HYPOTHESES ON THE A PRIORI RATIONAL NECESSITY OF QUANTUM MECHANICS

GERARD GOUESBET
Université de Rouen

Abstract. There is a huge number of laments concerning the lack of intelligibility of quantum mechanics. Some ingredients of quantum mechanics may however be possibly understood by referring to first principles, that is to say to basic principles (or postulates) which are clear and distinct to the intuition. In particular, if we rely on a first principle called non-singularity principle, which may be viewed as a hypothesis, we claim that quantum mechanics can be viewed as the *a priori* consequence of a rational demand. The status of the non-singularity principle, obvious to most physicists, may however be criticized, on the basis that there is no universal intuition and that any statement is in principle revisable.

Keywords: Quantum mechanics, rational necessity, non-singularity principle, optical rainbow, mechanical rainbow, ultra-violet catastrophe.

1. Introduction

There is a huge number of laments concerning the lack of intelligibility of quantum mechanics, not only from students but also from experts in the field, such as by Einstein, Schrödinger, Feynman, Gell-Mann, and even Bohr ... that we may compile from various sources such as Squires 1986, Heisenberg 1972, Feynman 2000, Omnès 2000, Gell-Mann 1981, 1995. Van Fraassen acknowledged that, *to a traditional mind, quantum theory is perplexing—and we all start with traditional minds* (van Fraassen 2000). Nevertheless, even after having been learning, studying, thinking, and having spent a lot of time to escape from tradition, the perplexity of the mind is still there, may be not for a few inspired individuals, but at least for most of us.

The lack of intelligibility of quantum mechanics ultimately originates from two sources (i) the strangeness of quantum events, so remote from our everyday experience, making our physical intuition hopeless and (ii) correspondingly, the lack of *a priori* principles (later called first principles, not to be confused with basic principles or postulates), making our intellectual intuition disarmed.

In this paper, we argue that, if we accept to rely on two hypotheses (which easily match the intuition), one concerning the power of reason, the other the rejection of any actual infinity in space-time, then we obtain the result that quantum mechanics, for matter waves, may be viewed as the consequence of an *a priori* rational demand. In other words, it is rationally necessary. Telling that a certain thing is necessary,

Principia **14**(3): 393–404 (2010).
Published by NEL — Epistemology and Logic Research Group, Federal University of Santa Catarina (UFSC), Brazil.

and could not be otherwise, and understanding why it is necessary, transitively (by transitivity from the understanding of the necessity of the thing to the thing) provide an understanding of the thing itself.

The paper is organized as follows. Section 2 discusses the first hypothesis, telling us that we are allowed, at least tentatively, to use our mind to detect *a priori* principles which, when they match our intuition, are called first principles. Section 3 introduces the second principle under the form of a non-singularity principle. Section 4 discusses facts of matter and of radiation (optical rainbow, mechanical rainbow, ultra-violet catastrophe), introduces the idea of the rational necessity of wave mechanics, and provides additional comments on the non-singularity principle. Section 5 is a conclusion.

2. First hypothesis: we can detect *a priori* principles

Even nowadays, there is no general agreement on the issue to know whether we can or not detect *a priori* principles, or more generally develop *a priori* demonstrations. In favor of the hypothesis that we can indeed detect *a priori* principles and/or run *a priori* demonstrations, we had Plato and his world of Ideals, Descartes (this high priest of rationality) and his world from God, and Kant and his synthetics *a priori*. Also, it is certainly fair to say that most mathematicians (which do not have to rely on experiments to manipulate their concepts and symbols, and to give sense to them) are instinctively Platonists, like the emblematic Erdös with his Big Book (Hoffman 2000). We must furthermore mention Einstein's belief that *pure thought is competent to comprehend the real, as the ancients dreamed* (Forsee 1963). Against the hypothesis, we might meet a collection of positivists (in the mood of the process of dissolution of metaphysics) and of naturalists. In this paper, the hypothesis is accepted, that is to say we give some credence to the power of reason, although we know, if only from features pertaining to the history of science, that this credence may be misleading and has to be dressed with a certain amount of suspicion. One of the best way to give credit to the credence is to refer to an efficient tool of research used by theoretical physicists, known as Gedanken Experiments, made famous by Einstein (although the word is usually better attached to the name of Mach).

