Cordus optics: Part 2.2 Reflection

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Abstract

Optical effects such as reflection and refraction are conventionally best described by Electromagnetic Wave theory, at least when they involve beams of light. However that theory does not explain why single photons should also show such behaviour. This paper shows that optical effects can also be explained from a cordus particuloid perspective. Several principles are proposed for the interaction of a cordus photon with an optical surface, and these are used to explain reflection and subsequently refraction. The formula for critical angle is derived from a particuloid basis. The cordus and wave theory perspectives are compared and contrasted. The significance of this work is that the cordus mechanics explains the reflection and refraction behaviour of both single photons as well as beams of light, so it is a more universal explanation.

Keywords: electromagnetic wave theory; reflection; refraction;
Revision 1

1 Introduction

While Electromagnetic Wave theory (WT) adequately describes optical effects involving beams of light, the explanation of single-photon behaviour is fundamentally problematic. This paper shows that optical effects can also be explained as the interaction of a single cordus photon with the optical surface. Thus Wave theory is not the only way of conceptualising effects like reflection and refraction.

Background

Wave theory takes the perspective that a beam of light is not so much a stream of photons, as a continuously existing electromagnetic wave, comprising an electric field and a magnetic field. This is a powerful method, and well-suited to the analysis of optical effects, at least of whole light-beams. Many of the effects in optical devices can be described as interference between the electromagnetic fields of the incoming and exit beams. Notice however that the underlying premise of WT is that both incoming and exit beams exist *at the same time,* i.e. the fields are temporally enduring. This becomes a problematic assumption when considering how an individual photon traverses the device, because a point particle cannot be in two places at once.

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The problem may be partly solvable in Quantum mechanics (QM) by assuming superposition and that the particle *is nothing more* than a probability wave-function. Though this solves the mathematical part, it does little to add explanatory value because of its abstraction and lack of identifiable natural mechanics.

Wave-particle duality assumes that both WT and QM are needed to model the behaviour of light: neither is sufficient on its own. However, even while the combination of theories *does* cover most of the applications, the explanatory power is discontinuous. Some explanations rely on QM and others on WT, and there is no overall integration. It is apparent that neither WT nor QM fully describe reality, and this raises the question of whether there might be a deeper or more-integrative mechanics that does.

What is needed is a mechanics that accommodates both single particles and beams of light, rather than the separate mechanics at present. The more problematic area is with the single photons, so the problem may be reformulated thus: is there a mechanics that shows how a single photon reflects and refracts, and uses natural mechanics in a coherent manner?

The Cordus conjecture has already shown (ref. ‘Cordus conjecture’) that a particular internal structure for the photon, namely a cordus, is conceptually able to explain the photon path-dilemmas in the double slit device, as well as the fringes that build up from multiple single photons. In that sense the cordus solution already resolves one important part of wave-particle duality. However the Cordus conjecture cannot claim to offer a coherent solution until it is also able to explain conventional effects, like optical reflection and refraction. This present bracket of papers shows how the Cordus concept meets that test and is applicable to explaining conventional optical effects from a particuloid perspective.

Cordus Background

The concept of a cordus is that a photon consists not of a point but of two reactive ends (RE) connected together with a fibril. The REs emit hyff (hyperfine fibrils), which are lines of electrostatic force. The companion paper 'Cordus conjecture', describes the background to this idea, applies it to path dilemmas in the double-slit device and Mach-Zehnder interferometer, and uses it to explain fringes.

The first part develops a novel model of the dynamic internal variables that cause the behaviour we see as ‘frequency’. The second, which is this paper, uses this to explain the interaction of light with surfaces: reflection. Mechanisms are provided for reflection, and the critical angle for total internal reflection is derived. In the third part refraction is explained and Snell's Law derived.

The method is described in the previous papers, and the lemmas included here are a continuation of the previous numbering. The results follow, starting with some general premises on how the frequency interacts with the optical surface, and then extending to determine the specific mechanics of reflection and refraction.

