GRAVITY WEIGHS IN ON SPECTROSCOPY

The visible spectrum of neon and its characteristic emission lines. By Jan Homann via Wikimedia Commons

In 1814 the German physicist Joseph von Fraunhofer observed narrow dark lines in the otherwise continuous spectrum of light emitted by the sun. Hundreds of them. As Gustav Kirchhoff and Robert Bunsen later showed, these lines correspond to the absorption of light by various chemical elements in the sun. Each element has its own unique set of lines that correspond to energetic transition between the electronic states of these atoms. This discovery has laid the foundation to the field of spectroscopy, where the interaction of matter and light is probed.

A study published in *Nature Physics* this week by Hartmut Abele and colleagues from the University of Vienna in Austria now reports how gravity can be used instead to probe quantum states. And they're not using atoms either, but neutrons, which are the electrically neutral particles in the atom's core.

These neutrons are produced in nuclear research reactors, for example at the Institute Laue-Langevin (ILL) in Grenoble, which I visited last year. In fact, the experiment by Abele and colleagues was done at ILL because there ultracold neutrons are available for research – “still the only source of ultracold neutrons for users in the world,” says Peter Geltenbort from the ILL, who took part in the experiments.

These ultracold neutrons are so slow that they can be kept in a container. Even though neutrons are subatomic particles that normally can pass easily through matter, when they are sufficiently slow they don’t have enough energy to overcome nuclear forces and pass through the container walls. Instead they’re bounced back.

Here, the ultracold neutrons pass horizontally between two mirrors. The top mirror has a rough surface, which leads to the absorption of neutrons that reach the mirror. However, it is only neutron with enough energy to overcome gravity that reach the top mirror. So, at the bottom mirror neutrons are confined through the hard surface, whereas at the top they are confined by the forces of gravity. Moreover, the absorption of neutrons that reach the top mirror ensures that only neutrons with low energy can pass through the experiment.

Furthermore, the distance between the mirrors is small enough, about 20 to 25 micrometers, to distinguish between quantum states of the neutrons. These quantum states can be seen as standing waves that form between two walls. As neutrons with higher energies are absorbed by the top mirror, those neutrons remaining in the experiment are for the most part in the lowest quantum state. Next, the researchers wiggle the lower mirror at a fixed frequency, and measure the impact this has on the neutrons after they have passed through the mirrors. They find that for certain resonance frequencies the neutrons are elevated into a higher quantum state. In other words, the experiments can be used to measure the energy difference between two quantum states of neutrons.

This experiment is therefore in direct analogy to optical spectroscopy, say on neon atoms. The quantum states of the neutrons correspond to the electronic states of neon, and the resonant movements of the bottom mirror correspond to the oscillations of the lightwave.

The implications, however, are quite different.

In spectroscopy, typically the interesting part are the electronic states of atoms and molecules. Here, such experiments could be used to learn more about gravity itself. Small deviations in the gravitational force would have a direct impact on the experiments, as these would alter the energy difference between the quantum states of the neutrons. “New forces would change or modify Newtonian gravity,” explains Abele. “Such effects are for example predicted by string theories,” adds Tobias Jenke from the team.

Furthermore, Abele says, the sensitivity of the approach beats competing techniques that use mechanical vibrations occurring in micro-scale materials. Geoffrey Greene from Oak Ridge National Laboratory and the University of Tennessee in Knoxville, United States, who works on neutron scattering experiments, agrees. “To date the best limits have been seen using very sensitive force balances, but these are limited to ranges greater than microns. Because the neutron is uncharged (and essentially non-polarizable), is massive, and is point-like down to the femtometer scale, it, in principle, could be used as a probe for very short range forces.”

Both, Greene and Abele stress that one particularly interesting force arising from string theories, and that could be verified for the first time are so-called axion fields. In the same way that Fraunhofer’s discovery opened the door to the spectroscopy of atoms and molecules, the realization of this new spectroscopic tool could lead to an entirely new insight into gravity and related forces.

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