Wave-particle duality: A conceptual solution from the cordus conjecture

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Abstract

There are several integration problems of fundamental physics that still lack coherent solutions, the case in point being wave-particle duality. While empiricism and mathematical modelling have served physics well, they have not yet been able to achieve integrated causal models. Conventional theories and approaches have only provided partial solutions, and it is possible that a more radical reconceptualisation of fundamental physics may be required. This work comes at the issue from a totally different approach: it applies design thinking to the problem. The result is the cordus conjecture, which proposes that the photon, and indeed every matter 'particle', has an internal structure comprising a 'cordus': two reactive ends that each behave like a particle, with a fibril joining them. The reactive ends are proposed to be a small finite distance apart, and energised [typically in turn] at a frequency. When energised they emit a transient force pulse along a line called a hyperfine fibril [hyff], and this makes up the field. This concept is used to explain the path dilemmas of the single photon in the double-slit device, and the wave behaviour of light including the formation of fringes by single photons and beams of light. In addition it provides a tangible explanation for frequency. It also yields new quantitative derivations for several basic optical effects: critical angle, Snell's law, and Brewster's angle. Thus the cordus structure offers an alternative conceptual explanation for wave-particle duality.

Il existe plusieurs problèmes d'intégration de la physique fondamentale qui requièrent, encore à ce jour, une solution cohérente. Le problème en question ici est celui de la dualité onde-particule. Alors que l'empirisme et la modélisation mathématiques ont bien servit la physique, ils n'ont pas, à ce jour, permis l'élaboration de modèles causaux intégrés. Les théories et approches conventionnelles n'ont fournit que des solutions partielles, et il est possible qu'une reconceptualisation plus radicale de la physique fondamentale soit nécessaire. Ce travail traite ce problème avec une toute autre approche en appliquant des processus de pensée relatifs au génie de conception. Le résultat est la « conjecture de cordus « qui propose que le photon et en fait toute particule matérielle a une structure interne comprenant un « cordus « : deux extrémités réactives se comportant comme des particules connectées par une « fibrille «. Il est proposé que ces deux extrémités réactives, séparées par une petite distance finie, sont

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énergisées [typiquement tour à tour] à une certaine fréquence. Lorsqu'elles sont énergisées, elles émettent une force impulsive transitoire le long d'une ligne appelée fibrille hyperfine créant ainsi un champ de force. Ce concept est utilisé pour expliquer les dilemmes de la trajectoire d'un photon dans l'expérience de la double fente et le comportement ondulatoire de la lumière incluant la formation de frange par un photon unique et de rayon lumineux. De plus, cela donne une explication tangible pour la fréquence. Cela induit également de nouveaux raisonnements quantitatifs pour plusieurs effets d'optique : l'angle critique, la loi de Snell, et ailleurs l'angle de Brewster. Donc, la structure en cordus proposée résout le problème de la dualité particule-onde au niveau conceptuel.

Keywords: wave-particle duality, photon, light, double-slit, double slot
Document: Pons_2012_WaveParticleDuality_E2.6.27.doc

1 Integration problems in fundamental physics

The dominant existing frameworks for fundamental theoretical physics are quantum mechanics (QM) for particles, electromagnetic wave theory (WT) for light, electrostatics and magnetism, and general relativity (GR) for gravitation. While those are generally accepted as valid in their particular areas, they do not integrate well. Furthermore, their explanations can be difficult to reconcile with physical reality, this being particularly so with QM [1].

A case in point is wave-particle duality. In the double-slit experiment, light apparently sometimes behaves like a wave, and sometimes like a particle, depending on how it is observed. Wave theory and quantum mechanics adequately describe the fringe and particle behaviours respectively, but their explanations do not naturally overlap. Attempts to solve this particular problem result in QM resorting to non-physical mechanisms e.g. both wave-and-particle, virtual particles, many-worlds/parallel universes, or the de Broglie-Bohm pilot wave theory [2-4]. None of these are particularly descriptively congruous with physical reality.

Is the duality even worth solving?

The null explanation is to simply accept the paradoxes and consider the matter intractable. Thus Physics has come to accept the duality as the reality, and after all QM is capable of quantifying the behaviour. That it has been possible to achieve so much with QM, without directly solving the duality, might seem evidence that the duality is irrelevant. If the qualitative descriptions of QM are poor, or seem weird, does that really matter?

