CURIE'S PRINCIPLE AND INDETERMINISM

EL PRINCIPIO DE CURIE E INDETERMINISMO

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Abstract: Curie's principle expresses an invariant connection between the symmetry of causes and symmetry of effects in deterministic systems. Here a probabilistic version of such principle is proposed and proved for indeterministic systems. The concept of symmetry in question embraces the invariance of the holding of the laws of physics under certain transformations. In contrast with Curie's principle, which involves the invariance of the effects under symmetry transformations, our probabilistic version involves invariance of the probabilities that laws assign to physically possible final states of random processes under symmetry transformations, although with exceptions when a phenomenon breaks the symmetry in question.

Keywords: Symmetry transformation, invariance, asymmetry, broken symmetries, quantity conserved.

Resumen: El principio de Curie expresa una conexión invariante entre la simetría de las causas y la de los efectos en sistemas deterministas. Aquí se propone, y se demuestra, una versión probabilista de tal principio para sistemas indeterministas. El concepto de simetría en cuestión envuelve la invariancia de la validez de las leyes de la física bajo ciertas transformaciones. En contraste con el principio de Curie, el cual involucra la invariancia de los efectos bajo transformaciones de simetría, nuestra versión probabilista involucra la invariancia de las probabilidades que las leyes asignan a los estados finales físicamente posibles de procesos aleatorios bajo transformaciones simétricas, aunque con excepciones cuando un fenómeno rompe la simetría en cuestión.

Palabras clave: Trasformación simétrica, invariancia, asimetría, simetrías rotas, cantidad conservada.

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1. Introduction

The principle that Pierre Curie formulated in his *Sur la symétrie dans les phénomènes physiques* (1894) has an intended causal character for synchronic physical systems, included the medium, governed by deterministic laws, where some feature of a given system could be regarded as the cause of other feature of the same system simultaneously. This principle contrasts with the view of deterministic causality formulated by Pierre Simon de Laplace in his famous *Essai philosophique sur les probabilités* (1814), where he expressed that view in diachronic terms for the past, present and future states of the universe ruled by Newtonian laws. The originality and worth of the principle proposed by Curie consists in that he explicitly states it in terms of symmetries of both causes and effects, and invariance properties of deterministic laws. However, in his original version, Curie's Principle (CP) is not suitable, at least not directly, to diachronic systems reigned by dynamic laws.

Chalmers (1970) reformulated CP in a way which becomes appropriate for dynamic systems, and since then his version is considered as the "received view" of CP.1 Most philosophers that had written on CP discuss the meaning of this principle (how it can be interpreted?) and its applications to physical systems which display symmetrical properties under some groups of transformations (see, e.g., Chalmers, 1970; Ismael, 1997; Roberts, 2013; Norton, 2016; Castellani and Ismael, 2016). It is not our intention to discuss the question about the meaning of CP, instead we shall adopt Chalmers' reformulation. Also, some of those philosophers have proposed proofs of CP giving some distinct —but possibly equivalents— versions (Chalmers, 1970; Earman, 2002; Castellani and Ismael, 2016). We will attend these proofs later on. All the previous issues have been focused, following Curie, on deterministic physical systems. However, Jenann Ismael (1997) poses questions about the possible application of a reformulation of CP to indeterministic systems governed by probabilistic laws, and in particular, quantum systems. He responds affirmatively to both questions (1997: 176). We agree with him, and so, borrowing some of his key ideas, in this paper we mainly try to give a probabilistic version of CP, to provide a proof of such version and, finally, to explore its plausibility for some quantum systems.

[1] See Castellani and Ismael (2016: 1002).

2. Invariance and symmetry

We can distinguish between the two following assertions. First, laws of physics hold invariably across an intended domain of application. Second, laws of physics hold invariably under symmetry transformations.[2] These two claims are related with, but they are independent of, CP. One can find them in books of physics, e.g., in Feynman et al (1963) and Beiser (1987). The two levels of invariance are indeed different. The first one refers to an invariance of the manner in which physical systems change in accordance with some law. The second one refers to a higher invariance, to an invariance of the laws themselves, associated with the symmetry operations such as translation in space, translation in time, rotation in a fixed angle, inversion of time, reflection of space, and exchange of matter-antimatter (charge conjugation). Thus, on the one hand, the relata of invariance are physical systems and the processes they suffer, that is expressed by a law of evolution which prescribes the possible changes of state of the systems allowable by such a law. One the other hand, at a high level of abstraction, the relata of invariance are laws themselves expressed by principles of symmetry which state the sort of transformations under which the holding of the laws of evolution is preserved.

