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Bragg's law, continuity and discreteness[1]

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RÉSUMÉ. La découverte de la fonction d'onde associée à l'électron, par la richesse de ses applications, a conduit souvent à oblitérer l'aspect corpusculaire de particules comme le photon ou l'électron entre autres. Pour tant sur le plan de la réalité physique c'est le discontinu qui prime sur le continu, tout objet occupant un volume bien défini. Si l'onde nous permet une description de certains phénomènes il y a lieu de l'associer à un flux de particules sans oublier de décrire l'aspect corpusculaire. Nous proposons une approche corpusculaire concernant la réflexion de Bragg

ABSTRACT. The discovery of the wave function associated to the electron, due to the abundance of its applications, has often led to obliterate the corpuscular aspect of particles as the photon or the electron among others. But the prevailing aspect in the physical reality is the discontinuous, since each object occupies a certain volume. If the wave allows a description of several phenomena, one appropriately associates it to a flux of particles without forgetting to describe the corpuscular aspect. We propose a corpuscular approach concerning the Bragg reflection.

1 Introduction

Up to the beginning of the twentieth century, the mass of a body has been conceived as invariable. This conception was linked to the notion of inertia that is to the resistance a physical body opposes to a velocity variation. Inertia seems to coincide with mass. However, after proposing in June 1905 his theory of special relativity [1] Einstein showed, in September of the same year, that « if a physical body undergoes an energy loss L in the form of radiation, its mass decreases by L/c^2 » [2]. Here is a clue allowing to assume that acceleration can be described by the means of mass exchanges in the form of matter grains, whose volume and mass are much smaller compared to particles as electrons and protons. This approach has at last allowed to propose, taking support of some magnetic properties of different elements and compounds, an interpretation of hydrogenous atoms of the corpuscular model [3]. So the particle acceleration becomes part of the special relativity, and the space where our observations are placed defines uniquely in presence of matter. A body's motion can only be described with reference to another one and the field concept associates with matter flowing between

[1] This is the English version of the French work: "La loi de Bragg, le continu et le discontinu", published in: Ann. de la Fondation Louis de Broglie, 38, 33-39, (2013).

the two. This approach emphasizes the difficulties one meets investigating phenomena from the discontinuity aspect of the matter compared to the continuous space notion, as particularly in wave optics. At a macroscopic scale, the space appears to us essentially continuous but we have learnt that, a crystalline medium is discontinuous so that our notions of points, straight lines and surfaces are inadequate to understand phenomena on atomic or electron scale, it is the problem of continuity and discreteness recently discussed by Bocvarski, Baudon and Reinhardt [4].

So what kind of matter we have to consider, for instance, when light interacts with a reflecting or diffracting body? Have we to think light as made up of photons with both well-defined energy and momentum, although in limited volumes? To tackle these questions let us start with coming back to the synchronous motions of electrons in their quantum states.

2 Synchronous bond

The study of the quantum state leads to recognize the existence of a quantum of action ***h*** imposing to the action of the motion to be an integer multiple of quanta over a period, for each electron. The periodic table gives a remarkable synthesis of this property. In particular, it shows that each element, through an important number of properties, keeps the mark of the quantum state corresponding to its place. This quantum state is the one corresponding to the additional electron of this element. This fact, is interpreted supposing that the interactions are the result of exchanges of mass, described as very small grains, between the atoms, that is the nucleus and the electrons [3]. These exchanges thus allow to modify the period of the trajectory of the interacting electrons, in such a way to keep the number of quanta of the trajectory.

Therefore in the solid state the electrons belonging to different atoms, in a same quantum state and in the same crystallographic site, have synchronous movements [5]. Let us first consider an elliptical trajectory in an hydrogenic atom. To characterise the syncronisation of the motions, consider in a crystal, a chain of atoms of the same chemical species and of same cristallographic site. In this chain let us consider two neighbour atoms A and B and in each of them an electron in the same quantum state e_A and e_B (*figure 1*). To simplify the figure their motion is supposed close and periodic, but the following reasonings stay valuable with almost close motions.