We think it does. We think the inability of current physics to provide physically realistic explanations points to a conceptual deficit somewhere. Many fundamental issues, like wave-particle duality, are still unresolved after nearly a century. Thus we take the perspective of epistemic discontent - that cognitive dissonance and lack of integration between theories may be symptoms of a deeper conceptual lack.

However, if there is a deeper theory, e.g. one that subsumes both wave and particle perspectives, it is not obvious what that might be. Also, there is reason to believe, per Bell's theorem, that no theory of internal (or hidden) variables is possible for the photon and particles generally. Thus the problem of wave-particle duality may be fundamentally unsolvable. Nonetheless we see value in exploring new conceptual solutions to wave-particle duality, and that is the purpose of this paper.

The issue preventing resolution is not obviously resources, nor even more accurate physical measurement. Instead, it may be that we have simply painted ourselves into a conceptual corner, one where there is no solution. Therefore, there may be value in coming at the issue from a totally different direction.

2 Approach taken

Methodology

While empiricism and mathematical modelling have served physics well, in this particular case we deliberately approach the problem with a different method, one that is focussed on generating new ideas. This is conceptual design. It is a different way of thinking, and may need a brief explanation.

The conventional scientific method seeks to find precise objective causal relationships (usually mathematical algorithms) describing how the input variables determine the observed behaviour. Variables are invariably quantitative. In contrast, concept-design works with qualitative variables and seeks to find a concept that meets the constraints of the situation. The resulting concept is an idea or descriptive statement of a solution, and the constraints are those requirements that the solution need to fulfil. With design it is acknowledged that the resulting concept is merely a *sufficient* solution, not necessarily the only solution, nor even a perfectly valid solution. Design results in a plurality of sufficient solutions rather than a single uniquely valid solution. Indeed, it is for that reason that the method has been used here, because we wish to see if there are other concepts that might usefully be applied to wave-particle duality.

The general application of the concept-design method involves several activities. First is to note the required features of the solution or the empirical facts of the phenomena: these become the constraints that the solution has to meet. Second is the lateral-thinking process of finding different ideas (or candidate solutions as they are termed), and this is a creative and intuitive process. Third is a process of selecting one idea over the others, typically based on how well it meets the constraints (fitness). Concurrent with this is a fourth activity of testing the idea and iteratively refining and developing it into a workable solution. This may involve discarding some features of the concept, and further developing others. It may also involve dead-ends and return to earlier stages to find other concepts.

Concept-design is a process of synthesis, as distinct to the analysis more commonly used in physics. Yet that does not mean that it is an invalid approach, only that it is unusual in this particular area. Readers will appreciate that in other areas of human endeavour, for example the creative arts, concept-design is the norm and analysis is the unusual method.

Process

In this particular case, application of the concept-design method started with that simple yet subtle experiment: wave-particle duality of the photon in the double-slit device. The empirical evidence for that set of phenomena became the constraints that the concept would have to meet. We then applied the creative methods to come up with a set of starting concepts. Of these one concept, which was a two-ended particle structure, stood out and was selected for further development. Several variants were considered, and the more promising were further developed.

To put it another way, we applied the principle of requisite variability. We considered several different candidate internal structures, determined how well they accommodate the physical evidence, and selected those solutions, or variants thereof, that had the best fit. We progressively refined our solution by exposing it to additional phenomena. We added additional internal structures (hence also variables) to our proposed geometry, as necessary to describe the physical phenomena. We did so parsimoniously. We also checked whether such variables might later be contradicted by other considerations, and where this happened we went back and reworked our earlier design.

The core concept that emerged at this stage was that of a cordus – explained below. Thereafter we admitted further phenomena to the arena, including optical reflection and refraction, and tested the cordus idea against those constraints. Refinement to the concept, particularly in the area of 'frequency', allowed those effects to be explained too. That it was possible to do so, without needing to abandon the concept and seek another, confirms that the cordus idea has conceptual-fitness (which is not necessarily the same as validity). We report the results up to this point in the development.

To create a conceptual model, we needed to make assumptions, add conjectures, and include intuitive material. Thus the central strand in the Cordus conjecture is a set of lemmas, and these we do not attempt to prove, nor are they provided in this summary paper. The resulting Cordus model is primarily conceptual and descriptive, rather than mathematical, at least at this point in time. What we present in this paper is the final result of this process, not all the details of the many intermediate stages in the development of the concept.

