COLOURED RINGS ON DUSTY SURFACES ON NATURAL PHENOMENA IN THE EVERYDAY LIFE WORLD

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ABSTRACT

An everyday life phenomenon is described, which – from the physical point of view – turns out to be a nontrivial optical effect produced by the interaction of light and matter. The coloured rings are presented as an example to develop a physical view for the everyday life world. The aesthetical aspects of the phenomenon are expected to contribute to a kind of reenchantment of the world by means of physics. Besides to this general goal the phenomenon itself is shown in different contexts, demonstrated by a simple experiment and physically explained by a simple model.

1. INTRODUCTION

One important goal of general educating schools is that physics teaching shall help students to understand and cope with their lifeworld. This implies that physics has to be related to everyday life in one or another respect. But this is not as simple as it seems to be because some educational problems may be provoked. On the one hand, the physical and the common sense view are totally different. To describe the world physically means “to describe it in a way we do not experience it“[1]. On the other hand, the everyday life world is familiar and taken for granted. Therefore, everyday life phenomena and problems have to be taken into question, familiar facts have to be experienced as something unfamiliar. In addition, a physical approach can be rather complex because the physical aspects of the phenomena have to be worked out within a nonphysical context. Normally, students are not trained to do this. They learn basic physical laws within an ideal physical framework but not to apply them to nonphysical situations.

Against this background we present an example where an everyday life phenomenon, coloured rings on dusty surfaces, is recognized and described as a physical effect, which until now is only known as a nearly forgotten and reportedly seldom laboratory experiment relying on the interference of light.

2. THE PHENOMENON IN DIFFERENT SITUATIONS

We encountered the phenomenon for the first time as a system of slightly bent coloured stripes on the water surface of a pond (see Fig. 1). The first assumption was that it could be a shadow phenomenon on muddy water, which often shows a bluish and a reddish borderline. But closer inspection showed that there could be seen more than two colours. The coloured rings appeared close to the reflection spot of the sunlight on the water surface suggesting that it could be a pollen corona. But in contrast to the rings of the pollen corona, which are concentrically ordered around the reflection of the sun, here the visible parts of the coloured rings are eccentric to it.

Moreover, it turned out that the coloured rings disappeared when the transparent layer of algae covering the water surface was destroyed showing that the rings strongly depend on this layer [2].

Fig. 1 Parts of the coloured rings appearing eccentrically to the reflection of the sun, partly eclipsed by a stone.

A big window illuminated by the headlights of a car represented a second everyday life situation in which coloured rings could be observed (Fig. 2). On account of the totally different context we first were not aware that this phenomenon was of the same nature as that shown in figure 1.

Fig. 2 Parts of coloured rings appearing eccentrically to the reflection of the headlight of a car illuminating a large window of a bank building (Foto by Eva Seidenfaden).

But by closer inspection the similarities became more and more obvious: Again a layer of dirt (apparently the window had not been cleaned for a long time) was a necessary condition for the appearance of the coloured rings. Also the observation that the ring containing the reflection of the light source was white and the fact that the order of the rings' colours at both sides of the white ring was the same referred to the same physical origin.
After this we discovered the coloured rings again and again even in rather inconspicuous situations as e.g. on glass plates steamed up with tiny water drops or on ordinary overhead transparencies.

3. QUÉTELETS RINGS

The phenomenon of the coloured rings turned out to be a special interference effect among others called Quételels rings, which had already been observed by I. Newton in 1704. Still toward the end of the 19th century distinguished scientists like Th. Young, J. Herschel, G. Stokes and A. Quételet investigated it more thoroughly and explained it on the basis of the wave theory of light. Newton's very detailed description of his experiments almost invites to be reproduced. Stimulated by his description we set up a simple classroom experiment to demonstrate the Quételets rings (Fig. 3).