2 Cordus effects at surface interfaces

Reflection and refraction are effects that occur when the photon encounters the interface between two media. The following assumptions are made about the behaviour of hyff in these situations. These form a set of basic principles that are subsequently applied to more specific reflection and refraction cases.

Lemma O.3 Surface interaction

O.3.1 The path taken by a reactive-end depends on (1) the frequency state (see O.2) of the reactive end at the time it contacts the material, and (2) the material properties.

O.3.2 A reactive-end can therefore take one of many loci as it approaches a surface, depending on its frequency state (primarily the strength of C+, C-).

O.3.3 The extreme loci for the reactive-end are termed the C+ and C- extremes. All other loci are within the envelope of those two. Assume that the analysis of the encounter of a reactive-end with a surface is sufficiently characterised by the C+ and C- extremes.

O.3.5 The path of the reactive-end at the surface is not a straight line but rather a bent locus under the influence of the hyff forces.

O.3.5.1 For reflection the particle does not necessarily touch the surface.

O.3.5.2 The hyff may repel before or after nominal contact is made.

O.3.5.3 For analysis purposes the effective locus may be considered a series of straight lines.

O.3.5.4 Hyff detect the change in medium before the reactive-end physically reaches that point.

O.3.5.5 The detection range of hyff is limited. There is effectively a dermis (skin layer), one on each side of the surface. We term these the cisdermis (near-side skin) and transdermis (far-side skin).

O.3.5.6 Bending of the locus occurs in both derma.

O.3.9 The reactive-end has momentum.

O.3.9.1 Consequently its current trajectory is determined by its past locus and the current C+ or C- hyff forces.

O.3.9.2 If the reactive-end penetrates beyond the transdermis, then it cannot be recovered back to the first medium.

O.3.10 Net force over the hyff determines the resulting force on the RE.

O.3.10.1 The hyff may span different materials. Hyff that partly straddle a boundary surface will have net forces dependent on the electron-interaction properties of the various materials.

O.3.10.2 The REs of a cordus may be in different materials.

O.3.10.3 A RE that re-energises within the bulk of a material and beyond the dermis has equal hyff forces around it and hence no net force to bend its path. However it still has momentum and will wriggle about the mean.

O.3.11 Forces on a RE, or displacement, cause angular deflections of the path of that RE only.

O.3.12 Forces collapse when the hyff collapse. The RE is then free to continue on its path, unless the whole cordus has collapsed.

O.3.13 Geometric variables: The actual hyff *frequency state* and *strength* at the time of meeting the material, and the orientation of the interface plane of the material, determine the outcome. It is the behaviour of the electrons in the plane, in response to the hyff in their (rt) plane, that is important.

O.3.14 *Optical activities* of materials, namely reflection, transmission, and absorption, (RTA), depend on the *frequency state* when the reactive end strikes the material. Given that multiple cordi strike the material, each in different *frequency states*, one material may do multiple *optical activities*.

O.3.14.1 RTo: A transparent material (e.g. light on glass) reflects on one frequency state and not on another.

O.3.14.2 Roo: An opaque reflective material (e.g. light on chrome) reflects on all frequency states.

O.3.14.3 ooA: An opaque non-reflective material (e.g. light on black paint) absorbs all states.

O.3.14.4 It is assumed that the different optical properties of materials arise from the different mobility of the electrons (plasmons).

O.3.15 The electron has a span much less than that of an optical wave-length photon, and higher frequency, and therefore greater mobility other than the hindrance of its mass.

Note the implication of O.3.15 is that electrons are much ‘smaller’ than a photon, and can move around in response to the relatively large and slower-frequency photon.

3 Cordus model for Reflection

3.1 Reflection in general

From the perspective of Wave theory, reflection is caused by the mirror surface absorbing and re-emitting its own EM waves. Depending on the perspective taken, these interfere with each other or with the incident wave to produce the reflected wave. The mathematics of wave theory accurately quantifies the phenomenon, though its qualitative explanations are not intuitive.