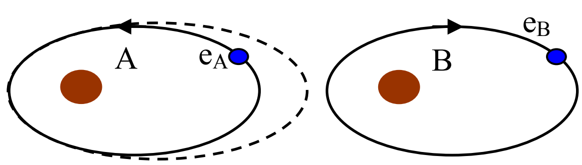

Figure 1. The contraction of trajectory with the interaction between the electron of an atom A and the positive charge of a neighbouring atom B. Dashed line, trajectory without interaction; full line, trajectory with interaction.

In absence of disorder at zero Kelvin degrees, there is a correlation between the motions of the bonding electrons in such a way that the maximum of cohesive energy is attained. For example the e_A electron goes in between A and B when e_B is as far as possible from e_A. Thus the kernel of B attracts the electron e_A, but the presence of e_B prevents it from leaving its atom. The same occurs for e_B in connection with another neighbour in this chain, and so on.

As a result, the energy of bond of the electron to the kernel of its atom is higher and the trajectory contracts as pointed out in figure 1, thus preserving the number of quanta of its state that is the constant value of the action along its trajectory. So the kernel of an atom attracts more each of its electrons of bond, than the one of another neighbour. It is the same for the set of directions where there are chains of identical atoms. There is synchronisation of the motion of the electrons being in the same quantum state on an atom of the same chemical species and in the same crystallographic site. In addition, this notion of synchronisation is still gradually valuable with successive neighbours, in non-crystalline solid as glasses and amorphous solids.

3 The reflection and the photon

Let us consider a metallic surface made up of a single species of atoms, lighted up by a monochromatic, coherent, visible light beam. Because of the weak photon energy, they do not penetrate deep into the metal so that only the atoms of the surface reflect the visible light. To explain the interference with a very low flux of photons we have supposed that each photon is absorbed on an atom, causing breaking of the corresponding synchronous bonds, so that after time they are in sufficient number to exhibit interferences [6]. This hypothesis is to compare to the fact that there is no perfect crystal and that the symmetry assumption of the site is an approximation, as we have recently underlined with the violation of the selection rules [7]. As a result, during the absorption, the electron absorbing a photon can modify its trajectory. Thus, one has in the case of the reflection to take again this hypothesis of the absorption of the photons. To have a better understanding of this property it is useful to consider the following description of the photon.

We assume the photon made up of a flow of grains moving at the light velocity. The same velocity is assumed for the grains exchanged between the nucleus and the electron. The photon matter flow is emitted into a precise direction during the motion of the electron around the nucleus; note that, as a result of the interactions, this flow comes from the emitting atom that is mostly from the electron, but from the nucleus and the atomic neighbourhood as well. The photon has no inert mass but the sum of its grains amounts to an equivalent mass making up the energy $E = mc^2$. During the emission the emitting electron and the nucleus around which it is orbiting, lose a given momentum p, the same which will be transmitted to the electron and atom going on to absorb the photon afterwards.

Photons will be reemitted, soon or late after absorption. In order that the photon is reemitted leaving the electron in a synchronous motion with other non-absorbent electrons in the atoms nearby, it is necessary that the electron orbital components are the same that before absorption. This process can occur if the additional parallel translational component given by the photon at the absorption can be subtracted at the emission. This implies that the photon leaves the electron with a reflection angle equal to the incidence one. Thus, it gives raise to the reflected beam implying the reflexion law by the notion of photon.

4 The coherent emission

This approach of the reflexion leaves aside the capacity of the photons to interfere. To understand this property, consider the photons arriving on the surface, we suppose that they are coherent, that is they are separated in time by an integer number of periods T. Since they have been emitted by different atoms, they are also separated in space, what implies that every plane intersecting the light beam is crossed by the photons in a multitude of small distinct spots. When striking the metal surface they are stocked into different nearby atoms and, for each atom, by an electron on an identical quantum state.

