Eur. Phys. J. D (2023) 77:2
https://doi.org/10.1140/epjd/s10053-022-00578-1

THE EUROPEAN
PHYSICAL JOURNAL D

Editorial

# Quantum optics of light and matter: honouring Alain Aspect

David Clément[1,a], Philippe Grangier[1,b], and Joseph H. Thywissen[2,c]

[1] Laboratoire Charles Fabry, Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, 91127 Palaiseau, France
[2] Department of Physics and CQIQC, University of Toronto, Toronto, ON M5S 1A7, Canada

Published online 4 January 2023


**Abstract.** The topical issue "Quantum Optics of Light and Matter: Honouring Alain Aspect" encompasses a set of historical and personal perspectives on Alain's career, and a series of scientific articles on contemporary research in quantum and atom optics. These contributions celebrate the amazing scientific career of Alain Aspect and provide fascinating perspectives for quantum information science and quantum technologies. It is a wonderful conjunction of events that this topical issue appears only a few weeks after Alain, together with John Clauser and Anton Zeilinger, was awarded the 2022 Nobel Prize in Physics.

It is a privilege to be guest editors for this special issue of *European Physical Journal D*, a Festschrift celebrating the research career of Alain Aspect. The original impetus was Alain's 75th birthday, but the timing was actually better than any of us could have expected: we learned shortly before completing the Issue that Alain was awarded, along with John Clauser and Anton Zeilinger, the 2022 Nobel Prize in Physics "*for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science.*"

Alain Aspect was born in 1947 in Agen, France. His undergraduate and master's degrees were at the ENSET (Ecole Normale Supérieure de l'Enseignement Technique) of Cachan and at Université Paris-11 in Orsay. Starting in 1971, he spent three years in Cameroon, where teaching left him time for independent study of quantum mechanics. Alain returned to Orsay for this PhD work, "Three experimental tests of Bell's inequalities with entangled photons," defended in 1983 at the Institut d'Optique.

After this impressive achievement, Alain struck out in a new scientific direction. In 1985, together with Jean Dalibard and Christophe Salomon, Alain started a new group to cool and trap atoms, under the aegis of Claude Cohen-Tannoudji's chair at the Collège de France. In 1992, he returned to the Institut d'Optique (then at Orsay, but now at Palaiseau, and part of the Université Paris-Saclay) to launch the new Atom Optics group. Since 2012, Alain has been emeritus from CNRS and has held the chair Augustin Fresnel at Institut d'Optique. He is also a Professor at Ecole Polytechnique and at Ecole Normale Supérieure Paris-Saclay.

The first three articles of this issue [1–3], completed before the announcement of the 2022 Nobel Prize, provide personal perspectives on Alain's career.

Olival Freire analyses the impact of Alain's experimental tests of Bell's inequalities on the foundations of quantum mechanics [1]. In addition to personal anecdotes and a detailed historical account, he describes the seminal role played by these experiments for the field of quantum information and its associated technologies.

Franck Laloë and Claude Cohen-Tannoudji share a fascinating piece of history, the scientific questions at the origin of their meeting with Alain and those on which they worked together [2]. Their scientific exchanges covered an impressive range of topics, from Bell's inequalities and single-photon sources to velocity-selective coherent population trapping of atoms.

Finally, over the summer of 2022, William D. Phillips and Jean Dalibard interviewed Alain on the occasion of this special issue [3]. Their article reveals Alain's own view on the experimental tests of Bell's inequalities 40 years after their realizations, along with a series of little-known historical moments from that period.

The eleven scientific articles in this Festschrift celebrate the amazing breadth and impact of Alain's scientific works. The contemporary research topics in quantum and atom optics include fundamental quantum physics and quantum simulations, on photonic, atomic, and solid state systems. These works introduce novel theoretical and experimental approaches and provide us with fascinating perspectives for the coming years.