Cordus model for reflection

The Cordus explanation is that both reactive-ends of the cordus separately reflect off the surface as their hyff interact elastically with the substrate. The frequency model within Cordus states that the reactive ends change their state. Thus in some ways the hyff *are* the reactive ends. Given the dynamic nature of the hyff, the state of the reactive end at the time it contacts the surface will determine the path taken by that reactive end.

Assuming passage into a denser material, as the RE approaches a reflective surface, its hyff already detect the surface plane some distance before nominal contact, while in the cisdermis. What happens next depends on the frequency state:

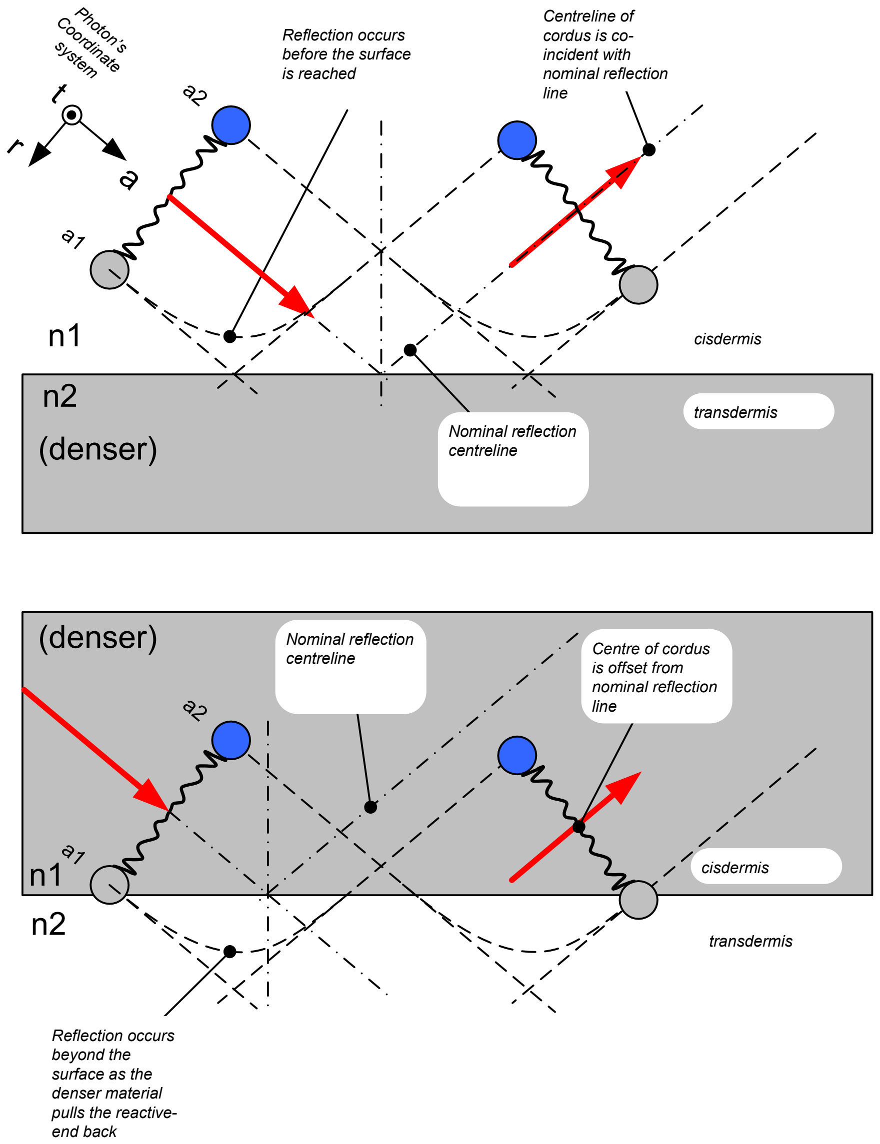
- If the hyff are in the C- frequency state, then they repel the RE from the electrical plane at the surface. This bends the locus back into the first medium.
- Hyff that are in the C+ state draw the RE towards the second medium.