During photon absorption, the absorbing electron e_A modifies its trajectory, decreases its binding energy, partially in mass form, and changes its moment components. The trajectory without the photon corresponds to the maximum of bonding energy; after the absorption the electron e_A is in a new equilibrium state where the bonds of the atom with its neighbourhood are different, the absorbing atoms then have a different site of those having not absorbed a photon. The momentum of the absorbing electron has an orbital rotation component, another one of parallel translation with respect to the rotation axis, and a radial component. By action and reaction the grains composing the photon matter modify the electron momentum in the photon propagation direction. The electrons having absorbed a photon, have a different period and tend to have synchronous motion, ***there is coherence***. They give to their atom a different character allowing them, as far they are not in a too great number, to ignore their neighbourhood. This is possible for the coherent absorbed photons. Indeed such photons arrive all separated in time by the same period; on the other hand, the absorbent electrons in their site start the absorption in the same spatial and temporal conditions, the direction of the beam staying the same.

The reemitted photons thus give raise to a coherent emission, this allows to understand the coherence of the reflected photons during the reflection. Indeed, the great number of absorbed photons is not compatible in the long term with the metal solid state and as soon as a photon leaves the absorbing atom, it implies disequilibrium in the crystal determining the emission of many photons.

5 Bragg's law

The X diffraction is governed by the same reflection law with a restrictive condition because of the deep penetration of X photons. Let us consider an X-rays beam reaching on a crystal, *figure 2*. X rays penetrate the crystal. Every crystal plane can reflect the beam; the reflected photons by different planes will be reemitted in the same direction of reflection, if the time interval between the planes is equal to an integer number of periods. The electrons having absorbed a photon then have synchronous motions. Be then *d* the distance between the parallel planes including A et A_1. Be π_i and π_r the planes orthogonal to the incident and reflected rays. The reflected ray in A_1, compared to the one reflected in A, goes through an additional distance $mA_1 + A_1n$:

$$mA_1 + A_1 n = 2d\sin\theta \qquad (1)$$

The additional time interval to run over that distance is:

$$\frac{2d\sin\theta}{c} = nT \qquad (2)$$

i.e. :

$$2d\sin\theta = n\lambda \qquad (3)$$

There again, the atoms having absorbed a photon become different as a result of their bond with the neighbourhood and the absorbed photon can stay stocked during a certain time. Photons will be reemitted by stimulated emission into directions obeying to Bragg's law.

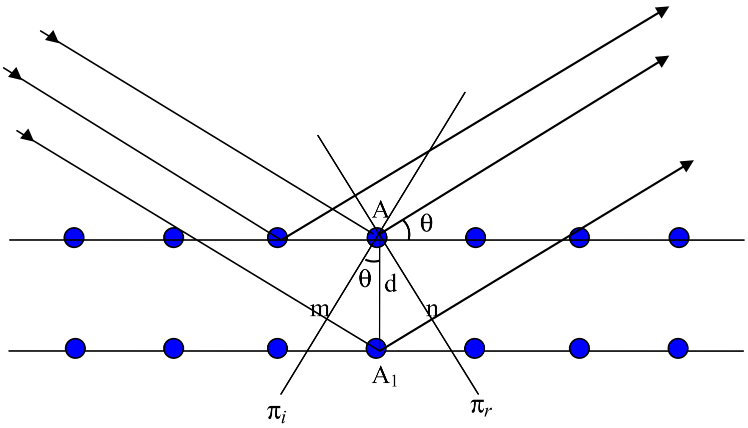

Figure 2. Bragg's law demonstration.

6 Conclusion

The Louis de Broglie assumption of a wave associates to the electron led to the discovery of the wave equation. It extends the continuum notion at the scale of the atomic interactions. So the continuum looks to us strongly linked to discreteness. However, we must keep in mind that a point is a mathematical object without a volume, so it cannot have a physical reality [7]. The continuum is a very comfortable utility but one has to keep in mind that material reality is discreteness. It has been by underlying that light comes from atoms, i.e. from a finite ensemble of atoms, that Einstein proposed the photon hypothesis [8]. Let us then come back to the symmetry between the motion of a mobile and the propagation of a wave which led de Broglie to associate a wave to the electron [9], it comes then possible to associate a flow of material particles to the wave, per example to light, in this way rejoining the Einstein photon hypothesis. However, when the number of photons becomes small, the continuum (i.e. the wave) is of no help any more to explain interferences: then one has to consider the concepts of the storage «in situ » of the photons to explain them [6].

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