To illustrate the power of mind, and its ability to run *a priori* demonstrations, reflected in Gedanken Experiments, I shall be content to provide a very striking and emblematic example borrowed from Galileo Galilei. Following this scientist, let us consider two objects of masses m and M, with $M > m$. According to Aristotle, the heavier object of mass M must fall down at a velocity v_M larger than the velocity v_m of the lighter object ($v_M > v_m$). Now, let us make a third object of mass $(M + m)$ by assembling the two previous objects. Since we have $(M + m) > M$, the velocity v_{M+m} of the composite object must be larger than the velocity of the object of mass M: $v_{M+m} > v_M$. However, we may take another point of view. When falling down, the lighter object of mass m in the composite system, falling down slowly, must decelerate the heavier object of mass M, falling down quickly, and reciprocally. Therefore, the composite object must fall down with a velocity comprised between v_m and v_M: $v_M > v_{M+m} > v_m$. Hence a contradiction. By using only the mind (this mysterious entity with mysterious properties), Galileo Galilei obtained some kind of knowledge on the laws of nature, and this: *a priori*, in the Kantian sense. After two millenia of dominance, the mechanics of Aristotle was destroyed in a few lines.

Another example, concerning the relativity theories, is more directly related to the use of first principles in physics. The special principle of relativity states that the laws of nature have to be the same in all inertial reference frames. Its extension in general relativity states that the invariance of the laws of nature should remain true in all reference frames, whether inertial or non inertial. These are rather technical accounts. But, if we accept the anthropocentric point of view to attach a human observer to each frame, the meaning is incredibly clear and distinct. It is simply a principle of mediocrity. It means that the laws of nature should be the same whether they are expressed by Einstein or by Bohr, by Alice or by Bob. Although it took a long time since *homo faber* and the beginning of *homo sapiens* to express it clearly, the principle of relativity, which nowadays possesses the taste of a Kantian *a priori*, is something that we would like most reluctantly to challenge. It is a basic principle of physics in the strongest sense, perceived as obvious by the intuition, that is to say a first principle.

In this section, I did not intend to make any theory to explain how and why we can correctly *a priori* demonstrate and reach first principles. I just intended, and this is sufficient for the sequel, to exemplify that it is indeed possible.

3. Second hypothesis: the non-singularity principle

The concept of infinity has been a subject of great debates among mathematicians, philosophers and physicists. For mathematicians, let us just recall that many of them are keen to accept the use of infinities, with Cantor as the most famous architect of infinities in the mathematical world, while others are reluctant to use them, in the mood of a current named finitism, well represented by Kronecker (a contemporary fervent opponent to Cantor). Concerning philosophers, let us here recall two milestones, namely Zeno of Elea and his paradoxes, in the pre-socratic age, and Aristotle who accepted the infinity of time but rejected the infinity of space (Aristotle 2004), and introduced the distinction between potential and actual infinities. Indeed, for Aristotle, an infinite body is impossible, with an argument running as follows. Assume a physical object which is infinite. Then, it is boundless, but a body must have bounds. Hence, the associated infinity does not exist. Much later on, Kepler, at the frontier between the two systems of the world (the closed world of Aristotle and the modern one), was still sharing the same opinion. For Kepler, an infinite body cannot be understood by the mind, and the concept of infinity, such as perceived by the mind, cannot refer to an actual infinity, in so far as an infinite measure cannot be conceived (Koyré 1973). A bit later on, Galileo Galilei, in a letter to Ingoli, could ask: don't you know that it is still not certain (and I believe it will always remain so for human science) whether the world is finite or infinite? (Koyré 1973). Nowadays, it is fair to state that the issue is still not solved. What we can reach with our sense data, dramatically improved by our modern cosmic probes, is limited (and finite) inside a cosmic horizon inescapably generated by the speed of light. What happens behind this horizon is empirically inaccessible, and might be spatially infinite, in the same way that the extension of time might be infinite as well. But, *locally*, with respect to space and with respect to time, physicists are very reluctant to accept the (*in concreto*) occurrence of actual infinities in the real concrete actual physical world of phenomena evolving in space-time (or in its degenerated space *and* time version), even if infinities are conceivable in the mind and encountered (*in abstracto*) in the mathematical world.

