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# Discovery experiments and demonstration experiments

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Science is distinguished from other creative activities by the central role played by experiment (in which we include observation). Experiments enable us to discover new things, to confirm or falsify our theoretical expectations, and suggest new directions for exploration and analysis. Our aim here is to identify two kinds of physics experiment that are philosophically very different.

The first kind is what we will call *discovery experiments*. Realms previously inaccessible become open to exploration with a new instrument. For example, telescopes (Galileo's, Hubble, James Webb…), microscopes (Hooke, Leeuvenhoek…), and particle accelerators. Each observation reveals something surprising. Sometimes, there are theoretical expectations, and the aim of experiments is to decide between alternatives. The Michelson-Morley interferometer failed to detect an absolute reference frame. The Large Hadron Collider discovered the Higgs boson. The Laser Interferometer Gravitational-wave Observatory discovered merging black holes. The Aharonov-Bohm fringe shift, and the violation of Bell inequalities, established quantum nonlocality, in two qualitatively different forms. Antimatter falls down.

In a subclass of discovery experiments there is no doubt that an underlying theory applies but its implications are either unanticipated or beyond current abilities to compute or conceptualise. In condensed matter, the theory is quantum mechanics: the Schrödinger equation for an assembly of many electrons and nuclei. As Philip Anderson declared: 'More is different'. This was behind the discovery of completely unexpected phenomena such as high-temperature superconductivity, and the integer and fractional quantum Hall effects.

Common to discovery experiments is that the result is not known in advance. Underlying fundamental theory is lacking, or ambiguous, or has not been tested or fully explored in the regime being investigated. The popular understanding of scientific experiments is of the discovery type.

The second kind is what we will call *demonstration experiments*. Existing well-established theory, correctly and uncontroversially applied, unambiguously predicts a new phenomenon, and the aim of experiment is to confirm that it occurs. Such experiments can be regarded as analogue computations. Into this category fall, for example, nonhermitian optical effects in systems with PT symmetry, optical and neutron interference effects revealing geometric phases, and random-matrix spectral statistics of quantum energies of classically chaotic systems and their counterparts in optical and acoustic modes. Common to demonstration experiments is that the result is known in advance. If the experiment fails to conform to theoretical expectation, this means it was wrongly conducted, either through a failure of correct modelling or insufficiently sensitive instrumentation. Such experiments are repeated until they give the correct result.

We do not underestimate demonstration experiments. We are delighted when our theories, and the mathematics underlying them, are brought to life in the physical world. And they have scientific value, beyond educating students in physics laboratories. They are often difficult, and experience gained when they fail to give the expected result guides the development of new instruments and the search for disturbing influences not initially included in the modelling. And demonstration experiments often lead to new technology.

We have emphasised discovery and demonstration, but of course this demarcation is not exhaustive (thought experiments and numerical experiments come to mind), and there is a large literature discussing experimentation, in physics and science more generally, from different perspectives. We simply draw attention to the fact that in the everyday practice of physicists, discovery and demonstration experiments are often conflated. Knowing the subtle differences between them may make little difference to how experiments are done. But if we want to conceptualise our efforts to understand nature, it is worth highlighting the distinctions between them. ■