


# Scientists reveal ultrafast melting dynamics in matter heated to extreme temperatures


January 10 2022

### Going to the Extremes: Ultrafast Electron Dynamics in Warm Dense Matter


Matter behaves differently under extreme temperature and pressure conditions, such as inside stars and planets



Such extreme states can be realized in laboratories with intense ultrafast lasers...




...but the two-temperature model (TTM) cannot describe electron dynamics at femtosecond ( $10^{-15}$  s) time scales



**What exactly happens in noble metals when heated abruptly to extreme temperatures?**

### Investigating femtosecond dynamics of copper (Cu) electrons heated to 20,000 K

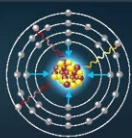
Femtosecond laser irradiation heats Cu beyond its melting point




Taking snapshots of Cu electrons with ultrafast X-ray absorption spectroscopy


#### Electron dynamics beyond the TTM observed!


After heating, some electrons are excited, but rest are attracted more strongly by the nucleus




For about  $10^{-15}$  s, Cu is more solidified before softening and melting









First experimental evidence for this counter-intuitive phenomenon predicted over a decade ago




Relevant insight for current and future applications



Fusion



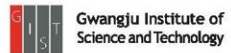
Laser machining



Nanosurgery

**This study deepens our understanding of extraordinary material properties under extreme conditions**

Investigation of Nonequilibrium Electronic Dynamics of Warm Dense Copper with Femtosecond X-Ray Absorption Spectroscopy  
 Lee et al. (2021)  
 Physical Review Letters | 10.1103/PhysRevLett.127.175005



Femtosecond X-ray snapshots of warm dense copper electrons reveal elusive phenomena predicted over a decade ago. Credit: Gwangju Institute of Science and Technology

Ordinary matter behaves very differently when subjected to extreme temperatures and pressures, such as that inside stellar and planetary cores. Conventional rules of condensed matter physics and plasma physics are not applicable in such scenarios. In particular, an extreme

state known as "warm dense matter" (WDM) straddles the boundary of condensed matter physics and plasma physics.

One might think that such states can never be created in a terrestrial setting. But, in fact, [short laser pulses](#) that are only femtoseconds ( $10^{-15}$  s, or a quadrillionth of a second) long are intense enough to recreate such conditions in a laboratory. Conventional physical models that describe such states typically assume that electrons become excited by the laser pulse attain equilibrium within tens of femtoseconds while the ions remain "cold." However, in doing so, the non-equilibrium dynamics of the electrons are completely disregarded.

To explore this non-equilibrium dynamics under [extreme conditions](#), a team of researchers led by Associate Professor Byoung Ick Cho from the Gwangju Institute of Science and Technology in Korea studied the WDM state for copper created by using intense laser pulses. The optical pulse excitation created copper electrons with a [temperature](#)  $\sim 20,000$  K, which is similar to that of a giant planet's core. Then, right when the copper sample was about to melt, the researchers took snapshots of the electrons using ultrafast X-ray pulses from an X-ray free electron laser (XFEL). This allowed them to analyze what happens in noble metals, such as copper, when their bonding electrons are highly excited and the metals are about to melt. The results of the study were published in *Physical Review Letters*.

One remarkable observation was that when heated quickly, the bonds between copper atoms first hardened for about one trillionth of a second ( $10^{-12}$  s) before [melting](#). Put simply, the sample solidified before turning into liquid. The team carried out detailed theoretical analysis backed by simulations, which revealed that while some electrons were excited to higher energies at such high temperatures, some experienced a stronger attraction towards the nucleus. "This phenomenon was, in fact, predicted about a decade ago, but we have now managed to observe it directly for

the first time," comments Prof. Cho. "This can improve our understanding of extraordinary material properties under extreme conditions and their underlying mechanisms."

These findings could be applied in contexts where materials are subjected to extremely high pressures and temperatures. "By capturing the precise moment when a material starts to melt or vaporize, we can generate new phases of matter or energy, which would be relevant to fields such as fusion, laser machining, and even nanosurgery," speculates Prof. Cho.

Who would've thought that understanding the interior of stars could have such practical terrestrial applications?

**More information:** Jong-Won Lee et al, Investigation of Nonequilibrium Electronic Dynamics of Warm Dense Copper with Femtosecond X-Ray Absorption Spectroscopy, *Physical Review Letters* (2021). [DOI: 10.1103/PhysRevLett.127.175003](https://doi.org/10.1103/PhysRevLett.127.175003)

Provided by GIST (Gwangju Institute of Science and Technology)

Citation: Scientists reveal ultrafast melting dynamics in matter heated to extreme temperatures (2022, January 10) retrieved 27 June 2024 from <https://phys.org/news/2022-01-scientists-reveal-ultrafast-dynamics-extreme.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.