3 Cordus conjecture

The Cordus conjecture is that all 'particles', e.g. photons of light, electrons, and the protons in the nucleus of the atom, have a specific internal structure. This structure is a 'cordus': two reactive ends that each behave like a particle, with a fibril joining them. The reactive ends are a small finite distance apart, and energised [typically in turn] at a frequency. When energised they emit a transient force pulse along a line called a hyperfine fibril [hyff], and this makes up the field, see Figure 1 for application to the photon [5].

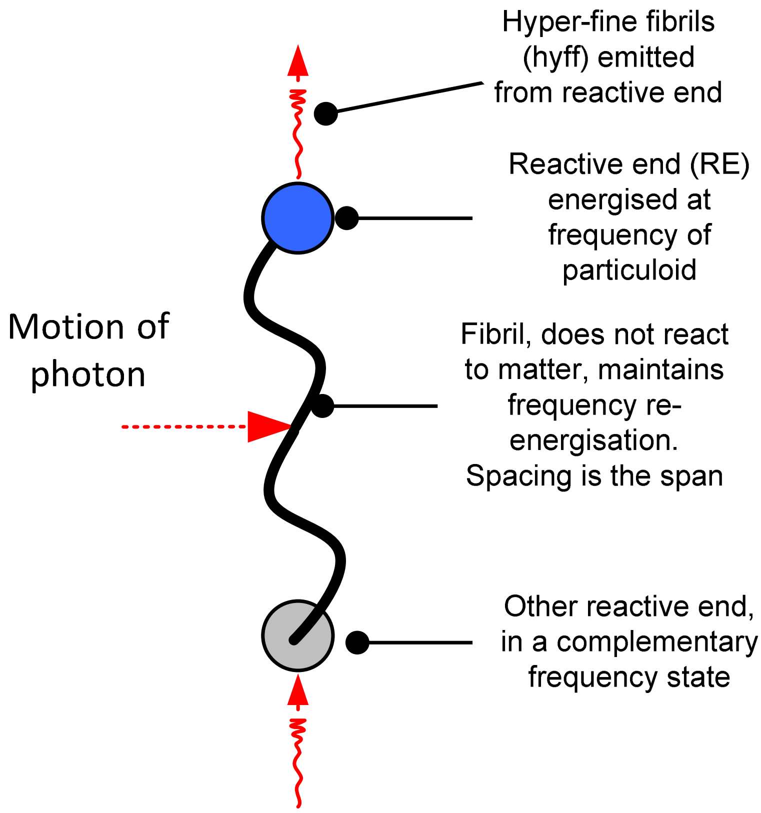


Figure 1: Cordus model of the photon. It is proposed that the photon probably only has a single radial hyff at each reactive end, whereas the electron has three, but the fundamental structural concept is similar. Image is in the common domain http://en.wikipedia.org/wiki/File:CordusConjecture2.21_PhotonCordus.png

