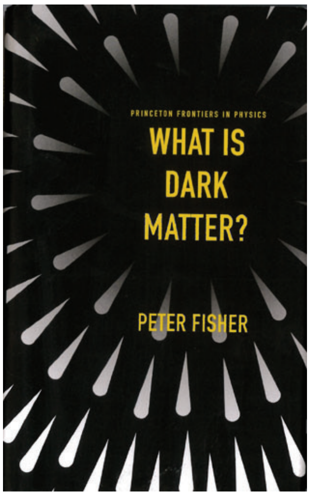

What is Dark Matter? Peter Fisher. Princeton University Press, 41 William Street, Princeton, New Jersey 08540; and 99 Banbury Road, Oxford OX2 6JX. 2022. x + 179 pages. Price: US$ 35.00/£28.00.

While all the matter on Earth is made of atoms, memorably arranged in the periodic table of chemical elements, the same cannot be said of matter elsewhere in the Universe. The fact is, most of the matter in the Universe is not made of electrons, protons and neutrons. Decoding the nature of this mysterious 'Dark Matter' is an important goal in astro-particle physics and cosmology. Peter Fisher gives a bird's eye view of this exciting area of research in his book *What is Dark Matter*?.

The task of understanding dark matter brings a sense of *deja vu*. In 1892, after meticulous measurements, Lord Rayleigh reported that the 'nitrogen' obtained indirectly by burning away the oxygen from the air weighs about 0.5% more than the nitrogen directly synthesized using chemical reactions in the laboratory. We could compare this with the dark matter problem: masses of galaxies and clusters inferred indirectly through their gravitational effects exceed the mass directly inferred by adding up the known forms of matter. This excess mass is dubbed dark matter. In keeping with this terminology, the additional component of atmospheric air could have been dubbed dark air! It is now well known what this discrepancy stems from – the dark air is mainly argon, which makes up about 1% of atmospheric air. However, let us pause to speculate how one could have discovered the presence of argon in a bid to explain dark air.

Broadly, there are three approaches to addressing the problem of missing mass. The macroscopic approach, e.g. essentially using thermodynamics and conservation laws, can establish the presence of a new substance. This approach is very robust but does not usually reveal detailed properties. For the case of argon, unbeknownst to Rayleigh, in 1795, Cavendish had isolated this unreactive air component that remained as a small bubble in the reaction flask after oxygen and nitrogen were removed. Yet, it was not clear what this substance was made of. Most cosmological and astrophysical evidence for dark matter falls in this category. The data tells us that dark matter exists; it tells us how much and where, but not what it is. At the largest distances, dark matter behaves like a fluid that generates gravitational potential and responds to it like ordinary matter. One has little information on its non-gravitational properties except that it experiences negligible pressure. The typical quantity of interest is the dark matter density and how it evolves as the Universe expands. This theoretical framework, best described as thermodynamics in an expanding Universe, tells us how these quantities evolve as the Universe expands. The most important observational probes in this regime are the abundance of nuclei created in Big Bang nucleosynthesis and the properties of the Cosmic Microwave Background. With these observations, it is well-established that about 80% of all matter in the Universe is dark matter.

The microscopic approach appeals to detailed structure and interactions of the new substance. In fact, already in 1882, Newall and Hartley had seen unexplained lines from atmospheric air, which they could have used to argue for the existence of a new element and predict its detailed atomic structure. But quantum mechanics and atomic theory had not sufficiently matured for such a leap to have been made. Most of the particle physics searches for dark matter take this micro approach. At the smallest scales, typically smaller than galaxies, and mainly in laboratory experiments, the detailed particle microphysics of dark matter can be important. Observational strategies, such as direct detection (dark matter directly scattering with the detector), indirect detection (dark matter annihilating or decaying to a secondary particle that interacts with the detector), as well as direct production in the lab, are naturally very model-dependent – so far mainly designed to look for specific particles. The greatest challenge here is to find the right lamppost to look under.

The middle-path approach uses kinetic theory and nonequilibrium statistical mechanics to connect the microscopic and macroscopic descriptions and extract specific microscopic properties while ignoring other details. For dark air, measurement of the diffusion constant or ratio of heat capacities could have been used to ascertain some combination of its properties, such as its mass or monoatomic, while remaining agnostic of its detailed atomic structure. This is what Lord Rayleigh and William Ramsay did in a joint 54-page paper on their way to winning the Nobel prizes for physics and chemistry. In the field of dark matter, the corresponding approach represents the search for non-gravitational effects of dark matter mainly through transport phenomena. On the distance-scales of galaxies and clusters of galaxies, as well as in stars, processes can occur out of thermodynamic equilibrium. Transport coefficients quantify the relaxation rate, revealing properties such as their interaction rates, mean free paths, etc. The relevant observational probes are CMB anisotropies, features in the large-scale structure of observable matter, exotic heating or cooling of stars and galaxies, and a variety of new measurements. This area has many new ideas and may give the first glimpse of dark matter's particle identity.

In his book, Fisher reviews the evidence for dark matter, explains why it must be a new particle, and discusses direct and indirect detection efforts for the two most prominent dark matter candidates (WIMPS and axions). The glossary of the book helpfully explains the technical terms. Overall, the book is quite readable and gives a healthy overview of the dominant ideas while mentioning some others (primordial black holes, modified Newtonian dynamics, etc.). The descriptions of the particle physics experiments are clear and concise, which is not surprising given Fisher's expertise. For more astrophysical and cosmological aspects, the book is a launching pad, guiding the reader to related literature. The field of dark matter is expected to remain exciting for many decades to come – a detailed investigation of its properties will indeed follow the earliest detections. This book is an accessible and fun introduction to the field for any curious mind.

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