Curie's principle in his own words: "*When certain causes produce certain effects, the symmetry elements of the causes must be found in their effects*" (1894: 312), asserts something else and stronger than the two former assertions, namely: the symmetry of the causes is preserved in the effects under symmetry transformations.[3] When one converts this principle, as Chalmers does, from synchronic physical situations to diachronic physical systems, one presupposes the two previous assertions. Indeed, these two claims are assumptions to obtain CP.[4] A

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[2] Elena Castellani points out the former distinction when she says that "Symmetries can be attributed to physical states or to physical laws" (2003: 321) and adds that there is a connection between both sorts of symmetries, linking this distinction with an elucidation of the meaning of symmetry breaking.

[3] It seems that this claim is synthetic in character, not virtually analytical (see Earman, 2002: 178), and that it could be unfulfilled in some cases. The fact that some versions of CP can be proved in a simple way is due to the premises which are assumed; in particular, to the assumptions that the state of the system, in a given time, is symmetrical and to the attributed invariance of deterministic laws.

[4] We can see this in the proof of CP due to Castellani and Ismael (2016: 1008-1009). The first former assertion amounts to the assumption about the holding of deterministic dynamics laws, whereas the second former assertion is involved in the assumption that such laws are invariant under certain symmetry transformation.

central question is about how we must understand the assertion that causes are symmetrical, which is the point of start of CP. Chalmers provides a notion of symmetry transformation which could be key to clarify that: Given a description of a physical system by means of the specification of its magnitudes then a *symmetry transformation* for the system is an operation performed on it which leaves the specification unchanged (cf. 1970: 134-135). Chalmers opts correctly to speak in a formal mode, in contrast to a material mode one, i.e., instead of talking directly about physical systems and their states he talks about the *descriptions* of physical systems and their states in reference to a conceptual framework, since "the descriptions of a system will always be some abstraction which will depend on the conceptual framework in which, or the theoretical standpoint from which, it is viewed, so that, in a sense, a symmetry transformation is a property of the description rather than of the physical system itself." (1970: 135). In that way, one can say that a cause C is symmetrical under a transformation T, $T(C)$, if T does not change the description of C, i.e., if the description of the untransformed cause is the same, or equivalent, to the description of the transformed cause. The same applies to the effects: an effect is symmetrical under T if the description of E is equal, or equivalent, to the description of $T(E)$, i.e., the effect transformed by T. The converse of CP is the claim that if under T, the specification of the effect E is not equal to that of $T(E)$ then the associated cause C is different from $T(C)$. What does mean that a cause C is asymmetrical under certain transformation T is a controversial issue related with the so-called symmetry breaking, which we overlook here.

3. Curie's principle for deterministic systems

The proof of Curie´s Principle due to Castellani and Ismael (2015) is quite different from the one that we provide below. They follow Chalmers' (1970) approach to the issue consisting of extending CP to dynamic systems ruled by deterministic laws, and demonstrating its validity and applications. Indeed, they reproduce formally the brief proof via reduction to absurd due to Chalmers' reformulation of CP in such a way to make possible its applications to the evolution of physical systems in terms of causes and effects, providing a deductive argument. The conclusion of such argument is the claim about the symmetry of the effects E under a symmetrical transformation T, i. e., $T(E) = E$. The premise of the argument is a general formulation of a deterministic law with the form: $E = f(C)$, where f is a function equivalent to a set of ordered pairs of causes and effects (C, E), which is known if the laws of nature are known. The proof is based on invariance properties of deterministic laws as follows:

$E = f(C)$	Deterministic law
$T(E) = T(f(C))$	Apply T
$T(E) = f(T(C))$	T-symmetry of the law, i.e., $Tf = fT$
$T(E) = f(C)$	T-symmetry of the cause, i.e., $T(C) = C$
$T(E) = E$	Again by Determinism

This proof links symmetry transformations with deterministic physical laws.[5] It seems as a proof of the symmetry of such laws under certain transformations, according to Curie's thesis: "The symmetries are in the laws of the phenomena not in the phenomena themselves".[6] Nevertheless, it is not clear that the previous deduction is a proof of CP. According to Castellani and Ismael it amounts to a demonstration of Chalmers' claim: CP follows from the invariance properties of physical laws if these are deterministic. It may be closer to Curie's Principle, as formulated before: 'When certain causes produce certain effects, the elements of symmetry of the causes must be founded in the effects produced', to say that for synchronic systems the symmetry of the effects under a transformation T follows from the symmetry of the causes under the transformation T and the invariance properties of the laws involved if these latter are deterministic.

