Relational Quantum Light

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Quantitative statements in physics are dominantly relational, position relative to a coordinate system or energy relative to a reference energy are prime examples. Relational dynamics assumes that physical phenomena are intrinsically relational and emerge in the separation into subsystems. In this spirit time and temperature originate from a stationary global entangled state. Time evolution emerges for one subsystem in relation to its complement, even if both parts interact [1]. Interpreting the complement as the environment, imaginary relational time gives rise to temperature and the canonical ensemble for the system, if the global state is maximally entangled [2].

Here, we extend this idea to photons where a free field of N photons does not only preserve energy but also momentum. Separating such an entangled photon state into two subsystems by conditioning one subsystem in a suitable way, converts entanglement into coherence. Thereby a dependence not only on time but also space emerges. The space-time four-vector functions as Lagrangian multiplier realizing the four-fold constraint of free photons regarding momentum and energy. From a practical point of view the relational approach allows a gradual interpolation from quantum to classical light.

References

[1] S Gemsheim and J M Rost, Phys. Rev. Lett. **131**, 140202 (2023)

[2] S Gemsheim and J M Rost, Phys. Rev. D **109**, L121701 (2024)