Gravity and gravitational tests

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Gravity has a universal character, but its strength rapidly decreases with distance, being the weakest of the four fundamental forces of physics[1]. In the 4th century BC, the Greek philosopher Aristotle considered as the cause of the fall of heavy bodies their tendency to move to their natural place[2]. In Book VII of *De Architectura*, the Romanian engineer and architect Vitruvius argues that gravity does not depend on the "weight" of a substance, but rather on its "nature"[3]. Indian astronomer and mathematician Brahmagupta argued that the Earth is spherical and attracts objects[4]. In the seventeenth century, Galileo discovered that, contrary to Aristotle's teachings, all objects were accelerating equally when they fell[5]. After Newton's count of gravity as a force, general relativity considers gravity to be a consequence of the curvature of spacetime due to mass distribution. According to the current main theory, gravity appeared with the birth of the Universe, during the Planck era (10^{-43} seconds after the Big Bang). Currently, there are attempts to develop a quantum theory that unifies gravity with the other three fundamental forces in nature. Quantum mechanics with quantum field theory[6] and general relativity are the fundamental theories in which gravity is approached.

Allan Franklin and Slobodan Perovic, in *Experiment in Physics*[7], state that theories in science in general, and in physics in particular, are confirmed (temporarily)

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[1] Cele patru forțe "fundamentale"sunt cea electromagnetică, nucleară "slabă" responsabilă de dezintegrarea radioactivă, nucleară "puternică" legând elementele constitutive ale nucleelor, și gravitațională.

[2] Edward Grant, *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional and Intellectual Contexts* (Cambridge ; New York: Cambridge University Press, 1996), 60–61.

[3] Vitruvius Pollio, *De architectura* (Torino: Giulio Einaudi, 1997), 215.

[4] Muḥammad ibn Aḥmad Bīrūnī, „Alberuni's India", text, 1910, 272, http://www.columbia.edu/cu/lweb/digital/collections/cul/texts/ldpd_5949073_001/index.html.

[5] Stillman Drake, *Galileo at Work: His Scientific Biography* (Courier Corporation, 2003).

[6] Quantum field theory is the common framework for light and electron theory in the form of fields (quantum electrodynamics), weak nuclear forces theory, and quarks and gluons theory. The standard model of particle physics combines these approaches and describes the internal structure of atoms through quantum fields.

[7] Allan Franklin și Slobodan Perovic, „Experiment in Physics", în *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2016 (Metaphysics Research Lab, Stanford University, 2016), https://plato.stanford.edu/archives/win2016/entries/physics-experiment/.

by experiments that verify the assertions and predictions of theories, thus laying the groundwork for scientific knowledge. Francis Bacon was the first to support the concept of a crucial experiment, which can decide the validity of a hypothesis or theory. Later, Newton argued that scientific theories are directly induced by experimental results and observations, excluding untested hypotheses. Hobbes stated, on the contrary, that human reason preceded experimental techniques, criticizing Boyle's optimism about the role of the experimental method[8]. In the 20th century, logical positivism separates observational deductions from theoretical ones. Thomas Kuhn and Paul Feyerabend criticized this view, saying that all experiments are based on a theoretical framework and therefore cannot independently confirm a theory[9]. Ian Hacking agreed with this idea, but says the comments remain reliable through independent confirmations. In the case of a single viable experimental system, Allan Franklin and Slobodan Perovic propose specific strategies for validating the observation, which, together with Hacking's strategy, constitute an epistemology of the experiment:

1. Experimental verification and calibration, with the help of known phenomena.
2. Reproduction of previously known artifacts.
3. Elimination of plausible sources of error and alternative explanations of the result ("Sherlock Holmes strategy").
4. Using the results to argue their validity.
5. Using a well-corroborated independent theory of phenomena to explain the results.
6. Using an apparatus based on a well-corroborated theory.
7. Use of statistical arguments. [10]

But applying these strategies does not guarantee the correctness of the results. Because of this, physicists use several strategies, depending on the experiment.

Peter Galison, in *How Experiments End* (1987), states that experiments end in a subjective way, when experts believe they have reached a valid result[11]. Most experiments are based on the traditions in the field and the personal experience of the

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[8] Steven Shapin și Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton University Press, 1989).

[9] Ian Hacking, „Do We See Through a Microscope?”, *Pacific Philosophical Quarterly* 62, nr. 4 (1981): 63: 305–322.

[10] Franklin și Perovic, „Experiment in Physics”.

[11] Peter Galison, „How Experiments End”, *Journal of Philosophy* 87, nr. 2 (1990): 235.

researcher (including his theoretical assumptions), both in designing the experiment and in accepting a theory that "allows" the conduct of experiments. The theoretical assumptions of the experimenters are accepted.

Harry Collins has developed an argument called "experimenters' regress[12]," according to which there are no formal criteria that you can apply to decide whether an experimental device works properly or not. What actually matters is negotiation within the scientific community, which depends on factors such as the career, social and cognitive interests of scientists and perceived usefulness for future work, but which is not decided by what we may call epistemological criteria or rationalized judgment[13].