We now convert this reluctance to a first principle, named the non-singularity principle, which forms our second hypothesis, telling us that "local infinity in physics is not admissible", that is to say: a local infinity in physics is an impossible happening, or: nature (locally) abhors infinity. This should be easy to accept for physicists who most usually would not accept an infinite result when measuring something. For example, a local body with infinite mass or containing an infinite amount of usable energy would be implacably frightening. Yes, physicists use the notion of infinite plane waves, but they are well aware that it is an idealization which simplifies their theories and facilitates their computations, but that nothing of that sort is to be found in nature. They also use the Dirac function, or better said the Dirac distribution δ, but they are well aware as well that it pertains to the mathematical world and that it is an idealization of a narrow function with great amplitude. We can find the manifestation of such narrow functions in nature, but not the limit δ of a series of such functions. In other words, it is not claimed that singularities should not be used in physics. They may be used indeed in imperfect theories (say models), which is actually the case of all our theories, which may possess a significant or even huge domain of validity, in such a way that we shall go on using them forever. Other examples are general relativity which generates singularities, whether they are naked or not, or the ubiquity of (1/r)-potentials.

Therefore, each time physicists encounter local infinity in physics, they immediately recognize that something is going deeply wrong, or that they are dealing with convenient but incorrect idealizations, and possibly that they have to think more.

The non-singularity principle is indeed something, at least implicitly, anchored in the mind of physicists. For them, an infinite outcome from any computation relevant to the physical world, as would be an infinite outcome from any experiment (a detector is not allowed to receive an infinite amount of energy; it would be destroyed), is something which cannot be thought, a real meaningless non sense. What we have done in this section is simply to dress a reluctance, or even a repugnance, with the formulation of a first principle. We are now going to use this principle to the issue of the understanding of quantum mechanics.

4. Facts of matter, and consequences

4.1. The optical rainbow

As a preliminary exercise, we are considering a first fact of matter (which is also a fact of radiation), namely the optical rainbow which is one of the most beautiful phenomena in nature (Kerker 1969, Hulst 1981, Adam 2002). The simplest way to understand the basic features of the optical rainbow (we only consider the primary rainbow) is to start with geometrical optics, more precisely with ray tracing, an approach usually granted to Descartes, although there are precursors. The existence of the rainbow then comes from the fact that the deviation of the once internally reflected ray passes through a minimum when the angle of incidence is varied (this is called a stationary ray). The concentration of rays, near the stationary ray, generates a singularity which is a real caustic, separating a bright side from a dark side. The singularity corresponds to an abrupt transition between both sides of the stationary ray, one associated with an infinite intensity (divergence at the rainbow angle), the other with vanishing intensity. We therefore have actually two kinds of singularities, one that we may call a longitudinal singularity associated with the divergence at the rainbow angle, and the other one that we may call a transverse singularity associated with the abrupt transition perpendicularly to the emerging rays. More generally, infinite intensities are predicted by geometrical optics at focal points, lines and caustics. The word “caustics” can be viewed as a generic word to refer to any kind of singularity produced by ray families filling regions of space.

Invoking the non-singularity principle, the appearance of infinities in the geometrical optics rainbow is *a priori* (somehow in the Kantian sense, that is to say without referring to experiments) inadmissible. This points out to the fact that something is going wrong and that actually geometrical optics must be an approximation to a more general theory which is a wave theory (waves remove singularities). Indeed, such is the fact. We know how nature solves this problem: light waves are described by the vectorial Maxwell’s equations. The exact theory of the rainbow is provided by the Lorenz-Mie theory (Lorenz 1890, 1898; Mie 1908) which describes the interaction between a sphere defined by a complex refractive index and a diameter, and an illuminating electromagnetic plane wave, or by the generalized Lorenz-Mie theory (Gouesbet 2000) in the case of laser illumination.

