



## PAPER

## Geometric aspects of quantization and relationship to integrability

## OPEN ACCESS

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**Keywords:** quantum, geometry, integrability, conservation, curvature, evolution, connection, integrable.**Abstract**

It is the case that quantum mechanics has a deep geometric structure and can be presented accordingly. Quantum mechanics is to a certain degree foreshadowed by the geometry inherent in the geometric structure of classical mechanics. The purpose here is to present some new results and proofs which impact the mathematical structure of quantum mechanics. The relationship between integrability and quantum physics is investigated in terms of geometric ideas and structures. Two physical examples are drawn from these mathematical ideas which directly relate to physics. An introduction as to how these ideas can be extended to infinite degrees of freedom is also described.

**1. Introduction**

Quantization is a process that refers to the construction of a quantum mechanical system with respect to a particular classical system. It is this process and its implications for the relationship of quantum mechanics and integrability that is the subject studied here. We attempt to justify the machinery of geometric quantization on something like physical grounds.

Classical systems have a deep geometric structure at their root as they are founded on symplectic manifolds. A symplectic manifold is a pair  $(M, \Omega)$  such that  $M$  is a manifold and  $\Omega$  is a closed non-degenerate two-form defined on  $M$ . In general,  $\Omega$  is required to be closed which means  $d\Omega = 0$  and  $d$  is exterior differentiation. This means the induced Poisson bracket satisfies the Jacobi identity and so the flows of Hamiltonian vector fields consist of canonical transformations [1–6]. A vector field  $X$  on  $M$  is called Hamiltonian if there exists a function  $H: M \rightarrow \mathbb{R}$  such that  $i_X \Omega = dH$  for all  $w \in T_x M$  then  $\Omega_p(X, w) = dH(X)w$  and  $X_H$  is written for  $X$ . Hamilton's equations are the evolution equations

$$\dot{z} = X_H(z). \quad (1.1)$$

In finite dimensions, these are given in canonical coordinates by

$$\frac{dq^i}{dt} = \frac{\partial H}{\partial p_i}, \quad \frac{dp_i}{dt} = -\frac{\partial H}{\partial q^i}. \quad (1.2)$$

The classical phase space  $M$  is oriented and carries a natural volume element

$$d\omega_c = (-1)^{n(n-1)/2} \frac{1}{n!} \omega^n = dp_1 \wedge \dots \wedge dp_n \wedge dq^1 \wedge \dots \wedge dq^n. \quad (1.3)$$

This is the Liouville form and there is an obvious Hilbert space associated with  $M$ . This is the space  $L^2(M)$  of square integrable complex valued functions on  $M$  with inner product

$$\langle \varphi, \psi \rangle = \int \varphi \bar{\psi} d\omega_c, \quad \varphi, \psi \in L^2(M). \quad (1.4)$$

Many of the original paths to quantization can be formulated as what is called Dirac's quantization rule. This rule associates operators to the simplest classical observable which appear in dynamical problems such as position and momentum functions. Thus it is a map from classical observables to symmetric operators which preserves the bracket relations and sends the constant function 1 to the identity operator  $\mathbf{1}$ . The basic geometric construction is called pre-quantization and was originally presented by Souriau and Kostant [7–10]. The construction of the physical quantum Hilbert space makes use of an additional structure which is called a

# Geometric Quantum Aspects Of Integrabl

**Sabine Zange**



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