A common theme among four of the articles [4–7] is using photon correlations to reveal profound physics. Such an approach was central in Bell's experiments but Alain also implemented it on many occasions, e.g., to

[a] e-mail: david.clement@institutoptique.fr
[b] e-mail: philippe.grangier@institutoptique.fr
[c] e-mail: joseph.thywissen@utoronto.ca (corresponding author)

study the first single-photon sources during the PhD thesis of Philippe Grangier. A study of the Siegert relation with light sources ranging from outer stars to cold atoms is reported by P. Lassègues et al., who also discuss how their work could be used to reveal astrophysical or random lasing in the future [4]. Since Alain is a lover of gazing at the night sky through a telescope, this paper truly combines all of his favourite topics. N. Fabre et al. give a novel perspective on the description of the celebrated Hong–Ou–Mandel effect using continuous variables [5]. This allows them to envision measuring time-frequency Wigner functions and realizing logical gates with these continuous variables. Since entangled pairs of photons were required to demonstrate the "weirdness" of our quantum world, it is natural to consider what three photons might reveal. K. Bencheikh et al. describe the generation of triple-photon states [6]. This tri-national work also shines new light on the nonclassical nature of these states. Finally, ideas from quantum optics have been carried into the acoustic regime by P. Kwiek [7]. The presented study of the diffraction of one- and two-photon NOON states of an ultrasonic wave confirmed a two-photon beat predicted theoretically.

Atom lasers and analogues of Quantum Optics experiments with atoms were studied by Alain and his colleagues at Institut d'Optique, from the observation of Hanbury-Brown and Twiss bunching to the Hong–Ou–Mandel effect. In these studies, the single atom detection of helium in a metastable state hold a special place. One paper in this Special Issue follows that legacy: K. Thomas et al. have demonstrated and tested a new Rarity-Tapster interferometer with metastable Helium atoms [8]. In connection with the 2022 Nobel Prize, their future goal is to violate Bell's inequalities with external degrees of freedom—the momentum of Helium atoms—which would be an extension of Bell test experiments with the internal degrees of freedom—polarization of photons.

Four papers [9–12] concern localization of matter waves and the properties of disordered quantum systems. Alain and his collaborators understood that laser speckle could provide a well-controlled disorder potential for ultracold atoms and in 2008 observed Anderson localization of a matter-wave in a one-dimensional system (1D). A novel experimental approach using a bichromatic speckle potential is presented by B. Lecoutre et al. [9]. It allows the team of Vincent Josse, with whom Alain still collaborates, to propose a realistic scheme to address the phase transition of the Anderson localization in a three-dimensional system. An experiment with an atomic kicked rotor investigates the shape and the statistics of the Anderson-localized wave packet in 1D [10]. In particular, C. Hainaut et al. show that the localized density profile does not exactly decay as an exponential but rather follows the predictions made by Gogolin in the 1970's. A theoretical work by M. Bahovadino et al. investigates a disordered one-dimensional Fermi-Hubbard model in the presence of a magnetic field [11]. The authors calculate a phase diagram with remarkable results on the localization properties. Finally, S. Takayoshi and T. Giamarchi analyze the dynamical conductivity in a disordered 1D chain of interacting fermions [12], by investigating the variations of the conductivity and of the localization length with the disorder and the interaction strengths.

Two papers [13,14] present extensions of key paradigms from Alain's career into the solid state regime. M. Jacquet et al. propose to use a polariton fluid to study the Hawking Effect, which is the correlated emission of two waves from opposite sides of an event horizon [13]. In this work they set the stage for a series of experiments aiming to measure entanglement in Hawking emission. P. Jamonneau et al. use coherent population trapping in a lambda system to control the nuclear spin of $^{13}$C [14]. This advance provides a promising tool for quantum metrology using nitrogen vacancies in diamond.

So, within this very nice conjunction of events, and on behalf of all contributing authors to this special issue, it is time to say wholeheartedly: Happy Birthday, Alain!

**Acknowledgements** We thank the Editorial Board and staff of EPJD, especially Almut Beige, Isabelle Auffret Babak, and Muriel Bouquant, for their dedicated help in setting up this issue.