The frequency state may change again before the RE has completed the traverse, in which case the locus may be bent one way and then the other before the outcome is determined.

Transitional locus at reflection

The Cordus models of reflection suggest that the photon does not reflect at a single point, but rather at its two reactive-ends. Furthermore, the precise locus taken by a reactive end depends on its frequency state at the time it approaches the surface, and the nature of the surface. Thus the reflection is not a sharp instant change in direction occurring at the surface, but rather a curved transition. Depending on the situation, that curve might occur above the surface (cisdermis) or beneath it (transdermis).

Consequently the centreline of the reflected cordus may be laterally offset from the nominal: the photon is displaced sideways from where it should be by simple optics. This effect is known for p-polarised light at total internal reflection, and is termed the Goos–Hänchen effect. The Cordus explanation is that the actual reflection occurs in the transdermis in this situation, and Figure 1 provides a graphical explanation of how the offset arises.



(a) Reflection off a denser material (n2>n1)

(b) Internal reflection off a less dense material (n2<n1)

Figure 1: Reflection occurs as a curved transition some distance off the surface (a), not an abrupt change at the precise surface. In the case of internal reflection (b), the transition may occur in the second medium and result in the centre of the cordus being offset from the nominal.

This figure only shows the mean loci for the reactive-ends: not shown are the sinusoidal wriggles that are superimposed. These wriggles add further braided variability of path (within limits defined by the C+ and C- extremes). This is a simple representation, nonetheless it introduces the concept that refection is not a simple point bouncing off a surface, but rather a complex ranged interaction (see also the later Principle of Wider Locality, in 'Cordus Matter').

Steep incidence

If the cordus strikes the surface nearly perpendicularly (low q1) then the hyff plane RT is parallel to the frontal plane of the material. The alignment of the planes maximises the potential for hyff-electron interaction. For RTo material e.g. chrome, the electrons are able to move about to counter all the frequency states of the photon, so the reactive ends are reflected. The dormant phases tunnel through and are absorbed, hence the imperfect reflection.

Shallow incidence

At shallow grazing incidence (high angle of incidence) the reactive ends of the cordus have many opportunities to engage with the plane of electrons that make up the surface, and even materials with low mobility of surface electrons can support reflection.

Ridged mirrors

If the reflecting surface is very small, then the plane for the hyff to engage with is small, and normal specular reflection and refraction will be disrupted. Thus ridged mirrors are used to enhance the reflection of incident atoms. The tentative cordus explanation is that the valleys between the ridges provide a second opportunity for reflection for those REs that tunnelled through the plateau on the ridge.

Phase changes at reflection

The phase of reflected light may be the same or opposite to the incident light, depending on the ratio of refractive indices. For light reflecting off a denser material (higher refractive index), e.g. air to glass, then the polarity is inverted. For reflection off a less dense material, e.g. internal reflection glass to air, then the polarity stays the same. Why?

The external electric field represents the hyff strength, in cordus. So reversal of the electric field at reflection corresponds to inversion of hyff - but this only occurs for passage to a denser medium (higher n_2). Phase is not simply a planar effect, or a mirroring about the interface, since the *side* from which the light comes determines the phase-change.

The cordus explanation follows. We note in passing that phase changes are an interesting effect because cordus interprets them as showing the working of deeper mechanisms, which are useful in understanding other effects.

Reflection involves an interaction between the cordus and the material through the hyff or EM field, and this delays the renewal of the reactive end, but only when the denser material is in the transdermis, e.g. air to glass. This delay corresponds to the $\lambda/2$ phase delay in the Wave Theory. There is no delay in the glass to air case, because the cisdermis is the denser material and the delay has already occurred (in the form of the refractive index).