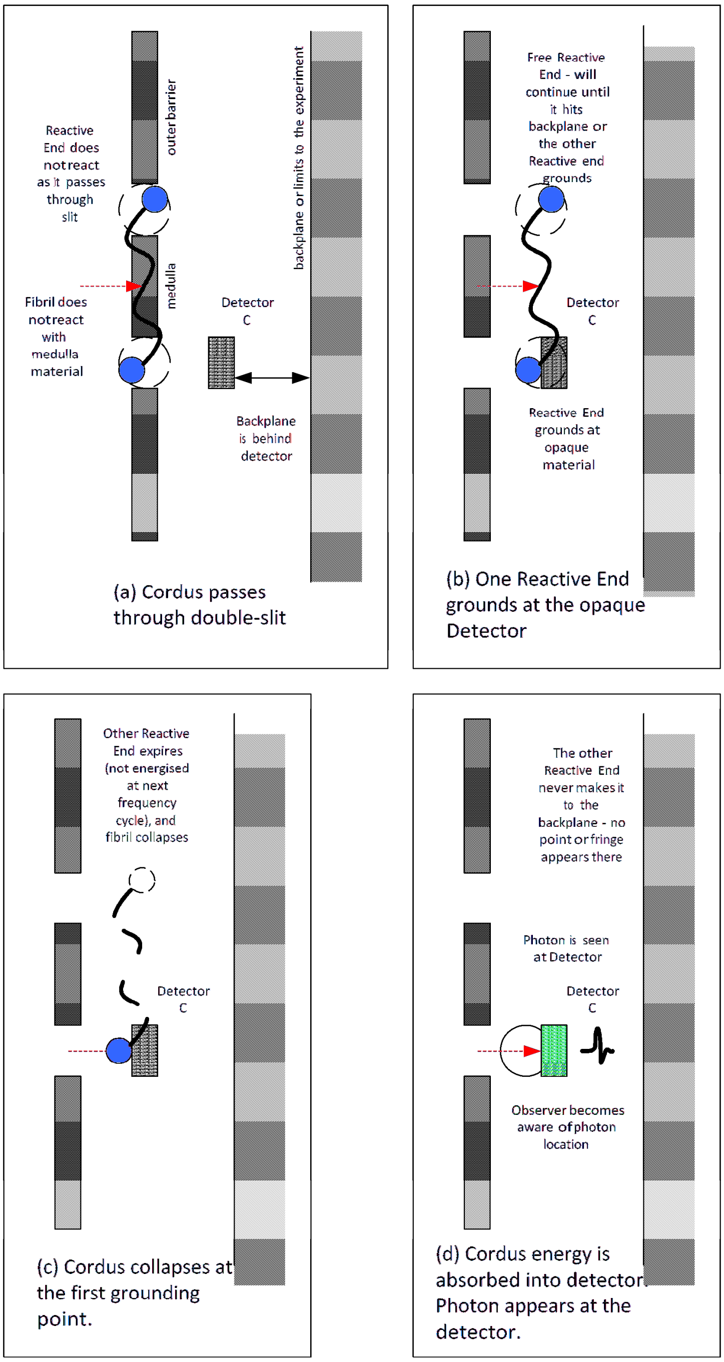
The core concept in the cordus conjecture is thus a particular bipolar internal structure for the photon and indeed all 'particles'. We term this a *cordus particule*, and emphasise that it is the *internal* structure of what is otherwise called a 'particle', and is not the same as a 'dipole' [separation of negative and positive charges] which is an *external* structure. It is not a zero-dimensional point moving along a one-dimensional locus. The idea of a cordus allows many puzzling phenomena to be explained at a conceptual level, starting with wave-particle duality [6, 7].

Double slit device

Light seems to behave either as a wave or a particle in the double slit experiment, and cordus explains this wave-particle duality. Thus the single photon, made up of a cordus, does pass through both slits: one reactive end through each slit. The reactive ends therefore take different paths (loci). The natural variability of the span of the cordus means that the effect is only approximately dependent on the spacing of the slits.

Particle behaviour

Once through the slits, the whole photon collapses to, and therefore appears, at the first place where a reactive end is arrested, see Figure 2. This describes the observed phenomenon that blocking one slit, (or placing a detector only at one slit) causes the whole photon to appear there.



Photon behaviour in the double-slit experiment with only one detector

Figure 2: Photon behaviour in the double-slit experiment

Wave behaviour and fringes

This basic idea can also explain how the fringes arise in single gaps and double-slits. Each of the two reactive ends also interacts, through the hyff electric field with the opaque material bounding the slits. The hyff become engaged with the surface plane of the material and exert a quantised force that retards the reactive ends and bends its trajectory by set angular amounts, causing fringes at set intervals.

The double-slit device best shows the fringe behaviour because the short-span cordi are barred entry by the medulla. Thus the device imposes an upper and lower filter on the range of spans admitted. Hence narrower slits produce more pronounced fringes.

The two locations of the fringe are the modes of the reactive ends, and it is somewhat random as to which will ground first. Note that this explanation accommodates the fringe behaviour of both single photons and beams of coherent light. Thus a solitary photon will be deflected into discrete angular steps, and will appear at one of the fringe locations. A whole beam of coherent light will likewise form fringes because all the photons have the same discrete angular deflection, providing that they are of the same energy. In the cordus model higher energy particules (i.e. also higher frequency) have shorter spans.

This also explains why both photons and electrons form fringes: in both cases the fringes arise because of the interaction of the electric field, which is in discrete pulses, with the frontal surface plane of the matter bounding the slit.

Wave-particle duality

The significance of this is that one mechanism, the cordus, is able to explain all three phenomena in the double slit: the blocked-slit behaviour of an individual photon, the fringes formed by multiple photons taken singly, and the fringes produced by of a beam of light. The same mechanisms also describes photon path dilemmas in interferometers [6].

4 Cordus mechanics

The basic cordus concept is now expanded and grounded in known phenomena to extract the broader mechanics for optical reflection and refraction.

4.1 Cordus frequency

Conventional particle and wave theories struggle to explain the frequency of photons and matter in a coherent manner using natural physics. By comparison, the cordus readily provides a physical interpretation. Thus it is proposed that there really is a part of the photon cordus that moves with a frequency [8]. The current working model is for a reciprocal motion: the energy alternates between the two reactive ends across the span of the cordus, and the hyff represent the observable electric field, see Figure 3.