The proof of the latter formulation of CP for diachronic systems is as follows:

$T(C) = C$	T-symmetry of the causes
$f(T(C)) = f(C)$	Apply the function f
$T(f(C)) = f(C)$	T-symmetry of the law, i.e., $fT = Tf$
$T(E) = E$	By the deterministic law

[5] It is worth to note that in the former deduction the equation $E = f(C)$ is used both as premise and as a rule of inference (it is similar to use the tautology $(P \rightarrow Q) \& (Q \rightarrow R) \rightarrow (P \rightarrow R)$ as our main premise and later on apply it as a rule to infer the conclusion).

[6] Quoted by Earman (2004: 1231) from Curie (1894: 401).

Thus, we can think of Curie's Principle for dynamic systems in the following terms: If the causes are symmetrical and the laws are symmetrical then the effects are symmetrical, granted that the laws involved are deterministic.

There are two possible exceptions to CP on deterministic systems. About the T-symmetry of f: When a function f is not invariant under some T it could mean that there is a phenomenon that breaks the symmetry of the corresponding law under such transformation T, that is, the law does not hold under the transformation T of the physical system involved (this does not means that the law that provides the function f does not hold at all, but that it does not hold when the physical system involved is transformed by the operation T). And in respect of the T-symmetry of the causes: If the effects are not symmetrical (i.e., they are not invariant under the operation T), then there is a hidden asymmetry in the causes, by the converse of Curie's Principle.

Besides, the principle does not hold when the law and the physical system involved are not deterministic, that is, when the causes are T-symmetrical and the law is T-symmetrical, but in both the untransformed system and the transformed system one obtains alternatively two, or more, different and mutual excluding effects. Can we obtain a version of Curie's principle for such indeterministic system? The point about this question consists in elucidating the role principles of symmetry play on indeterministic systems in connection with probabilistic laws.

Earman (2002) provides also a formal proof of CP which is in some respect equivalent to the prior proof due to Castellani and Ismael. Firstly, he formulated such a principle as a conditional statement and, secondly, he offered the formal proof for a Schrödinger dynamic. The former is as follows: *If* (CP1) the laws of motion/field equations governing the system are deterministic, and (CP2) the laws of motion/field equations governing the system are invariant under a symmetry transformation, and (CP3) the initial state of the system is invariant under such symmetry, *then* (CP4) the final state of the system is also invariant under such symmetry (2002: 176). Earman comments quite right that if an asymmetry appears in a physical system, it is due to one (or more) of three factors which correspond to the failure of one (or more) premises: either the initial state is asymmetric, or the laws are not symmetric, or determinism does not hold (2004: 177). Earman's version of CP proof for a Schrödinger dynamics resides in considering the "determinism" of physical systems as the evolution from an initial state $\omega 0$ at time $t0$ to a final state $\omega 1$ at time $t1$ given by an automorphism α of the algebra of observables in a Hilbert space, which amounts to premise (CP1) in the sense that it permits to say that for any pairs of evolutions allowed by the laws involved, sameness of initial states implies sameness of final states. Besides, if we suppose that α is invariant under a transformation θ (CP2), and if the initial state ω0 is θ-invariant (CP3), then the evolved state ω1:= α(ω0) is also θ-invariant (see proposition 2 in the appendix for his formal proof). He deems that, as in the classical case, this formulation of CP for Schrödinger dynamics is also virtually analytic (2002: 188). Nevertheless, Earman is not concerned about how CP could be formulated, and proved, for indeterministic systems where we cannot suppose a premise like (CP1) for the evolution of quantum systems.7 What is missing is to express CP for systems governed by Born's rule or Born's probabilistic version of Schrödinger equation. We will try to provide such probabilistic formulation below.

