conversion of two entangled photons. In the "black and white" schema there is not defined the missing hidden variable. In the "pleochroic" schema is an extra information describing the color and heat content of entangled photons. These "colored" photons later locally react in the pleochroic analyzers at Alice and Bob sites.

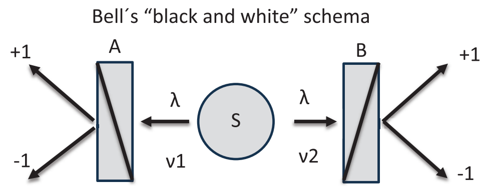

Fig. 4. Bell's schema with an un-known hidden variable λ leading to the impossibility of local hidden variables to describe events with entangled photons, Alice and Bob do not know the "hidden-variable" acting in the system.

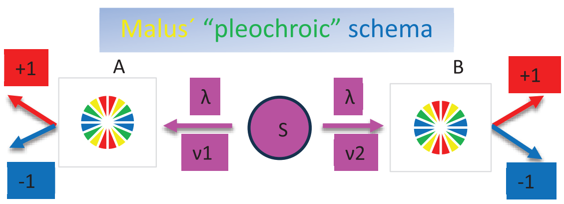

Fig. 5. Malus' pleochroic schema: entangled photons have their color and heat content λ. Alice and Bob operate independently with their pleochroic analyzers where local modifications of photon colors and heat content occur.

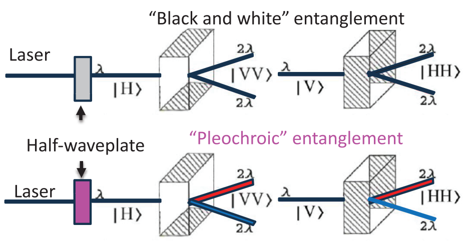

Fig. 6. The spontaneous parametric down conversion of entangled photons. In the "black and white" entanglement formation the hidden variable is not known. In the Malus' pleochroic schema: entangled photons have their color and heat content. Alice and Bob operate independently with their pleochroic analyzers where local modifications of photon colors and heat content occur. Based on reference [20].

4. Alice and Bob Individual and Joint Correlations in the Malus's "Pleochroic" Schema

Alice and Bob independently measure the color of their photons. They rotate independently their analyzers and will obtain locally modified colors of their photons. Fig. 7 shows schematically colors at individual analyzers. They both observe individually P+ = orange = red + yellow = 1/2 and P- = cyan = green + blue = 1/2.

If Alice and Bob evaluate their joint correlations, they will get four colors: red for P++ = $\frac{1}{2}\cos^2\theta$, blue for P– = $\frac{1}{2}\cos^2\theta$, chartreuse green = yellow + green for P+− = P−+ = $\frac{1}{2}\sin^2\theta$. This situation is given by Fig. 8.

5. Havercosine and Haversine at Individual Analyzers of Alice and Bob

Alice and Bob independently measure the color of their photons by their "pleochroic" analyzers. They rotate independently their analyzers and will obtain locally modified colors and heat content of their photons. Fig. 9 depicts the local color modification at the individual analyzers.

This independent rotation of analyzers with the individual entangled photon can be described by the trigonometric spherical functions: havercosine and haversine. Fig. 10 brings schema of the spheres for the determination of havercosine and haversine and the rotation of entangled photon in the analyzer.

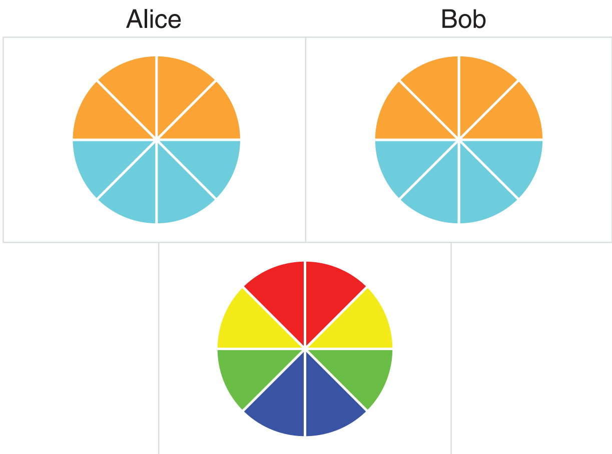

Fig. 7. Alice and Bob individual observation of photon colors: P+ = orange = red + yellow, P− = cyan = green + blue.

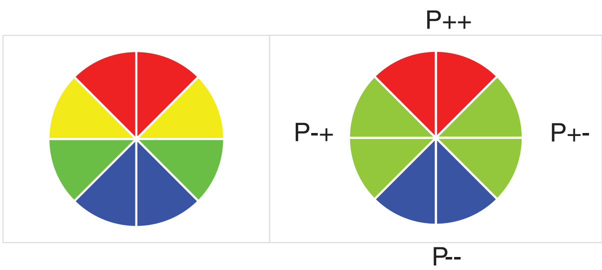

Fig. 8. Alice and Bob joint correlations of photon colors: P++ = red, P−− = blue, P+− = P−+ = chartreuse green = green + yellow.

