Friction Under Fire

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The Greek philosopher Heraclitus, believed to be born around 500 BC, once declared, 'everything flows; everything moves, nothing is ever stationary.' Heraclitus arrived at the above conclusion from his realization that the world is constantly changing, always 'becoming' but never 'being'. This concept has also been expressed more succinctly in one of his sayings, 'No man ever steps in the same river twice.'

However, our day-to-day experience contradicts the above. I am writing this article while sitting on a chair; my book is resting on the table and is not moving at all. To move the book, the book needs a push. A gentle push with my fingers doesn't make a difference until I exert more force on the book. Once the force reaches a critical value, the book starts moving. Similarly, if I start tilting the table upwards, the book continues to remain motionless until the table reaches a critical angle and the book starts sliding down. To slide an object on a surface, the applied force has to overcome the resistance between the two surfaces, called 'friction'. This transition from apparent stillness to sudden movement under the influence of a force is also seen in human joints or even in earthquakes and landslides. However, recent research shows that this concept of friction is outdated.

The observation of Heraclitus from thousands of years ago has been proved to be true in recent times. The recent research performed at the California Institute of Technology, Pasadena, USA, confirmed that although two surfaces in contact appear motionless, in reality, they are always sliding at a rate that is imperceptible to the human eye. These observations were reported in a paper published in the 12 March 2025 issue of the journal *Nature*. This finding happens to be a game-changer in our perception of friction learnt in our school days. It also helps us to have a more precise understanding of the mechanics of earthquakes and landslides and has major implications for engineering and materials interfaces.

Friction between two sliding interfaces has been historically explained by Coulomb's law. When two surfaces are in contact, whether it is a book on a table or two plates of the Earth's crust pressed and sheared along a fault, Coulomb's law indicates that there is a certain factor, called the 'coefficient of static friction', which quantifies the resistance to motion, that must be overcome before the interfacing surfaces start sliding. In other words, Coulomb's law states that the two compressed interfaces are completely motionless unless enough shear force is applied.

Over the last few decades, researchers who study rock mechanics and geological faults have started questioning the validity of Coulomb's law, suspecting that it may not provide the full story. Scientists have come up with more detailed equations, called rate-and-state laws of friction. The rate laws of friction tell that the friction changes based on how fast the two surfaces are sliding past each other. One might feel a different resistance when rubbing one's hands slowly versus quickly. In state-dependent friction, friction depends on the conditions of the surfaces, like roughness or contact time. If we leave a book on a table for a long time, it might 'stick' more than if we have just placed it down. This special kind of adhesion, called 'healing', is due to microscopic changes at the contact points, making the interface more resistant to sliding. In the paper, the team also quantified healing by measuring how it slows down the microscopic sliding under small forces.

Rate-and-state laws of friction predict that there is no static friction coefficient and that shear movement occurs under all shear forces. This means that even the slightest push on a heavy book with the tip of our finger will cause the book to slide, even if by a tiny, imperceptible amount. These laws help scientists to understand how faults in the Earth's crust behave, predicting how earthquakes happen. They show that friction isn't just a simple force but depends on both speed (rate) and surface conditions (state). Indeed, the team found that the friction between the interfaces during rapid sliding would be significantly higher, by about 20%, for interfaces that had been in contact for a year versus 5 minutes.

In this paper, the team presents the first direct proof that motion is happening at shear forces of strength even lower than that implied by the apparent static friction coefficient, validating the rate-and-state laws. In laboratory studies, the team used an optical method called digital image correlation (DIC) and a camera trained on two surfaces in contact. They determined that, under shear, the surfaces slide over each other at a rate of as small as 10^{-12} meters per second, or 0.000000000001 meters per second, unrecognised by our eye. At this rate, a millimetre of slip would take more than three years to occur.

One may question the importance of measuring such a minute sliding rate, which in terms of the static coefficient of friction is close to zero. Nadia Lapusta, one of the authors of the paper says, 'The importance is not just in validating rate-and-state friction but also in quantifying the interface healing. Rate-and-state friction laws predict that the healing should manifest itself in the decrease of sliding rates, which is exactly what we measure, enabling us to quantify healing. This, in turn, allows us to predict how the interface would resist a sliding event, such as an earthquake rupture propagating along a fault.'

Another group of scientists at the University of Amsterdam have also studied how and when the friction at the contact between two objects is overcome and sliding starts to happen using fluorescence microscopy.

This recent research on friction contradicts the classical concept of friction and points to redefining friction in textbooks in the future. ■

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