

## Subject card

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|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-----------------------------------|------------------------------------------------|-----|
| Subject name and code                       | Signatures of non-classicality, PG_00158049                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Field of study                              | Quantum Information Technology                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Date of commencement of studies             | October 2024                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                          | Academic year of realisation of subject                                                                                                                                                                                                                                                                                                                                                                         |                                     |                                   | 2024/2025                                      |     |
| Education level                             | Master's studies                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                          | Subject group                                                                                                                                                                                                                                                                                                                                                                                                   |                                     |                                   | Obligatory subject group in the field of study |     |
| Mode of study                               | full-time studies                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                          | Mode of delivery                                                                                                                                                                                                                                                                                                                                                                                                |                                     |                                   | at the university                              |     |
| Year of study                               | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                          | Language of instruction                                                                                                                                                                                                                                                                                                                                                                                         |                                     |                                   | English                                        |     |
| Semester of study                           | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                          | ECTS credits                                                                                                                                                                                                                                                                                                                                                                                                    |                                     |                                   | 6.0                                            |     |
| Learning profile                            | academic                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                          | Assessment form                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Conducting unit                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Name and surname of lecturer (lecturers)    | Subject supervisor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                          | dr Beata Zjawin                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
|                                             | Teachers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                          | dr Beata Zjawin                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Lesson types                                | Lesson type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Lecture                                                  | Tutorial                                                                                                                                                                                                                                                                                                                                                                                                        | Laboratory                          | Project                           | Seminar                                        | SUM |
|                                             | Number of study hours                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 30.0                                                     | 30.0                                                                                                                                                                                                                                                                                                                                                                                                            | 0.0                                 | 0.0                               | 0.0                                            | 60  |
|                                             | E-learning hours included: 0.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Learning activity and number of study hours | Learning activity                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Participation in didactic classes included in study plan |                                                                                                                                                                                                                                                                                                                                                                                                                 | Participation in consultation hours |                                   | Self-study                                     | SUM |
|                                             | Number of study hours                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 60                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.0                                 |                                   | 30.0                                           | 90  |
| Subject objectives                          | Get acquainted with the concept of nonclassical phenomena as a fundamental property of Nature.Learn about the traditional phenomena of Entanglement and Bell nonclassicality, the recently reformulated notions of Steering and Kochen-Specker contextuality, and the newly identified phenomena of Spekkens contextuality and Network nonclassicality.Understand not only the foundational implications of these nonclassical phenomena, but also their role as resources for information processing. |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                 |                                     |                                   |                                                |     |
| Learning outcomes                           | Course outcome                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                          | Subject outcome                                                                                                                                                                                                                                                                                                                                                                                                 |                                     | Method of verification            |                                                |     |
|                                             | [QITL3_W04] knows advanced methods of theoretical and mathematical physics necessary in creating models of quantum mechanics                                                                                                                                                                                                                                                                                                                                                                           |                                                          | Student has a clear understanding of models of classicality and how Nature does not respect them. Student knows and understands the basic concepts and terminology used in the quantum foundations approach to quantum information. Student knows the proofs of the main facts such as Asymptotic Equipartition Property, Shanonn's theorem etc., as well as knows basic methods such as compression algorithms |                                     | [SW4] test/exam - oral or written |                                                |     |

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|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|
| Subject contents                                               | Entanglement theory: bipartite and multipartite entanglement; separability criteria; entanglement distillation and monogamy; applications (e.g.,teleportation).Bell nonclassicality: Bells theorem; Fines theorem; Bell inequalities; Entanglement vs. Bell nonclassicality; bipartite and multipartite Bell scenarios;activation of Bell nonclassicality; the geometry of correlations (No-Signalling and Classical polytopes, the quantum set); applications.Contextuality: Kochen-Specker contextuality; state dependent vs. state independent contextuality; inequalities from hypergraphs; Spekkenscontextuality; applications.Steering: bipartite and multipartite steering; steering inequalities; applications.Network nonclassicality: brief introduction to networks, examples, and applications |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                  |
| Prerequisites and co-requisites                                | None.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                  |
| Assessment methods and criteria                                | Subject passing criteria                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Passing threshold                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Percentage of the final grade    |
|                                                                | lecture part: exam                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 51.0%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 50.0%                            |
|                                                                | tutorial part: test                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 51.0%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 50.0%                            |
| Recommended reading                                            | Basic literature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | R. Horodecki, P. Horodecki, M. Horodecki, and K. Horodecki. Quantum entanglement, Rev. Mod. Phys. 81, 865 (2009).N. Brunner, D. Cavalcanti, S. Pironio, V. Scarani, and S. Wehner. Bell nonlocality, Rev. Mod. Phys. 86, 419 (2014).D. Cavalcanti and P. Skrzypczyk. Quantum steering: a review with focus on semidefinite programming, Rep. Prog. Phys. 80, 024001 (2017).A. Cabello, S. Severini, and A. Winter. (Non-)Contextuality of Physical Theories as an Axiom, arXiv: 1010.2163 (2010).A. Acín, T. Fritz, A. Leverrier, and A. B. Sainz. A Combinatorial Approach to Nonlocality and Contextuality, Comm. Math. Phys. 334, 533 (2015).R. W. Spekkens. Contextuality for preparations, transformations, and unsharp measurements, Phys. Rev. A 71, 052108 (2005).C. Branciard, D. Rosset, N. Gisin, and S. Pironio. Bilocal versus non-bilocal correlations in entanglement swapping experiments, Phys. Rev. A 85,032119 (2012).T. Van Himbeec, et al. Quantum violations in the Instrumental scenario and their relations to the Bell scenario, Quantum 3, 186 (2019). |                                  |
|                                                                | Supplementary literature                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | None.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                  |
|                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | eResources addresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Adresy na platformie eNauczanie: |
| Example issues/<br>example questions/<br>tasks being completed |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                  |
| Work placement                                                 | Not applicable                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                  |

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