4. Curie's principle for indeterministic systems

4.1 Probabilistic Curie's Principle

Let us now explore how could Curie's Principle be for indeterministic systems and, hence, for probabilistic laws. Chalmers says that "The laws of a deterministic theory enable the effect, *E*, to be derived from the cause, *C*. We can write *E* = *f*(*C*), where '*f*' denotes a function which is known if the laws are known." (1970: 140). Similarly, we can say that the laws of an indeterministic theory enable the probability distribution of physically possible final states, S_{Fi}, to be derived from (a description of) the initial state, *SI*. We can write *L*(*SI*) = *p*(*SFi*) where '*L*' designs a probabilistic law and '*p*' denotes a probability function which is known if the law *L* is known. Or, as Ismael says, a probabilistic law maps state-descriptions of indeterministic systems onto probability functions which define a distribution of probability over the set of physically possible state descriptions (see 1997: 176-177).

An appropriate notion of symmetry for the laws of an indeterministic theory could be as follow: We say that a probabilistic law L is symmetrical under a

[7] The main concern of Earman in that paper consists in the topic of spontaneous symmetry breaking in relation to Curie's Principle.

transformation T if $L(T(SI,)) = T(L(SI,))$, which allows to prove, as we will see, that the probability values that L assigns to all physically possible final states SFi, given the initial state SI, are invariant under T, i. e., for all SFi in $\{SF\}$, $p(SFi) = p(T(SFi))$. The involved key idea consists in that the probability of the evolution of an untransformed system to a certain final state is equal to the probability of the evolution of the transformed system by T to the same final state. Perhaps, we can say that a probabilistic law L is asymmetrical under a transformation T, if for some possible final state SFj, $p(SFj) \neq p(T(SFj))$, i.e., the probability value of SFj is not invariant under T —however, the issue about the symmetry breaking is a controversial question and it goes beyond the scope of this paper (see, e.g., Earman, 2002 and Castellani, 2003).

Suppose that L is a probabilistic nomic statement such that for any pair $<SI, \{SF\}>$, which represents an indeterministic process in a physical system S (the evolution of S from the initial state SI to one of its final states in $\{SF\}$), $L(SI) = p(SFi)$, for all $<SI, SFi>$ with $i \geq 2$. A probabilistic version of Curie's Principle (PCP) is the following: If the initial state of a (kind of) indeterministic system is symmetrical under the transformation T and the probabilistic law L is symmetrical under T, then the probabilities of the physically possible final states are symmetrical under T.

So let us prove the following formal enunciation of Curie's Principle for indeterministic systems ruled by probabilistic laws: If $SI = T(SI)$ and $L(T(SI)) = T(L(SI))$ then $p(SFi) = p(T(SFi))$, given that $L(SI) = p(SFi)$, for every SFi in the set $\{SF\}$ of the physically possible final states, with $i \geq 2$.

Proof. For all SFi in $\{SF\}$:

(1) $SI = T(SI)$	symmetry of the initial state under T
(2) $L(T(SI)) = T(L(SI))$	symmetry of law L under T
(3) $L(SI) = T(L(\mathrm{SI}))$	from (2) by (1)
(4) $L(SI) = L(T(SI))$	from (3) by (2)
(5) $p(SFi) = p(T(SFi))$	from (4) by the probabilistic law L

Thus, the probability values of the physically possible final states, which the probabilistic law L assigns to them, are invariant under the symmetry operation T. This follows from the symmetry of the initial states under T and the symmetry of L under T, as it is required.

The left side of the former proof amounts to whenever one has an indeterministic system in a certain initial state and applies a probabilistic law to it, one obtains a probability distribution to its physical possible final states. We can think of Born's version of Schrödinger equation as an exemplar law of this, which assigns a probability value to every superposed states. The right side of that proof says that whenever one has an indeterministic system whose initial state is symmetrical under a transformation T and one applies to it a probabilistic law which is symmetrical by T, then one obtains a probability distribution of the physically possible final states of the transformed system. This PCP claims that Born's rule, or the nomic probabilistic equation appropriate for the quantum system in consideration, applies to the untransformed system and the transformed system as well: if Born's rule holds on the untransformed system then it holds also on the transformed system by T.

We can consider as examples of such transformation T the symmetry operations of interchange of particles by identical particles, translation in space and in time, matter-antimatter (charge conjugation), and inversion of space –although the two last in some nuclear interactions do not conserve the quantity associated, i.e., charge parity C and space parity P, respectively.