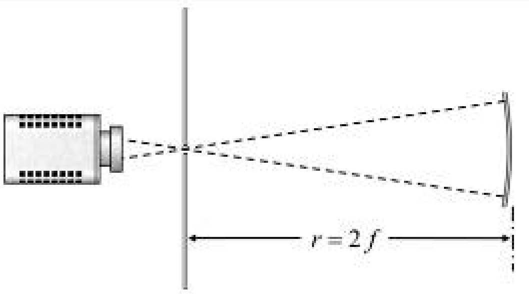

Fig. 3 Setup of the classroom experiment

By means of a bright electrical light source the hole (diameter: about 5 mm) of a screen (30 cm by 30 cm) is illuminated. The screen is placed in front of the concave side of a commercial cosmetic mirror so that the distance between the screen and the mirror corresponds to the radius of the mirror's curvature. This is the case when the light spot reflected to the screen has the same size as the circular hole.
At the beginning of the demonstration the students can at best see a very small band around the hole receiving light from the mirror. This is just what one should expect when the light is focused on the hole. How great is the surprise when by simply breathing against the mirror colourful rings are magically evoked on the screen. But the magic fades away as rapidly as the mirror is getting dry again thus showing directly that the mist was the reason for the phenomenon and nothing else.

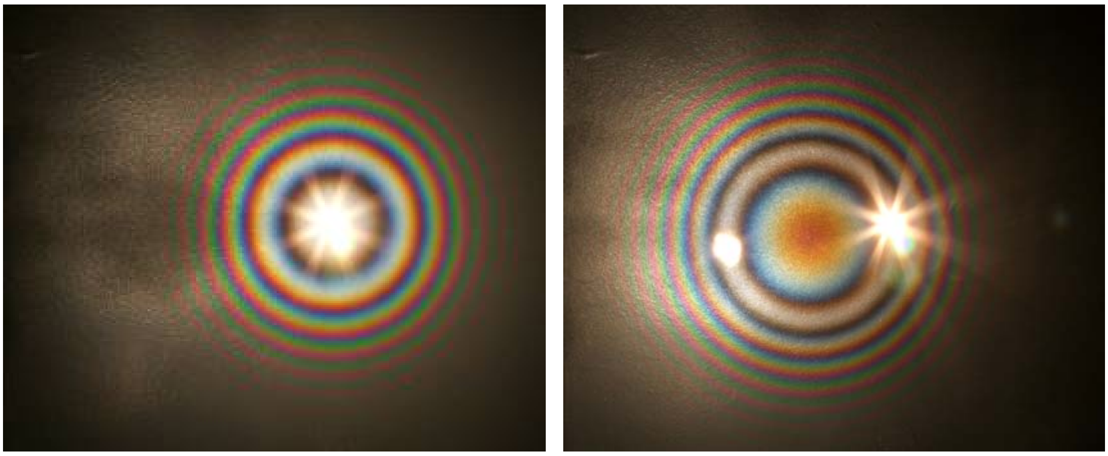

Fig. 4 Coloured rings produced with the setup shown in figure 3. On the left: Concentric rings. On the right: By slightly distorting the mirror eccentric rings appear.

(If the mirror is not very clean a more or less developed ring system may appear without breathing, which shows again that tiny particles are important for this effect.)

In order to demonstrate experimentally which element of the mirror contributes to which amount to the observed rings the illumination can be restricted to a small area of the mirror surface. This is best done by directing the narrow beam of a laser pointer through the hole of the screen onto different parts of the mirror. Regardless which surface element is hit by the laser beam the rings appear in the same form and size as if the whole screen was illuminated. (Of course, when using monochromatic light the coloration due to the spectral distribution is absent). The bright ring system produced by the completely illuminated mirror may thus be conceived of as a superposition of the elementary rings originating from each element of the mirror surface.