3.2 Critical angle for total internal reflection

Internal reflection is when light passes from a region of high refractive index n_1 to lower n_2, e.g. glass to air. Usually some of the light is transmitted and other reflected back to material 1. The critical angle is where total internal reflection occurs, i.e. no transmission, and is known to be: $\mathrm{Sin}(\theta_c) = n_2/n_1$. Noting that $n = c/v$ and $v = f \lambda$ where f is conserved but v and λ change, then: $\mathrm{Sin}(\theta_c) = \lambda_1/ \lambda_2$

The angle is measured off the normal to the surface. At steeper angles (θ_1 less than θ_c) some light reflects and some transmits through. As θ_1 increases the refracted ray bends closer to the interface and eventually at θ_c the ray is on the boundary. As θ_1 increases further refraction ceases and all light is internally reflected. The usual explanation is that no refracted ray is possible since it would violate the refraction law. However that does not explain how the law works.

Also, there is something strange happening from a system perspective. When total internal reflection occurs, why should properties n_2 (or λ_2) be required? Since the light stays on the surface and does not go into the bulk of medium 2, why should the property n_2 affect the phenomenon?

The Cordus explanation is that at the critical angle θ_c the reactive end a1 is inserted into in the faster material n_2 at t=0, and therefore moves forward a distance $\lambda_2/2$, see Figure 2. This motion is parallel to the surface because this is the angle of refraction. By comparison at the same time reactive end a2 continues to travel distance λ_1 in the slower medium, before it later also enters the faster medium, at t=1/2 of a frequency cycle. RE a1 is thus accelerated by the sudden freedom of being in the faster medium. The angle θ_c is steep enough to push the RE out of the slower medium, but only steep enough to place it at the boundary. A moment later the second RE is likewise positioned at the boundary.