4.2. The mechanical rainbow

Secondly, we now consider classical mechanics. A sub-topic of classical mechanics is classical scattering, e.g. Newton 2002, Nussenzveig 1992, which, in contrast with electromagnetic scattering, is a scalar scattering instead of being a vectorial scattering. Following Nussenzveig (1992), we discuss the scattering of a nonrelativistic particle of mass m by a central potential $V(r)$. The trajectory of the incoming particle is deflected by an angle $\overline{\theta}$ called the deflection angle which depends on the impact parameter b. For a repulsive interaction, $\overline{\theta}$ ranges from 0 to π but, for an attractive interaction, it can take arbitrary large values (in modulus). There is a simple relationship between the deflection angle $\overline{\theta}$ and the more usual scattering angle θ, namely: $\overline{\theta} + 2n\pi = \pm\theta, n = 0, 1, 2, \ldots$ Relying on the conservation laws of angular momentum and energy, it is then established that the differential cross-section in the direction θ reads as:

$$\sigma_{sca}(\theta) = \sum_j \frac{b_j(\theta)}{\sin\theta} \left| \frac{d\theta}{db_j} \right|^{-1} \tag{1}$$

where the summation over j arises from the fact that, in general, there exist several impact parameters b_j that lead to a same scattering angle θ.

This expression implies the occurrence of several singularities. In particular, we have a divergence whenever $d\theta/db = 0$, for at least one j, and for some angle $\theta_R = \theta$, that is to say when the deflection function, say $\theta(b)$, goes through an extremum. We then have a stationary trajectory and the singularity is a rainbow singularity occurring at the rainbow angle θ_R. Other singularities involved in the expression are glory, forward scattering, orbiting, but we do not need to discuss them here.

Invoking again the non-singularity principle, we conclude, without referring to any experiment, that the divergence exhibited by the mechanical rainbow (still having both a longitudinal and a transverse character) is inadmissible and that classical mechanics, which therefore contained the germ of its own destruction, is an approximation to a more general theory. This more general theory must be a wave theory, say a wave mechanics, in order to smooth out the rainbow singularity, and any other singularity as well (again, waves remove singularity). We therefore conclude *a priori* to the rational necessity of something more general than classical mechanics, namely a wave mechanics. Let us note that this second fact of matter does not concern radiation, but matter in a strict sense. It is afterward possible to use another principle (telling nearly tautologically that classical mechanics is an approximation to wave mechanics), to establish the most general expression to be satisfied by the wave equation of the wave mechanics, assumed to be an evolution equation. This expression takes the form of a set of generalized Schrödinger equations. Schrödinger's equation itself is found to be the simplest equation within the set (Gouesbet 2007).

The analogy between the optical rainbow, viewed as a consequence of geometrical optics with rays, and the mechanical rainbow, viewed as a consequence of the existence of mechanical trajectories, is further reinforced by the existence of a famous Hamilton's analogy between geometrical optics and classical mechanics (Hamilton 1833, 1834), which has been used by Schrödinger to derive his equation (Schrödinger 1928).

4.3. Ultra-violet catastrophe

The previous sub-section exhibited a connection, unnoticed up to now, between the occurrence of infinities in classical mechanics and the need of a wave mechanics for matter waves. For the sake of completeness, we recall in the present sub-section that there has also been a connection between the occurrence of infinities in the classical theory of radiation and the need for the development of quantum mechanics. This happened as follows.

Historically, at least if we rely on some textbooks and lectures on quantum mechanics, the quantum physics arose from experiments and associated features which could not be satisfactorily explained in the framework of classical physics. The failure of classical physics was not viewed as the consequence of its internal inconsistency (although it indeed contained the germ of its own destruction), but as the consequence of its inability to deal with the matters of fact. Among these matters of fact, we might select the most famous ones (but not actually the only ones), namely (i) the stability of atoms and their spectra (ii) photo-electric effect and (iii) black-body radiation. These three examples all involve and require a discussion of the properties of radiation, in contrast with our previous discussion which only dealt with matter waves.

