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# Mach's Principle, Time, Quantum Gravity, and the Origin of the Arrow of Time

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Since my three talks at Peyresq were all based on already published papers, I give here only an abstract of my talks, which were essentially a review of the work done by Bruno Bertotti and myself (Barbour and Bertotti, 1977, 1982) on the creation of Machian dynamical models in which both time and motion are treated relationally. This work eventually led us to conclude that Einstein's general theory of relativity is one of a large class of possible Machian dynamical theories (Barbour and Bertotti (1982), but with a very special and distinguished structure. The Machian nature of general relativity is expressed through constraints on the initial data for the Cauchy problem; these constraints play the central role in all attempts to quantize general relativity in the canonical approach. Indeed, because they reflect the deep dynamical structure of general relativity, they must be central to all attempts to quantize gravity. The constraint that has proved the most difficult to handle and understand conceptually is the so-called Hamiltonian constraint. In my talks I pointed out that this constraint arises because of the fact (which I believe has not been properly appreciated) that general relativity treats time in a very Machian manner. Indeed, there is a well-defined sense in which time does not exist in general relativity at all. These issues are discussed in some length in (Barbour, 1994). See also the discussions in Barbour and Pfister (1995), especially the final discussion on the problem of time in quantum gravity, in which I propose the notion of "time capsules" in order to explain how the *static* wave function of the universe that follows from quantization of the constraints of general relativity can still describe a universe experienced as full of motion and memories. A time capsule is *a static configuration of part or all of the universe containing structures which suggest they are mutually consistent records of processes that took place in a past*

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*in accordance with certain laws.* Mott's famous explanation of why α-particles make straight tracks in cloud chambers (Mott, 1929) suggests that the static wave function of the universe may be concentrated on time capsules. If this proves to be the case, this would constitute the ultimate explanation for the arrow of time (Barbour, 1994).

## REFERENCES

Barbour, J. B., and Bertotti, B.(1977). Gravity and inertia in a Machian framework, *Nuovo Cimento*, **38B**, 1–27.

Barbour, J. B., and Bertotti, B. (1982). Mach's principle and the structure of dynamical theories, *Proceedings of the Royal Society of London A*, **382**, 295–306.

Barbour, J. B. (1994). The timelessness of quantum gravity. I. The evidence from the classical theory. II. The appearance of dynamics in static configurations, *Classical and Quantum Gravity*, **11**, 2853–2897.

Barbour, J. B., and Pfister, H., eds. (1995). *Mach's Principle: From Newton's Bucket to Quantum Gravity*, Birkhäuser, Boston,

Mott, N. F.(1929). The wave mechanics of α-ray tracks, *Proceedings of the Royal Society of London A*, **126**, 79–84.