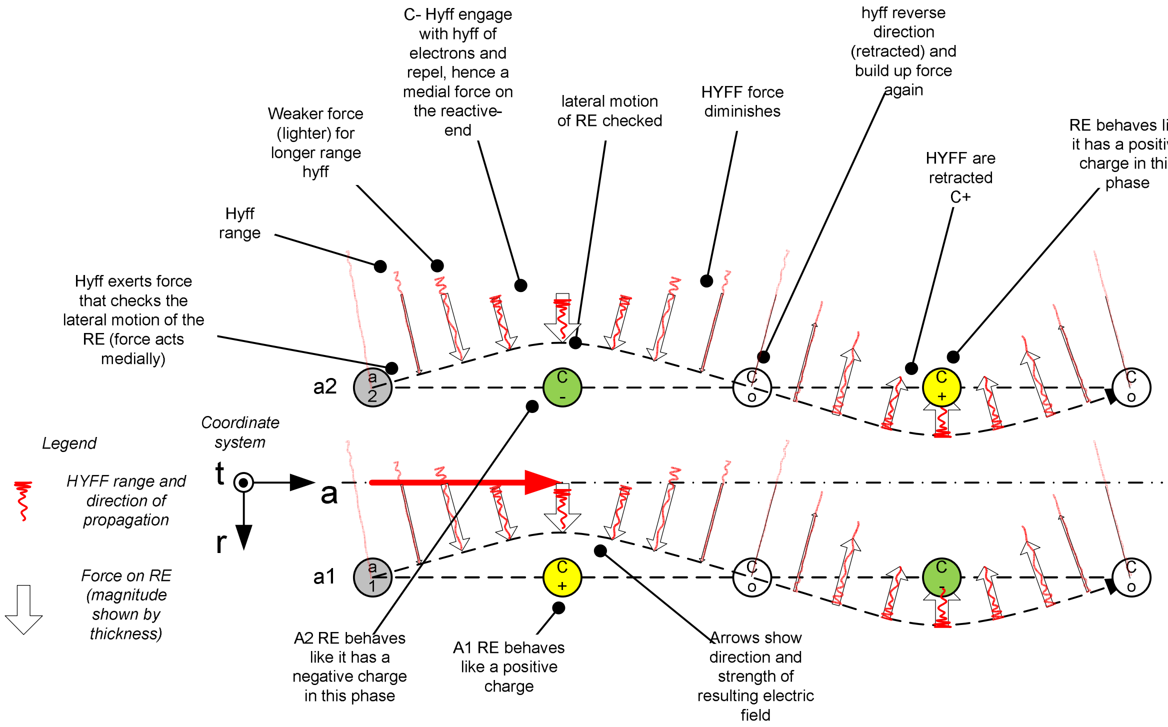


Figure 3: Working model for frequency behaviour of reactive ends.

This cordus model for frequency readily describes polarisation too: this is the orientation of the cordus relative to the line of motion. It also explains tunnelling. This effect involves a photon occasionally going through a barrier (e.g. the space between two glass prisms) instead of being reflected. The effect requires a small gap, and is known to be dependent on frequency. Tunnelling, from the cordus perspective, is when a reactive end energises too late for its hyff to respond to the change of media, so the reactive end goes right on through into the next medium before it has time to re-energise.

4.2 Reflection

Optical effects such as reflection and refraction are conventionally best described by electromagnetic wave theory, at least when they involve beams of light. 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. 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. Nor does that theory explain why single photons should also show such behaviour. Explaining basic optical effects is not possible with classical particle mechanics, and even with quantum mechanics it is not straight forward and the descriptive explanations not particularly intuitive.

Optical effects can be described from a cordus particule perspective [9]. Importantly, this explanation is applicable for single photons and beams of light. The Cordus explanation is that both reactive-ends of the cordus separately reflect off the surface as their hyff interact elastically (lossless) with the substrate. 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 4 provides a graphical explanation of how the offset arises. Phase changes at reflection are also explainable [9].