There are some possible counter examples of PCP in indeterministic systems. Suppose that for some $S_{p}j$, $p(S_{p}j) \neq p(T(S_{p}j))$. Then, premise (1) or premise (2) of the former deductions are not fulfilled. If (1) is not satisfied —the initial state is not T-symmetrical after all—, then there is a hidden asymmetry in the initial state of the system. For quantum systems one could say that there is a hidden local variable, perhaps introduced by the transformation T. If (2) is not satisfied —the law L is not T-symmetrical after all— means that the holding of the law L is not invariant under the transformation T, which involves the violation of the supposed symmetry of the law L. In other words, if one transforms the system according to the supposed symmetry operation T, the law L does not apply any more to the transformed system. In such case, there is a phenomenon that breaks the invariance of the holding of the law L. This is the case on weak interactions under reflection of space in beta decay, known as the violation of space parity P (see Penrose, 2004: 25.3).

4.2 Salva Probabilitas

As we have seen, the probabilistic version of Curie's principle for indeterministic systems is quite different from CP in that the invariance asserted is not about the physical effects, but about the probabilities of the physically possible effects. We can say that PCP expresses that the symmetry transformations applies to physical laws *salva probabilitas*. For that reason, it is not Schrödinger equation our focus of concern, but Bohr's rule instead, as far as one can define a probability distribution over the set of superposed states for a given system in evolution through it.

Recall that relative to the conceptual framework of standard quantum mechanics, for any event *x* in a quantum system Born's rule equals the probability of x with the absolute square of a wave function $\psi(x)$, i.e., $p(x) = |\psi(x)|^2$. In accordance with the superposition principle –if an individual quantum system S could be in a state represented by $|b_1\rangle$ and also in a state represented by $|b_2\rangle$ then any linear combination $|\psi\rangle = c_1|b_1\rangle + c^2|b_2\rangle$ represents a state of S (with c_1 and c_2 complex numbers)–, we can obtain a probability distribution when the function ψ expands to a superposition state $\sum jn\ |bj\rangle$, i. e., we obtain $|\psi(x)|^2 = \sum jn\ |c_j|b_j\rangle|^2$, where for each individual state $|b_k\rangle$, component of the superposition, $|c_k|b_k\rangle|^2$ represents its probability value. Thus, under Born´s probabilistic interpretation of Schrödinger´s wave function, the state descriptions of quantum systems are given in terms of state superpositions with associated probability distributions, not in terms of deterministic equations, which assign to every possible event *x*, a probability that it will occur: $p(x) = |\psi(x)|^2$.

4.3 Quantum processes and PCP

Again, the question of our concern here about quantum indeterministic processes is whether symmetry operations preserves the probabilities values from the untransformed system to the transformed system, i.e., if symmetry transformations hold *salva probabilitas*.

Earman maintains that: "It would be a worthwhile project to develop a statistical form of CP that could apply in cases where strict determinism fails but statistical determinism holds (2002: 180). It seems that he considers that a description of the evolution of a quantum system by means of Schrödinger equation corresponds to a deterministic evolution. However, in order to give account of genuine indeterministic processes (random state changes of quantum systems) in standard quantum theory it would be better to apply Born's rule to dynamics equations to obtain a superposition of the physically possible final states from an initial state. Such superpositions represent the random character of quantum processes since they assign probabilities to the physically possible final states of the developed systems. And, of course, it is a matter of physics that if some kind of process (e.g., Compton scattering effect) has a random character and a quantum equation assigns transition probabilities to the alternative physically possible final states, it assigns the same transition probabilities to every instance of that kind.

The former is just an illustrative case of a kind of indeterministic process. In general, there are quantum equations that hold invariantly in indeterministic processes which involve gravitational, electromagnetic, strong, and weak interactions. All this is just physics. Our question here with respect to PCP is whether the probability distributions that quantum equations assign to quantum random processes are preserved under symmetry transformations. In general, the answer is affirmative. Feynman indicates a case which illustrates the point:

> If ψ is the amplitude for some process or other, we know that the absolute square of ψ is the probability that the process will occur. Now if someone else were to make his calculation not with this ψ, but with a ψ' which differs merely by a change in phase (let Δ be some constant, and multiply $e^{i\Delta}$ times the old ψ), the absolute square of ψ', which is the probability of the event, is then equal to the absolute square of ψ: $\psi' = \psi e^{i\Delta}$; $|\psi'|^2 = |\psi|^2$. Therefore the physical laws are unchanged if the phase of the wave function is shifted by an arbitrary constant. (1963: 52-3).