**Data Availability Statement** This manuscript has no associated data or the data will not be deposited. [Authors' comment: Data sharing is not applicable to this article as no datasets were generated or analyzed.]

## References

1. O. Freire, Alain Aspect's experiments on Bell's theorem: a turning point in the history of the research on the foundations of quantum mechanics. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00542-z
2. C. Cohen-Tannoudji, F. Laloe, Alain, Claude, et Franck. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00573-6
3. J. Dalibard, W.D. Phillips, Experimental tests of Bell's inequalities: a first-hand account by Alain Aspect. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00557-6
4. P. Lassègues, M. Antônio, F. Biscassi, M. Morisse, A. Cidrim, N. Matthews, G. Labeyrie, J.-P. Rivet, F. Vakili, R. Kaiser, W. Guerin, R. Bachelard, M. Hugbart, Field and intensity correlations: the Siegert relation from stars to quantum emitters. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00558-5
5. N. Fabre, M. Amanti, F. Baboux, A. Keller, S. Ducci, P. Milman, The Hong–Ou–Mandel experiment: from photon indistinguishability to continuous-variable quantum computing. Eur. Phys. J. D **76**(10), 196 (2022). https://doi.org/10.1140/epjd/s10053-022-00525-0
6. K. Bencheikh, M.F.B. Cenni, E. Oudot, V. Boutou, C. Félix, J.C. Prades, A. Vernay, J. Bertrand, F. Bassignot, M. Chauvet, F. Bussières, H. Zbinden, A. Levenson, B. Boulanger, Demonstrating quantum properties of triple photons generated by $\chi^3$ processes. Eur. Phys.

J. D **76**(10), 186 (2022). https://doi.org/10.1140/epjd/s10053-022-00514-3
7. P. Kwiek, Interaction of two-photon NOON state with ultrasonic wave. Eur. Phys. J. D **76**(9), 157 (2022). https://doi.org/10.1140/epjd/s10053-022-00467-7
8. K.F. Thomas, B.M. Henson, Y. Wang, R.J. Lewis-Swan, K.V. Kheruntsyan, S.S. Hodgman, A.G. Truscott, A matter wave Rarity-Tapster interferometer to demonstrate non-locality. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00551-y
9. B. Lecoutre, Y. Guo, X. Yu, N. Myneni, M. Mukhtar, V. Volchkov, A. Aspect, V. Josse, Bichromatic state-dependent disordered potential for Anderson localization of ultracold atoms. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00549-6
10. C. Hainaut, J.-F. Clément, P. Szriftgiser, J.C. Garreau, A. Rançon, R. Chicireanu, Localization properties of the asymptotic density distribution of a one-dimensional disordered system. Eur. Phys. J. D **76**(6), 103 (2022). https://doi.org/10.1140/epjd/s10053-022-00426-2
11. M.S. Bahovadinov, D.V. Kurlov, B.L. Altshuler, G.V. Shlyapnikov, Many-body localization of 1d disordered impenetrable two-component fermions. Eur. Phys. J. D **76**(7), 116 (2022). https://doi.org/10.1140/epjd/s10053-022-00440-4
12. S. Takayoshi, T. Giamarchi, Dynamical conductivity of disordered quantum chains. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00524-1
13. M. Jacquet, M. Joly, F. Claude, L. Giacomelli, Q. Glorieux, A. Bramati, I. Carusotto, E. Giacobino, Analogue quantum simulation of the Hawking effect in a polariton superfluid. Eur. Phys. J. D **76**(8), 152 (2022). https://doi.org/10.1140/epjd/s10053-022-00477-5
14. P. Jamonneau, A. Dréau, G. Hétet, J.F. Roch, J.R. Maze, V. Jacques, Room-temperature polarization of individual nuclear spins in diamond via anisotropic hyperfine coupling and coherent population trapping. Eur. Phys. J. D (2022). https://doi.org/10.1140/epjd/s10053-022-00528-x