The stability of atoms is intimately connected with the properties of the classical description of radiation, in the framework of classical electrodynamics for, in this classical framework, an electron is vectorially accelerated in its motion around the nucleus (even if it orbits with a constant speed). Therefore, it must lose energy by emitting radiation, and spiral down to the nucleus, and eventually crash on it (this should happen in a very short time). Hence, this result of classical physics is in contradiction with the very existence of stable atoms. Furthermore, the radiation emitted by the electron during its fast journey to the nucleus should be continuous, in contrast with the observed fact that atom spectra are made out from a set of discrete lines. Hence, we have still another contradiction between classical physics and matters of fact. For the photo-electric effect, its connection with electromagnetism is even faster to report: it finds its best explanation by invoking light quanta. As for black-body radiation, it is still simpler: the word radiation is explicitly mentioned in the denomination of the issue.

It is on this black-body problem that I would like to make an important comment, relevant to the non-singularity principle. As is well known, even to students, a prediction of classical physics concerning an ideal black body at thermal equilibrium is that it emits radiation with infinite power. The infinite power divergence obtained is the result of the contributions from the high frequency region of the electromagnetic spectrum, justifying the denomination of ultra-violet catastrophe (coined in 1911 by Ehrenfest). Another denomination sometimes used is Rayleigh-Jeans catastrophe.

The ultra-violet catastrophe may be viewed as an ingredient of a more general feature: the properties of the black-body radiation, as calculated in the framework of classical physics, do not agree with experiments. Therefore, even without referring to the ultra-violet catastrophe, classical physics was falsified. This falsification may be viewed as being *a posteriori* (referring to experiments). To reconcile theory and experiments, Planck, in 1900, made the founding step of introducing the indivisible quantum of action $\hbar$. But it is important to remark that Planck did not feel really concerned with the ultra-violet catastrophe which therefore has not been, historically, a decisive feature for the emergence of quantum physics (Klein 2007, 1980).

The relevance of the ultra-violet catastrophe to the lack of validity of classical physics has been actually put forward later, in particular by Einstein, in 1905. What is very important with an argument using the ultra-violet catastrophe is that it is *a priori*, that is to say, once again, without referring to any experiment. A theoretical formula resulting from a theoretical framework is immediately perceived as leading to an impossibility. We could say that a non-singularity principle, concerning the ultra-violet catastrophe, implies the failure of classical physics.

But this invocation of a non-singularity principle actually does not concern all of classical physics. It is rather specific of this part of classical physics which treated of radiation, already sustained at this time by Maxwell's equations. It did not say anything on classical mechanics. Hence, it is clear that, with our invocation of a non-singularity principle in the framework of classical mechanics, we have done something else. We have actually demonstrated the inadmissibility of classical mechanics (without referring to the properties of radiation which is not relevant to mechanics), i.e. we have concentrated on matter waves.

4.4. Complementary comments

We have considered that the non-singularity principle is a first principle because it matches our intuition and therefore, *whatever the origin of this intuition*, we should, at least tentatively, examine its consequences. Indeed, when the intuition is satisfied, we have found a possible entry to the world of understanding. This does not mean that intuition is never misleading (unfortunately, it is often misleading). Furthermore, an intuition, even strong, is not necessarily universal. Nevertheless, the widely shared reluctance of physicists to the acceptance of local actual infinity means that the non-singularity principle can receive a large enough inter-subjective agreement, another reason for having to draw consequences. In other words, we may escape from any philosophical and metaphysical consideration by taking a societal point of view. The non-singularity principle is fruitful if it receives a large enough agreement, and if we can draw successful consequences from it. The inter-subjective world is then built and taken as an inter-subjective objectivity. But, because there is possibly no universal intuition, some individuals (whether physicists or not) may not recognize themselves in this inter-subjective objectivity. For them, the non-singularity principle used may be found not to provide a decent access to the rational necessity of quantum mechanics.