The former is the quantum mechanical phase symmetry which shows our claim: laws of quantum physics do not change under symmetry transformation, which entails that the probability distributions that these laws assign to diverse kinds of quantum processes are preserved under such transformations. We can add to the prior symmetry transformation the symmetry operations that Feynman indicates under which various physical phenomena remain invariant: translation in space, translation in time, rotation in space, uniform velocity in straight line (Lorentz transformation), reversal of time, reflection of space, interchange of identical atoms or identical particles, and matter-antimatter (charge conjugation). (1963: 52-2). We can express our claim with respect to the previous symmetries as follows: if a law L holds in a random process, assigning probability values to all the possible final states, and that law L holds invariantly under certain symmetry transformation T, then the probability values assigned to the untransformed process are the same assigned to the transformed process by T. This is just another formulation of the probabilistic Curie's principle.

4.4 On the measurement problem

So far, we have overpassed the question about the collapse of the wave function associated with von Neumann's projection postulate in processes of measurement. In the interaction involved in a measurement process of a quantum system –the interaction between a measured system and measuring apparatuses– the wave function in question "collapses" and the system adopts one of the states included in the calculated superposition state. However, the relata of the measurement processes are complex interactions between quantum systems and classical objects, and not the dynamical evolutions of quantum systems. So, it is not clear whether the measurement problem in quantum mechanics is relevant to our discussion about PCP.

Ismael considers two kinds of interpretations about the measurement problem. The standard interpretation, that incorporates the so-called "collapse postulate", under which the assignation of a probability to an observable **A** of a system in a state ψ represents the probability that if one measures the observable **A**, the system *will evolve* into an eigenstate of **A** with eigenvalue **a**. And an interpretation according of which: "Born's rule is treated as a law of coexistence relating *partial* state descriptions to a probability distribution over fuller state descriptions." (1997: 178). Under this second interpretation, which does not assume the collapse postulate, the probability of an eigenvalue **a** for an observable **A** for a system in a state ψ means that the system in fact *possesses* eigenvalue **a** for **A**. Ismael concludes that in either case "Born's rule is treated as an indeterministic law which maps the state-description onto a probability distribution over state-descriptions." (*idem*). If this is so, it seems that we can consider the plausibility of PCP apart from the hard measurement problem, and we can also maintain that Born's rule, not von Neumann's projection postulate, is the law which we have regarded with respect to CP in indeterministic systems.

But there is an additional reason to think of PCP separately from the collapse of wave functions. The sort of transformations on quantum systems which are our concern here are not the discontinued transformations involved in the measurement interactions, but the transformations that physicists consider as symmetry operations such as translation in space, translation in time, reversal of time, reflection of space, replacement particles by identical particles, and exchange matter-antimatter. With respect to these kinds of transformations *T*, we intend to say that a probabilistic law *L* is symmetrical under *T* if and only if for all physically possible effects E_i, given a symmetrical physical conditions *C* in an indeterministic system, the probability values of all E_i (with $i \geq 2$) are invariant under *T*, which means that the probability values are preserved when the indeterministic system is transformed.

Earman elaborates a quite different view on this point. For him, a measurement process interrupts the deterministic evolution of a quantum system, governed by Schrödinger equation, via a "collapse" of the state vector into an eigenstate of the observable under measurement –though he points out that it is highly controversial the idea that the collapse of the state vector is an objective physical process (2002: 181 and ft. 11). Such measurement collapse would violate his premise (C1) on the deterministic evolution of the quantum system, although he separated the question of his concern about the spontaneous symmetry breaking from the collapse of wave functions in measurement processes. Our indeterministic version of PCP avoids such sort of threat, because we do not suppose any description of a deterministic evolution, but descriptions of possible transitions or transmutations of quantum systems in terms of superposed states with assigned probability values –though one could ask what the physical status of such superpositions of quantum states is, as Cartwright does (1983). Both questions –the physical objectivity of the collapse of the state vector and the physical status of the quantum superposed states– are beyond the intended scope of this paper.

4.5 Symmetry and principles of conservation

There is a close relationship between the principles of symmetry and the principles of conservation. Beiser express this as follows: "Every symmetry operation corresponds to something being conserved, though not necessarily in every interaction."[8] (1987: 537). For example, in the Compton scattering effect the relevant quantities conserved are momentum under a translation in space and energy under a translation in time, in the same way that in the quantum-mechanical phase the electrical charge is the quantity conserved. These cases, which involve indeterministic systems, suggest the question about the relationship between PCP and the principles of conservation. Nevertheless, as it is known, there are important exceptions in certain interactions to the connection between symmetry operations and quantities conserved under some transformations, as Beiser said. This shows the pertinence of the question. We find with respect to this that whenever we deal with processes that are no invariants under a certain transformation, PCP does not apply; its scope is restricted to indeterministic systems which fulfill the symmetry transformations.