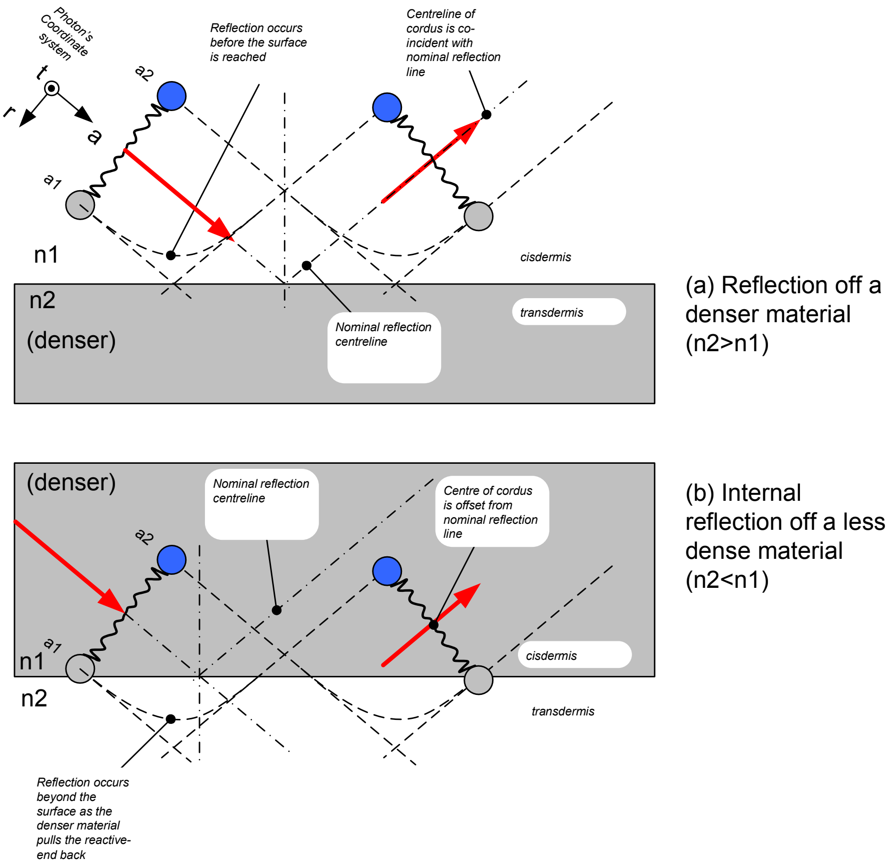


Figure 4: Reflection occurs as a curved transition some distance off the surface (a), not an abrupt change at the precise surface. In the case of internal reflection (b), the transition may occur in the second medium and result in the centre of the cordus being offset from the nominal.

Cordus derivation of critical angle

Critical angle for internal reflection is also explainable [9]. Internal reflection is when light passes from a region of high refractive index n_1 to lower n_2, e.g. glass to air. The critical angle is where total internal reflection occurs, i.e. no transmission, and is known to be: $\text{Sin}(\theta_c) = n_2/n_1 = \lambda_1/\lambda_2$ where λ are the wavelengths.

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 5. 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.

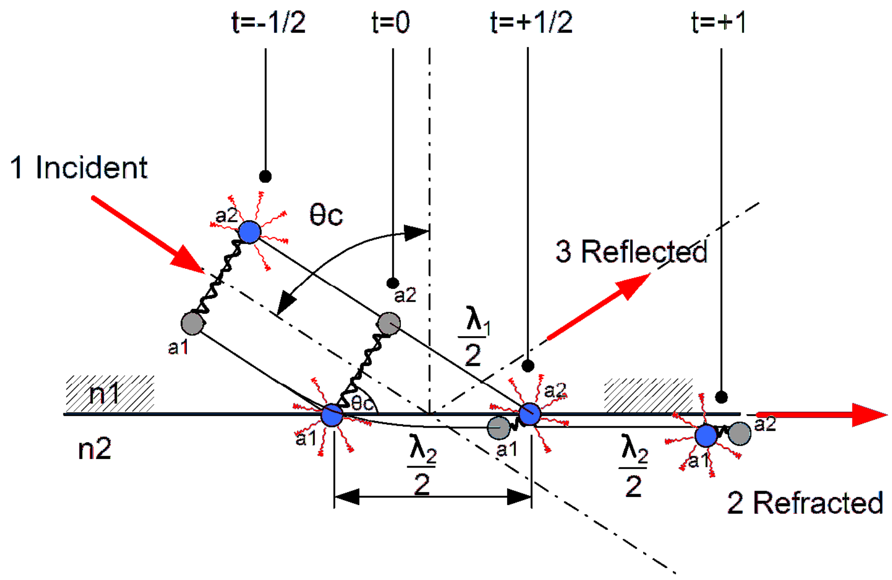


Figure 5: Geometry of the cordus at the critical angle ϑ_c for total internal reflection.