Another point of view, which does not require any hypothesis but just requires us to observe what we are doing and thinking is to state that our mind (we observe that we seemingly have a mind) likes to explore all possibilities it can and likes, and therefore likes to produce first principles. The mind may be obscured and the inter-subjective process inefficient, so that many of these so-called first principles will eventually fail. So, it has to be admitted that the non-singularity principle, like any other first principle of physics, may have to compete in a Darwinian and Popperian process of evolution of science (Popper 1973, 1991) and even that it could eventually be defeated. More generally, any first principle may possess a provisional character. This is in agreement with Quine's epistemology (Quine 1975, 1977, 2003) questioning the distinction between analytical and synthetical statements, and according to which any statement is in principle revisable, even any logical statement. Hence, there would be no room for genuine first principles, but there is enough room for provisional first principles. Possibly however, some statements, even revisable in principle, will escape to revision in the phenomenal human mind.

But, there is also an inescapable argument to assert that we indeed need first principles. In the words of Selleri (1971), *in fact, explaining a word (or an idea) means reducing its meaning to other words (or other ideas). But since the total number of words ever said (or ideas ever had) by human beings is finite, one cannot explain everything without circular reasoning. Some ideas must be taken as self-evident without the need for any explanation. These are the a priori ideas*. I dare to say that the non-singularity principle could be taken as such an idea.

5. Conclusion

We introduced a non-singularity principle telling us that "local infinity in physics is not admissible", and have drawn consequences. In the same way that geometrical optics is not admissible and has indeed been completed by a better theory, namely Maxwell electromagnetism, we used the non-singularity principle and the existence of singularities in the properties of the mechanical rainbow to state that classical mechanics is not admissible as well. Indeed, classical mechanics has been successfully completed by wave mechanics. However, the connection between the properties of the mechanical rainbow and the non-singularity principle provides an inroad for a better understanding of wave mechanics. For the sake of completeness, we also recalled a similar connection between the properties of the black-body radiation and the non-singularity principle (ultra-violet catastrophe). For the readers, whether positivists or naturalists, which would be much reluctant to the use of first principles, we listed a few epistemological loopholes. Admittedly however, for such readers, the benefice of having gained some amount of understanding of quantum mechanics is lost.

References

Adam, J. A. 2002. The mathematical physics of rainbows and glories. *Physics Reports* **356**: 229-365.

Aristotle. 2004. *Traité du ciel* (*De Caelo*). Presentation by P. Pellegrin. Paris: Flammarion.

Feynman, R. P. 2000. *Le cours de physique de Feynman, mécanique quantique*. French translation of *The Feynman lectures on physics, 1965*. Paris: Dunod.

Forsee, A. 1963. *Albert Einstein, theoretical physicist*. New York: MacMillan.

van Fraassen, B. 2000. *Quantum mechanics: an empiricist view*. Oxford: Clarendon Press.

Gell-Mann, M. 1981. *The Nature of Matter, Wolfson College Lectures 1980*. Edited by J. H. Mulvey. Oxford: Clarendon Press, pp.169–86.

———. 1995. *Le quark et le jaguar*. French translation of *The quark and the jaguar, adventures in the simple and the complex*. Paris: Editions Albin Michel.

Gouesbet, G. 2007. From the rainbow to the structure of atoms. *Particle and Particle System Characterization* **24**: 395–401.

Gouesbet, G. & Gréhan, G. 2000. Generalized Lorenz-Mie theories: from past to future. *Atomization and Sprays* **10**(3–5): 277–333.

Hamilton, W. R. 1833. On a general method of expressing the paths of light and of the planets by the coefficients of a characteristic function. *Dublin University Review and quarterly magazine* **1**: 795–826.

———. 1834. On a general method in dynamics. *Philosophical Transactions of the Royal Society*, Part II, pp. 247–308.

Heisenberg, W. 1972. *La partie et le tout, le monde de la physique atomique*. French translation of: *Der Teil und das Ganze, Gespräche im Umkreis der Atomphysik*. Paris: Editions Albin Michel.

Hoffman, P. 2000. *Paul Erdös: l'homme qui n'aimait que les nombres*. Paris: Librairie Lavoisier.

van de Hulst, H. C. 1981. *Ligth scattering by small particles*. New York: Dover Publications, Inc.