A significant exception is the known violation of space parity. The parity designs the behavior of the wave function under an inversion in space, i. e., the reflection of spatial coordinates through the origin, replacing x by –x, y by –y, and z by –z. That the parity is conserved on some kind of process means that the laws of physics are independent of whether a left-handed or a right-handed coordinated system is used to describe the process. If the sign of the wave function ψ does not change under such inversion –i. e., ψ(x, y, z) = ψ(—x, —y, —z)– the parity is even, if it changes –i.e., ψ(x, y, z) = —ψ(—x, —y, —z)– the parity is odd. The principle of conservation of parity affirms that a system of even parity retains even parity and a system of odd parity retains odd parity: the initial parity of an isolated system does not change during whatever events occur within it (see Beiser, 1987: 539). Both previous processes fulfill this principle of parity; in general, it holds in strong and electromagnetic interactions, but not so in some weak interactions. In the process of spontaneous beta decay, a weak interaction, the parity is not conserved. Beta disintegration is a nuclear process which converts a neutron into a proton (β–) or vice versa (β+), emitting besides an electron plus an antineutrino, and a positron plus a neutrino, respectively.

A simple case where space parity is not conserved refers to the asymmetry under reflection of space on weak interactions in which neutrinos and antineutrinos participate.9 The direction of spin of neutrinos is counterclockwise

[8] But it seems that the converse does not hold because, for example, the conservation of the baryon number *B* has not any known symmetry associated.

[9] Besides, the symmetry operations of time reversal (when *t* is replaced by – *t*) and charge conjugation (when *Q* is replaced by – *Q*) have exceptions in some weak interactions, where

while the direction of spin of antineutrinos is clockwise. The reflection of space transformation inverts the direction of spin of both kinds of particles. The spin of neutrino looks like the spin of antineutrino in its mirror image, and vice versa. This induces so an asymmetry between the directions of spin of each such particles and their mirror images. About that Beiser points out: “The neutrino has a left-handed spin and the antineutrino a right-handed spin, so that there is a clear difference between the mirror image of either particle and the particle itself.” (see, *idem*). Thus, the reflection in space operation violates the parity of description of neutrinos and antineutrinos. The initial parity of either sort of particles changes under such transformation, whether an even parity or an odd parity, and the equations that describe theirs beta disintegration invert its signs. It seems that this result is in accordance with Curie’s claim: “The phenomena breaks the symmetries of laws”.10

The former no conservation of space parity entails, e.g., that the initial state of a free electron undergoing a random process, with a left-handed spin, and the initial state of the same electron under a reflection of space operation, with a right-handed spin, are asymmetrical, i. e., $SI \neq R(S_I)$, where SI is the initial state of the free electron and R is the inversion of space. This implies, contrary to the conclusion of our proof of PCP, that the corresponding probability values of the possible final states in the untransformed system and in the transformed system are different, i.e., $p(S_{Fi}) \neq p(R(S_{Fi}))$. However, this is consistent with PCP, since the assumption about the symmetry of the initial state of the system under a given transformation is not fulfilled, and thus the equality of the probabilities of its possible final states is not implicated by PCP.

It seems that when the quantities are conserved the probabilities are preserved, although the contrary does not hold in general; i. e., in processes under an asymmetric transformation, which breaks the conservation of a quantity, the probabilities associated are not preserved.

time parity and charge parity are not conserved, respectively (see Beiser, 1987: 538).

[10] Quoted by Earman (2004: 1231) from Curie (1894: 401).

5. Conclusion

We have seen that laws of physics hold invariably across an intended domain of application and that laws of physics hold invariably under symmetry transformations. It is the latter claim that is relevant with respect to Curie's Principle. We have tried to maintain a probabilistic formulation of such principle for random processes. Our main thesis is that probabilistic laws about such processes, *if* they hold under symmetry transformations on a domain of application, as the quantum domain, *then* they do so *salva probabilitas*. Hence, on basis of PCP, from a symmetry T of the initial state of an indeterministic system we can *infer* the invariance of the probability values assigned by a law to its possible final states when the system is transformed by T, granted that the law holds on the untransformed system.

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