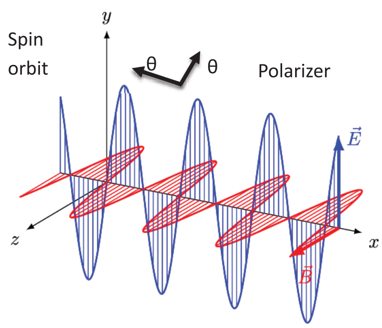

Fig. 9. Alice and Bob separately modify the color of photons (their spin orbit) by rotating of their analyzers by the angle θ (picture taken from Wikipedia).

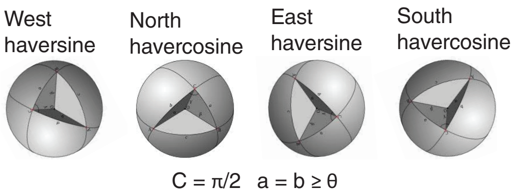

Fig. 10. Spheres for the determination of trigonometric spherical functions havercosine and haversine for individual entangled photons. These functions describe the rotation of polarized photons at the analyzer (picture taken from Wikipedia).

Individual correlations at analyzers can be evaluated using the havercosine and haversine formulae. Havercosine describes the probability of the particle to stay on the same latitude–(3) and (4). Haversine describes the probability of the particle to stay on the same longitude–(5) and (6):

$$P_{North} = \sin^2\frac{\theta-\theta}{2} + \cos\theta\,\cos\theta\,\sin^2\frac{\pi/2}{2} = \frac{1}{2}\cos^2\theta \tag{3}$$

$$P_{South} = \sin^2\frac{\theta-\theta}{2} + \cos\theta\,\cos\theta\,\sin^2\frac{\pi/2}{2} = \frac{1}{2}\cos^2\theta \tag{4}$$

$$P_{West} = \sin^2\frac{\theta-\theta}{2} + \sin\theta\,\sin\theta\,\sin^2\frac{\pi/2}{2} = \frac{1}{2}\sin^2\theta \tag{5}$$

$$P_{East} = \sin^2\frac{\theta-\theta}{2} + \sin\theta\,\sin\theta\,\sin^2\frac{\pi/2}{2} = \frac{1}{2}\sin^2\theta \tag{6}$$

The total probability for the particle to stay on the same latitude is given by the joint contributions of both the North and South poles of that sphere–(7):

$$P_{North} + P_{South} = \frac{1}{2}\cos^2\theta + \frac{1}{2}\cos^2\theta = \cos^2\theta \tag{7}$$

The total probability for the particle to stay on the same longitude is given by the joint contributions of both the East and West poles of that sphere–(8):

$$P_{East} + P_{West} = \frac{1}{2}\sin^2\theta + \frac{1}{2}\sin^2\theta = \sin^2\theta \tag{8}$$

The joint contributions of havercosine and haversine of individual particles leads to the mathematical description that "looks like the spooky action at the distance" known from the mathematical description of quantum mechanics derived for particles separated after their joint formation.

The famous quote of Étienne Louis Malus is still actual [76]: "We find that light acquires properties which are relative only to the sides of the ray, –which are the same for the north and south sides of the ray, (using the points of the compass for description's sake only) and which are different when we go from the north and south to the east or to the west sides of the ray. I shall give the name of *poles* to these sides of the ray, and shall call *polarization* the modification which gives to light these properties relative to these poles."

6. Conclusion

This contribution is based on the overlooked letter of Malus to Lancret in 1800 where Malus (the discoverer of the light polarization in 1808) explained heating effect of light colors as the composition of light with "caloric". There are two main schools dealing with the physical color theory. The Newtonian school and the Descartes' school. Both schools collected many experimental evidences on the color properties. We are now in the situation without a general physical color theory to explain all these experimental evidences with colors. Therefore, we should search for a more general physical model of color properties and "heat content" of polarized photons.

1. The Descartes' model of rotating globules (based on the spin-orbit of photons) was selected as the potential candidate to interpret the missing "hidden-variable" in quantum optics.
2. The process of the spontaneous parametric down conversion gives to entangled photons "heat content" and colors.
3. The separated entangled photons react at the Alice and Bob analyzers and independently modify their "heat content" and color based on the analyzer azimuth.

4. The spherical trigonometric function havercosine describes the probability of a particle to stay on the same latitude.
5. The spherical trigonometric function haversine describes the probability of a particle to stay on the same longitude.
6. In this thermochromatic model of polarized photons we study the "pleochroic" properties of entangled polarized photons as the local effect at individual analyzers.
7. The "heat content" of polarized photons can be studied in the "Herschel" type experiments with illuminated thermometers.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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