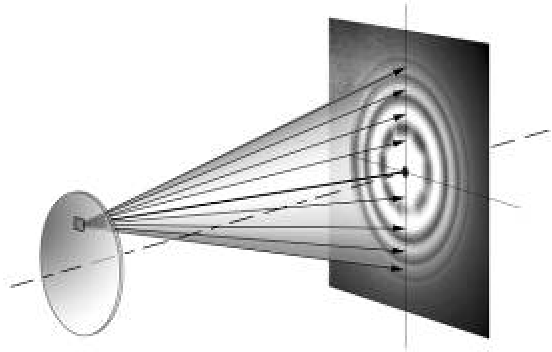

Fig. 5: Each element of the mirror produces a similar elementary ring system

4. A SIMPLE MODEL EXPLAINING THE COLOURED RINGS

We explain the Quételet's rings within a simple model according to ref. [3]. The setup of the experiment is schematically shown in figure 6, where *L* denotes a point light source and *O* the observer's eye. The surface of the mirror is lying in the *xy*-plane.

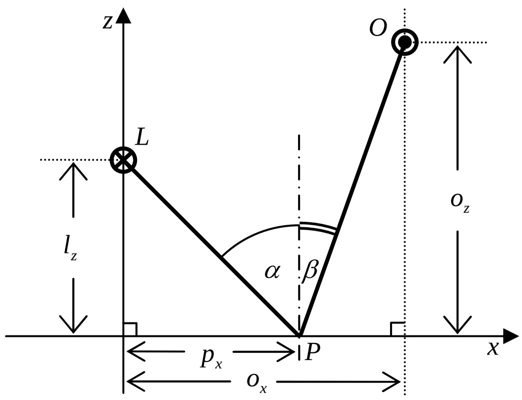

Fig. 6 Schematic representation of the experimental setup

It is assumed that the thickness *t* of the mirror glass is small as compared to the distances l_z and o_z. *P* denotes the position of a small particle at which the (almost parallel) light rays l_1 and l_2 coming from *L* are scattered forwardly. l_2 is scattered towards the silvered layer $\overline{MM'}$ whereas l_1 is first refracted into the glass at *A* and then reflected towards *P* (Fig. 7). l_1 and l_2 are supposed to arrive at the points *A* and *B* with the same phasing.
Among the rays scattered at the mirror element are the rays o_1 and o_2 which travel to the eye *O* of the observer. They have a constant phasing when leaving the points *F* and *L*. The optical retardation Δs can then be calculated to give:

$$\Delta s = (\overline{AP'} + \overline{PF})_{opt} - (\overline{BP} + \overline{P'E})_{opt} \tag{1}$$

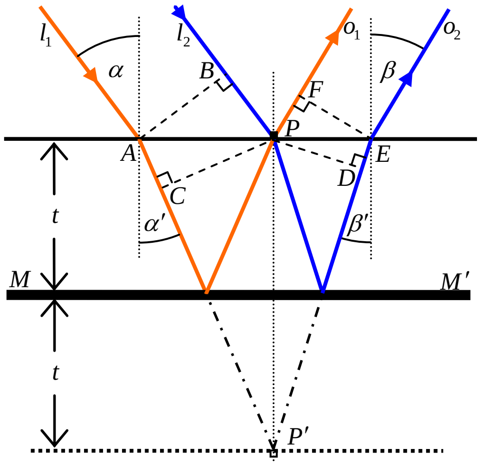

Fig. 7 Selected paths of rays refracted, reflected, scattered and then interfering.

In this calculation of the optical path length we make use of the fact that the distance covered by the light travelling from *A* through the mirror to the (real) particle *P* is the same as the distance to its virtual image point P'. According to this the light path between $\overline{PE}$ and $\overline{P'E}$ is the same, too.