Kerker, M. 1969. *The scattering of light and other electromagnetic radiation*. New York: Academic Press.

Klein, E. 2007. *Le monde quantique*, chapter: La naissance de la physique quantique, pages 6–12. Les dossiers de la recherche, France.

Klein, M. J. 1980. *Some strangeness in the Proportion*. Edited by H. Woolf. Reading, Mass.; Addison-Wesley, pp. 161–85.

Koyré, A. 1973. *Du monde clos à l'univers infini*. French translation of *From the closed world to the infinite universe*. Paris: Gallimard.

Lorenz, L. 1890. Lysbevaegelsen i og uden for en af plane lysbolger belyst kulge. *Vidensk. Selk. Skr.* **6**: 1–62.

———. 1898. *Sur la lumière réfléchie et réfractée par une sphère transparente*. Lib. Lehmann et Stage, Oeuvres scientifiques de L. Lorenz, revues et annotées par H. Valentiner. Paris.

Mie, G. 1908. Beiträge zur Optik trüben Medien speziell kolloidaler Metalösungen. *Annalen der Physik* **25**: 377–452.

Newton, R. G. 2002. *Scattering theory of waves and particles*. New York: Dover Publications, Inc.

Nussenzveig, H. M. 1992. *Diffraction effects in semiclassical scattering*. Cambridge: Cambridge University Press.

Omnès, R. 2000. *Comprendre la mécanique quantique*. Paris: EDP Sciences.

Popper, K. R. 1973. *La logique de la découverte scientifique*. French translation of *The logic of scientific discovery* (Hutchinson, 1959). Paris: Payot.

———. 1991. *La connaissance objective*. French translation of *Objective knowledge* (Oxford University Press, 1979). Paris: Flammarion.

Quine, W. V. 1975. *Philosophie de la logique*. Presentation par Denis Bonnay et Sandra Laugier. Paris: Aubier-Montaigne.

———. 1977. *Relativité de l'ontologie et autres essais*. Présentation par Sandra Laugier. Paris: Aubier-Montaigne.

———. 2003. *Du point de vue logique, neuf essais logico-philosophiques*. French translation of *From a logical point of view*. Paris: Editions Vrin.

Schrödinger, E. 1928. *Collected papers on wave mechanics*. Glasgow: Blackie and Sons, Ltd.

Selleri, F. 1971. *Foundations of quantum mechanics*. Proceedings of the International School of Physics "Enrico Fermi", course IL, edited by B. d'Espagnat. New-York: Academic Press, pp. 398–406.

Squires, E. 1986. *The mystery of the quantum world*. Bristol: Adam Hilger.

GERARD GOUESBET
Laboratoire d'Electromagnétisme des Systèmes Particulaires (LESP)
Unité Mixte de Recherche (UMR) 6614,
Centre National de la Recherche Scientifique (CNRS),
Complexe de Recherche Interprofessionnel en Aérothermochimie (CORIA),
Université de Rouen
Institut National des Sciences Appliquées (INSA) de Rouen,
BP12, avenue de l'université, technopôle du Madrillet,
76801, Saint-Etienne du Rouvray
FRANCE
gerard.gouesbet@coria.fr

Resumo.

Há um vasto número de lamentações a respeito da falta de inteligibilidade da mecânica quântica. Alguns ingredientes da mecânica quântica, contudo, podem possivelmente ser compreendidos pela referência a primeiros princípios, ou seja, a princípios (ou postulados) básicos que, para a intuição, são claros e distintos. Em particular, se nos basearmos em um primeiro princípio denominado princípio da não-singularidade, que pode ser visto como uma hipótese, afirmamos que a mecânica quântica pode ser vista como uma consequência *a priori* de uma exigência racional. O estatuto do princípio de não-singularidade, óbvio para a maioria dos físicos, pode, contudo, ser criticado, com base em que não há uma intuição universal e que qualquer enunciado é, em princípio, revisável.

Palavras-chave: Mecânica quântica, necessidade racional, princípio da não-singularidade, arco-íris óptico, arco-íris mecânico, catástrofe ultravioleta.