Team finds two theoretical physics models to be equivalent

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Two Yale-NUS College undergraduates are part of a research team that concluded that two different mathematical models, which describe the same physical phenomenon, are essentially equivalent. The discovery could have implications for future research into magnetoresistance and its practical applications in a wide range of electronic devices. After implementing the two different models of magnetoresistance as computer simulations, Lai Ying Tong, 21, and Silvia Lara, 22, found that the two simulations produced similar results under identical conditions. Magnetoresistance is a physical phenomenon where the electric resistivity of a material changes when subjected to a magnetic field. The research was published in the peer-reviewed journal *Physical Review B* in December 2017.

The two Yale-NUS undergraduate students worked on the project under the mentorship of Associate Professor Shaffique Adam from Yale-NUS College and the Department of Physics at the National University of Singapore's (NUS) Faculty of Science, and Associate Professor Meera Parish from Monash University. They were guided by Navneeth Ramakrishnan, a Masters student at the Department of Physics at the NUS Faculty of Science and NUS Centre for Advanced 2D Materials, who checked their results and wrote the paper. The findings provided a unified theoretical framework to understand a phenomenon known as 'linear unsaturating magnetoresistance', as well as clear predictions on how to manipulate the effect. Prior to their research, two separate theoretical mathematical models had been proposed to describe how the phenomenon works: the Random Resistance Network (RRN) model and the Effective Medium Theory (EMT) model. Empiricists exploring magnetoresistance generally refer to either of these two models to contextualise their experiments, but do not provide a detailed comparison between the theories and their experimental results. This latest finding not only unifies the two existing theories, but also validates that these theories are accurate descriptions which match with experimental data.

The findings have a direct impact on future research into magnetoresistance, which has practical applications in a diverse range of electronic devices, such as speed sensors, mobile phones, washing machines, and laptops. The principles of magnetoresistance are currently used in magnetic memory storage in hard drives, and certain companies are aiming to produce sensitive magnetometers - devices which measure magnetic fields - that can operate at room temperatures. This is a billion dollar industry which supports applications in many aspects of everyday life ranging from automobile collision warnings to traffic light burnout detection.

Ms Lai and Ms Lara began this research as a summer research project in their first year of undergraduate education, under the guidance of Assoc Prof Adam, who is also with the Centre for Advanced 2D Materials at NUS. Assoc Prof Adam highlighted both students' roles in the research, noting that they reviewed existing literature, implemented the mathematical models in the industry-standard software environment MATLAB, as well as ran the simulations and the subsequent analyses. The students also presented the research findings at international conferences, such as the American Physical Society March Meeting 2017.

Yale-NUS College funded the undergraduate students to work on this project. "This level of undergraduate engagement, not only in the research, but in shaping the direction of the work is extremely rare. At

Yale-NUS, science students are able to actively participate in such research very early on in their learning experience," said Assoc Prof Adam.

More information: Navneeth Ramakrishnan et al, Equivalence of effective medium and random resistor network models for disorder-induced unsaturating linear magnetoresistance, *Physical Review B* (2017). DOI: 10.1103/PhysRevB.96.224203

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