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, $\mathrm{Sin}(\theta_c) = \lambda_1/\lambda_2$, and this is the same as the critical angle derived from optics. For more details see reference [10].

4.3 Refraction

The bending of light as it enters an inclined boundary is usually explained in optical wave theory as a change in the speed [phase velocity], such that the wavelength changes but not the frequency. The angle of refraction θ_2 in the second medium (2) is given by Snell's law: $\sin\theta_2 = v_2/v_1 .\sin\theta_1 = n_1/n_2.\sin\theta_1 = \lambda_2/\lambda_1.\sin\theta_1$ where the angles are measured from the normal to the surface, and v are the velocities in the two media. Explanations vary for *how* the change in speed occurs. The wave interpretation is that the delay occurs because the electric field interacts with the electrons to radiate a delayed wave, thereby forming the new but slower wave. Hence the Huygens–Fresnel principle that each point on the wave propagates new waves and these interfere.

The Cordus explanation for refraction [11] is that the inclined incoming cordus strikes the surface and one reactive-end and then the next penetrates into the second medium n_2. Assuming the case where n_2 is more dense, e.g. from air to glass, then the cordus slows down. The case is shown in Figure 6.

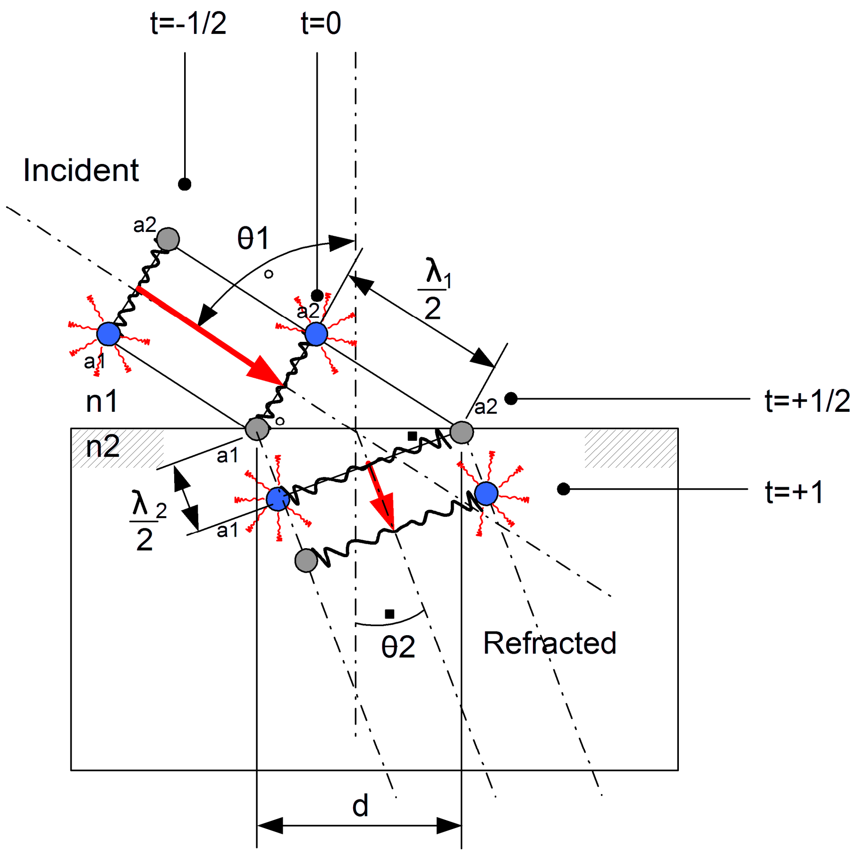


Figure 6: Refraction involves a dormant reactive-end penetrating into the second medium, and being angularly deflected with reduction in speed.

Cordus derivation of Snell's Law

The separation of the reactive ends along the interface, in Figure 6, is given by d = $\lambda_2/(2.\sin\theta_2) = \lambda_1/(2.\sin\theta_1)$, which simplifies to Snell's law. The frequency and other forms arise by noting that v_1=f. λ_1 and v_2=f. λ_2 and n = c/v where c is velocity of light in vacuum.

Birefringence is also explained by cordus, and Brewster's relationship derived. The cordus mechanics for optical phenomena are the same for single photons and beams of light, which is an advantage compared to wave theory. The same cordus mechanics are logically consistent with those for the double-slit device. Therefore cordus can describe particle behaviour, fringes, and optical effects, using a single coherent mechanics. The cordus explanation does not need the conventional concept of 'interference'. In fact cordus refutes interference as a physical mechanism. Instead cordus asserts that interference is only a mathematical model of the en-masse behaviour of the hyff from multiple cordi.