Pickering also argues that the reasons for accepting the results are their subsequent usefulness in scientific practice, and their agreement with existing community commitments[14]. He states that an experimental system rarely produces valid experimental results unless it is adjusted accordingly, and that the theory of apparatus, as well as the theory of phenomena, determines the production of a valid experimental result[15]. Later, he concludes that "the outcomes depend on how the world is"[16]: "In this way, then, how the material world is leaks into and infects our representations of it in a nontrivial and consequential fashion. My analysis thus displays an intimate and responsive engagement between scientific knowledge and the material world that is integral to scientific practice." [17]

Hacking claims that, despite appearances, constructivists, such as Collins, Pickering or Latour, do not believe that facts do not exist or that there is no reality. He

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[12] Harry M. Collins, *Changing Order: Replication and Induction in Scientific Practice*, Reprint edition (Chicago: University of Chicago Press, 1992), 79–111.

[13] Franklin și Perovic, „Experiment in Physics”.

[14] Andrew Pickering, „The Hunting of the Quark”, *Isis* 72, nr. 2 (1981): 216–36.

[15] Pickering, „The Hunting of the Quark”.

[16] Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science*, 1 edition (Chicago: University of Chicago Press, 1995), 182.

[17] Pickering, 183.

cites Latour and Woolgar that the result is a consequence of scientific work rather than its cause[18] [19], in a relative consensus with the scientific community.

Franklin and Perovic state that the accumulation of a large amount of data in an experiment may require a selection, by the technique of reduction used by physicists, of the data that will be used. This may be an important epistemological concern regarding the selection of data considered useful, minimizing the probability of unexplored results[20]. In such cases, physicists apply a robustness analysis in testing hypotheses, checking the equipment used, and establishing working algorithms.

In the case of the solutions of Einstein's equations of general relativity and of the modeling of quantum gravity theories, due to the complexity of these approaches, simulations of computer experiments are attempted. Currently, there is an ongoing dispute to what extent these simulations are experiments, theories or some kind of hybrid methods of doing science. [21]

Between 1965 and 1990 many experiments were developed for testing gravitational theories, including[22]

- High precision measurements of the effects of electromagnetic radiation in the gravitational field, confirming the GR for the weak gravitational field.
- Detection of the non-linear gravitational interaction of the masses at a pulsar in the gravitational field of a neutron star.
- Indirect confirmation of gravitational radiation by observing two nearby neutron stars, confirming GR.
- Attempts, so far failed, to ascertain the violation of the principle of equivalence or the existence of a fifth force.

[18] Bruno Latour, Steve Woolgar, și Jonas Salk, *Laboratory Life: The Construction of Scientific Facts, 2nd Edition*, 2nd edition (Princeton, N.J: Princeton University Press, 1986), 180.

[19] Ian Hacking, *The Social Construction of What?*, Revised edition (Cambridge, Mass: Harvard University Press, 2000), 80–81.

[20] Allan Franklin, *Shifting Standards: Experiments in Particle Physics in the Twentieth Century*, 1 edition (Pittsburgh, Pa: University of Pittsburgh Press, 2013), 224–25.

[21] Eric Winsberg, *Science in the Age of Computer Simulation* (Chicago: University of Chicago Press, 2010), 136.

[22] Vladimir B. Braginsky, „Experimental Gravitation (What Is Possible and What Is Interesting to Measure)”, *Classical and Quantum Gravity* 11, nr. 6A (iunie 1994): A1–A7, https://doi.org/10.1088/0264-9381/11/6A/001.

During this period most experiments confirmed the general relativity with the help of the newly developed technologies. A technological basis for gravitational wave astronomy has been created. Cryogenic barogenic antennas and laser interferometric antennas were built, associated with the theoretical analysis of the experiments with the test masses, resulting in the sensitivity of the experiments depending on the thermal insulation, if the device continuously records the coordinates the antenna sensitivity is limited, and the sensitivity can be increased if there are used quantum procedures[23]. The antennas can help in observing the gravitational background radiation and testing the general relativity in the ultra-nonlinear case.

Regarding the sensitivity of gravitational measuring devices, Vladimir B Braginsky states that the current level of knowledge allows us to hope that the sensitivity of the antennas can increase, and no limit of sensitivity has been set in the gravitational experiments, it depends on the knowledge of the scientists. [24]

Currently, experimental gravity is an emerging field, characterized by continuous efforts to test the predictions of gravity theories.

The *classical limit* or the *limit of correspondence* is the ability of a physical theory to approximate the classical version when it is taken into account by the special values of its parameters[25]. The *principle of correspondence* formulated by Niels Bohr in 1920[26] states that the behavior of systems described by quantum mechanics reproduces classical physics within the limits of large quantum numbers[27]. This principle has two basic requirements: the reproduction of the Poisson brackets, and the specification of a complete set of classical observables whose operators, when

[23] Braginsky.

[24] Braginsky.

[25] David Bohm, *Quantum Theory*, Revised ed. edition (New York: Dover Publications, 1989).

[26] N. Bohr, „Über die Serienspektra der Elemente", *Zeitschrift für Physik* 2, nr. 5 (1 octombrie 1920): 423–478, https://doi.org/10.1007/BF01329978.

[27] Paul A. Tipler și Ralph Llewellyn, *Modern Physics*, Sixth edition (New York: W. H. Freeman, 2012), 160–61.

acting through appropriate semiclassical states, reproduce the same classical variables with small quantum corrections[28].

[28] Abhay Ashtekar, Luca Bombelli, și Alejandro Corichi, „Semiclassical States for Constrained Systems", *Physical Review D*, 2005, https://www.academia.edu/587754/Semiclassical_states_for_constrained_systems.

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