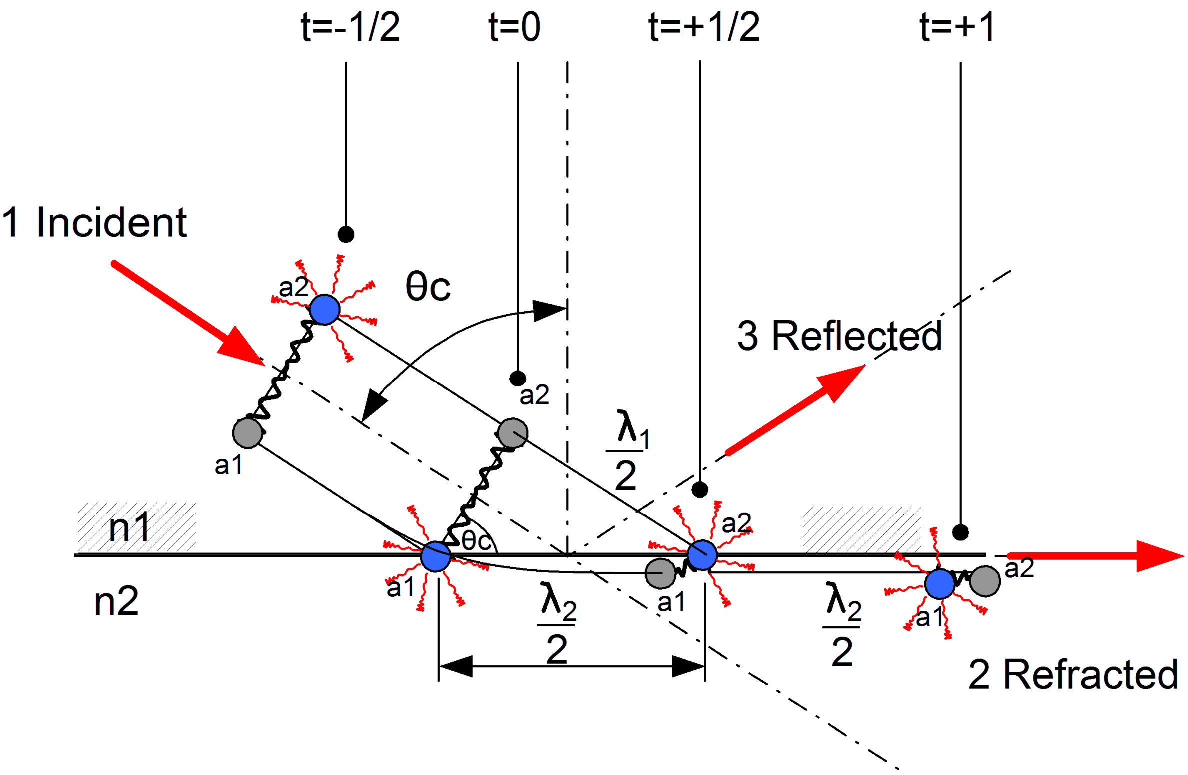


Figure 2: Geometry of the cordus at the critical angle ϑ_c

The important points are:

- Over the period from t=0 to t=1/2 cycles, a1 moves $\lambda_2/2$ whereas a2 moves $\lambda_1/2$, because they are in different media.
- The angle θ_c is such that there is only a half-cycle of frequency involved.

The angle at which the above two conditions is met is apparent from inspection of the geometry in the figure, $\text{Sin}(\theta_c) = \lambda_1/\lambda_2$, and this is the same as the critical angle derived from optics.

The figure illustrates the neat case where a1 is energised precisely at the boundary. In reality the timing is not always so neat, nonetheless the process is believed to work with all incoming frequency states and polarisations because the process itself is gradual, and providing that the range of the hyff is large enough.

The result is a cordus that exits in n_2 along the boundary of the two media. The fact that this occurs at all, regardless of the incident polarisation, suggests that the hyff are all in n_2, otherwise there would be path deflection. This in turn suggests that the hyff are not spherical.

Total internal reflection

Why does total internal reflection occur at all? Why should it be that ALL the photons are reflected? Why is the effect so absolute? The cordus interpretation is that for shallow grazing incidence, i.e. $\theta_1 > \theta_c$ then there is more than one hyff cycle that engages with the interface (at critical angle θ_c there is only one hyff cycle), and therefore certainty that the RE will detect the interface and reflect off it.

But why does the RE always *reflect,* regardless of the frequency state? Why does it not consistently *refract*? The explanation is that the attraction to the cis and transdermis sides is not symmetrical, but favours an interaction with the denser material, see O.4.4 part 2.3. For steeper incidence, i.e. $\theta_1 < \theta_c$, whether the hyff detect the interface depends on their frequency state (phase) at the time of approach. So some reflect and others go through (and onwards to refract).

External reflection

Why is total reflection possible off internal surfaces, but not off external? Why is the effect not symmetrical? This is addressed in O.4.7 (part 2.3). Why is some reflection possible, off almost any surface, with a sufficiently shallow incidence (large θ_1)? The cordus explanation is that this situation gives the photon cordus plenty of opportunity to be in an energised state but with a slow normal closing velocity on the surface (normal momentum). Therefore the surface is able to repel the occasional cordus that is at peak energised state at closest proximity, even if the surface is otherwise not a good reflector.

4 Discussion

While the usual explanation for optical effects such as reflection is wave theory, this paper shows that it is possible to explain the effects using cordus particuloids, and simple mechanics. Reflection emerges, in the cordus perspective, as an effect that occurs at interface surfaces, due to the interaction of cordus hyff with the electrons, particularly the surface plasmons. In this model, the surface plasmons are able to dynamically adjust to the hyff of the approaching photon, and therefore do not provide resistance in the plane of the interface (horizontal direction in the diagrams here). However the situation is very different in the normal direction, since the electrons have limited to no mobility. Consequently the material does interact with the photon in the vertical direction, and this results in reflection. Or refraction, depending on the frequency state at the time.

This model is significant because it shows that the cordus structure of the photon is conceptually valid over a larger set of effects than simply wave-particle duality in the double-slit and interferometers.