5 Discussion

Outcomes

What has been shown here is a different *conceptual* way of looking at several problems in fundamental physics:

1. The proposed two-ended cordus structure of the photon explains the path dilemmas of the photon in the double-slit device: one reactive end goes through each slit, and the photon collapses and becomes detected at the obstacle which first stops one of the reactive ends. The same principle also explains the path dilemmas in the Mach-Zehnder interferometer. Thus the 'particle' behaviour of the photon can be described.

2. The cordus structure also offers a descriptive explanation for the wave behaviour of light, particularly the formation of fringes in gaps, apertures, and the double-slit device. The suggestion is that these fringes form, not from classical destructive/constructive interference, but by the interaction of the electric field, which is discrete, with the frontal surface plane of the matter bounding the slit.

3. Cordus also provides a descriptive explanation for frequency of the photon, electron and matter generally. By comparison the idea of 'frequency' is difficult to express in a 0-D point construct.

4. Cordus also provides a novel explanation for the standard optical effects of reflection and refraction. The cordus conjecture as a whole is primarily conceptual, being a thought-experiment, but this is one area where it goes further: it provides a quantitative derivation of critical angle, Snell's law, and Brewster's angle. This is novel in that the derivations are from a different set of starting assumptions to wave theory or quantum mechanics.

Wave-particle duality

Thus the proposed cordus structure offers a different conceptual solution to the problem of wave-particle duality. A simple deterministic, unintelligent photon with dual modes of existence is all that is required. From this cordus perspective, wave and particle behaviours are simply the different output behaviours that the internal particule system of the photon shows depending on how it is measured.

Some may argue from a phenomenological position that no solution of hidden internal variables, such as cordus proposes, is permissible, as per Bell's Theorem. However we suggest that theorem is constructed on the premise that particles *must* be 0D point particles, and therefore uses circular reasoning based [12]. Bell's Theorem is relevant to solutions that use a 0D point design, but is not an impediment to hidden-variable solutions in general.

Implications

This paper describes only some of the features of the cordus conjecture. It has not solved all the integration issues, and much work remains to be done to check the mathematical validity of the idea. Nonetheless the cordus idea provides a logically consistent conceptual framework across the many physical phenomena, including others not detailed here. These others include entanglement and locality [12], special states of matter and coherence [13], discrete electric fields [14, 15], antimatter [16], and annihilation [17], among others. Achieving that without having to revert the basic concept gives confidence that the cordus idea has some conceptual fitness. The material is of course conjectural, as the title suggests, and should be considered merely a conceptual thought-experiment.

Comparison with electromagnetic wave theory

The biggest difference between wave theory and the cordus explanation is their interpretation of the mechanism for fringes. Wave theory describes fringes as 'interference': two separate waves of light differing by full (or half) fractions of wavelengths and thus constructively (or destructively) interfering. From the cordus perspective photons do not actually physically interfere or add together, and fringes are caused instead by interaction of the discrete field structures (hyff) with opaque planes.

Comparison with quantum mechanics

From the cordus perspective, quantum mechanics represents the average *output behaviour* of the particule, not the behaviour of the inner system. Hence the predominately statistical nature of the QM formulation.

Epistemological implications

Cordus is a thought-experiment. The treatment is primarily conceptual and descriptive, and the cordus mechanics only lightly sketched out. It is a conceptual model, not so much a full theory with all the details worked out. Thus the validity is uncertain, and the concept requires further critical evaluation.

6 Conclusions

The purpose of this paper was to explore new conceptual solutions to wave-particle duality. The results suggest that it is possible to reconceptualise the idea of a particle, with interesting outcomes. It is proposed that the photon has an internal structure after all, comprising two-ends and discrete field structures. This can conceptually explain both particle and wave behaviours. It explains the path dilemmas in the double-slit device, and the fringes made by single photons or a beam of light. It also derives the quantitative relationships for several optical reflection and refraction effects. It makes sense of the concept of frequency, which is otherwise a concept without a physical interpretation. Even more surprising, and unexpectedly contrary to the prevailing probabilistic paradigm, cordus suggests that reality is deterministic, but at a higher frequency than we can readily observe.

Acknowledgements
We acknowledge with gratitude the assistance of Dr Mathieu Sellier for translating the abstract.

List of captions

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