The geometrical relations show that $\overline{BP} = \overline{AP} \cdot \sin\alpha$ and $\overline{AC} = \overline{AP} \cdot \sin\alpha'$. Making use of the law of refraction and substituting $\sin\alpha = n \cdot \sin\alpha'$ we get: $\overline{BP} = n \cdot \overline{AC}$ and, correspondingly, $\overline{FP} = n \cdot \overline{DE}$. Due to the identity of these optical path lengths the calculation of the optical retardation is reduced to:

$$\Delta s = \left(\overline{CP'} - \overline{P'D}\right)_{opt} . \tag{2}$$

In order to express this retardation as a function of the thickness *t* of the mirror glass and its index of refraction we use the relations $\left(\overline{PP'}\right)_{opt} = 2tn$, $\sphericalangle CP'P = \alpha'$ and $\sphericalangle PP'D = \beta'$. The lengths in eq. (2) can then be replaced by equivalent trigonometric expressions to obtain:

$$\Delta s = 2nt(\cos\alpha' - \cos\beta') . \tag{3}$$

Using the relations between the trigonometric functions, the law of refraction and approximating for small angles we get the following expression (for details see [3]):

$$\Delta s = \frac{t}{n}\left(\sin^2\beta - \sin^2\alpha\right) . \tag{4}$$

If only the distances are known one may profit from the approximation $\sin^2\alpha \approx \tan^2\alpha$ (which is valid for small angles). Making use of $p_x / l_z = \tan\alpha$ and $(o_x - p_x)/o_z = -\tan\beta$ eq. (4) can then be written as:

$$\Delta s = \frac{t}{n}\left[\left(\frac{o_x - p_x}{o_z}\right)^2 - \left(\frac{p_x}{l_z}\right)^2\right] . \tag{5}$$

COMPUTER SIMULATION OF THE COLOURED RINGS

In order to compare the experimentally produced Quételet’s rings with the corresponding rings calculated on the basis of our simple model the optical retardation has been determined for all points of the mirror surface by means of a computer program. According to the RGB- colours of the monitor this calculation has been performed for the wavelengths of 605 nm, 545 nm and 460 nm. The intensity of the corresponding R-, G- and B- components is quantified by values proportional to the intensity of the superposed light. The respective points on the mirror are then given a colour composed of these components.

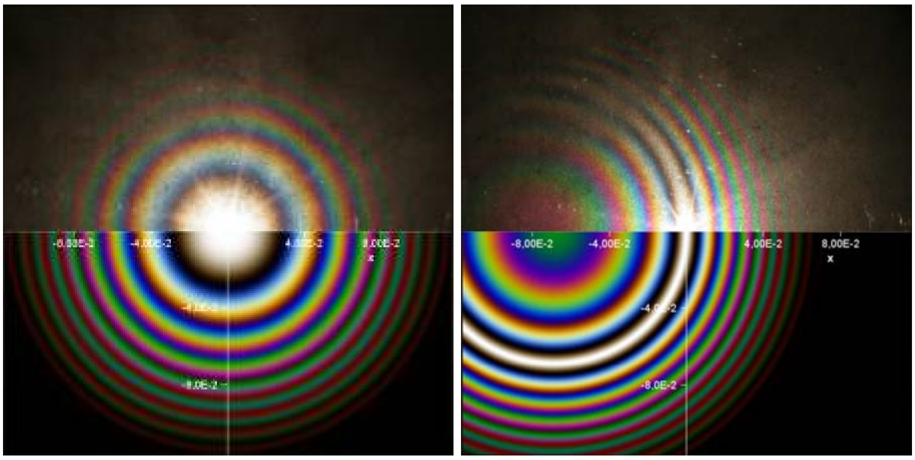

Figure 8 Concentric (left) and eccentric (right) interference rings. Upper part: Photograph of an impure mirror. Lower part: Representation of the corresponding model calculation.

In figure 8 the simulated results are compared with photographs of the corresponding experiments for both the concentric (left) and the eccentric (right) case. For the diffraction orders next to the white 0^{th} order the simulation is in good agreement with the original. For higher diffraction orders the location of the calculated rings deviates from that of the observed rings although the correspondence of the colours is well reproduced. The fact that for rings produced by monochromatic laser light the agreement is surprisingly well suggests that the deviation may be mainly due to the simplicity of the colour model we used here.
Moreover, the photographs show that the light intensity of the coloured rings decreases with the distance from the 0^{th} order of diffraction. This decrease has been modelled by taking into account the restriction of the coherence length of only a few micrometers.

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