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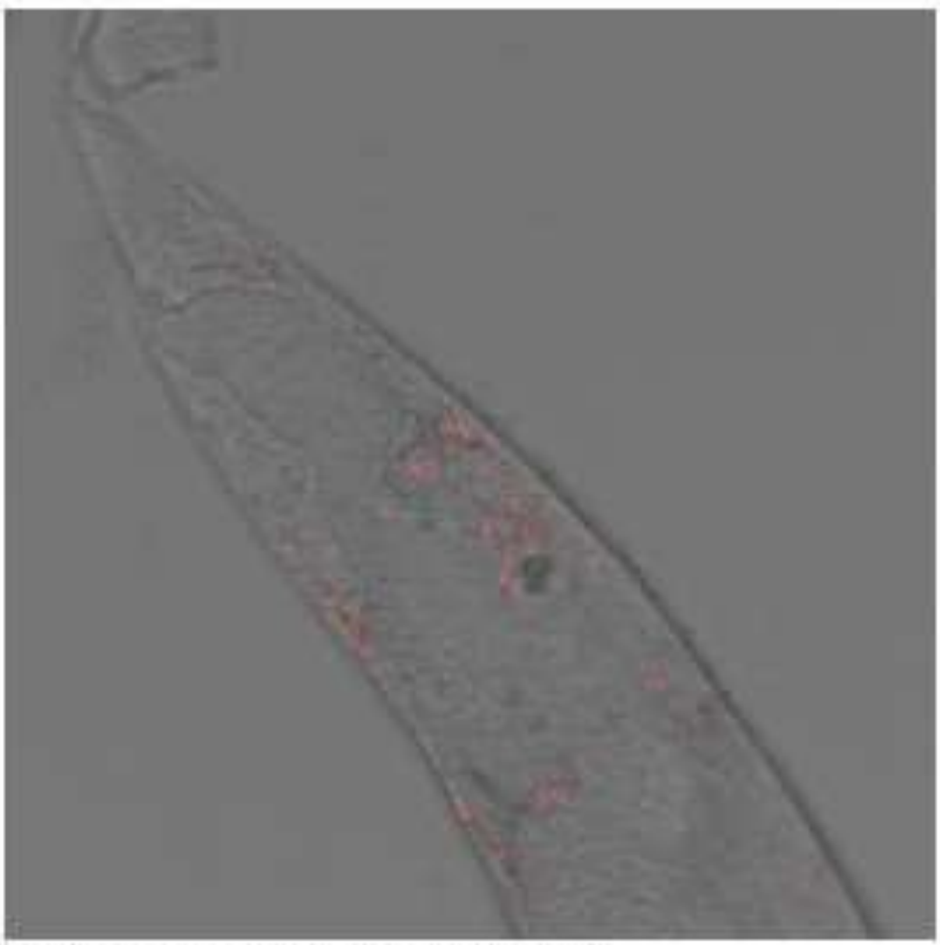
Nanodiamonds shine as subcellular thermometers

By taking advantage of the electron spin in nitrogen-vacancy centers and carefully tracking the centers, researchers detected temperature variations as small as 0.22 °C.

Alex Lopatka

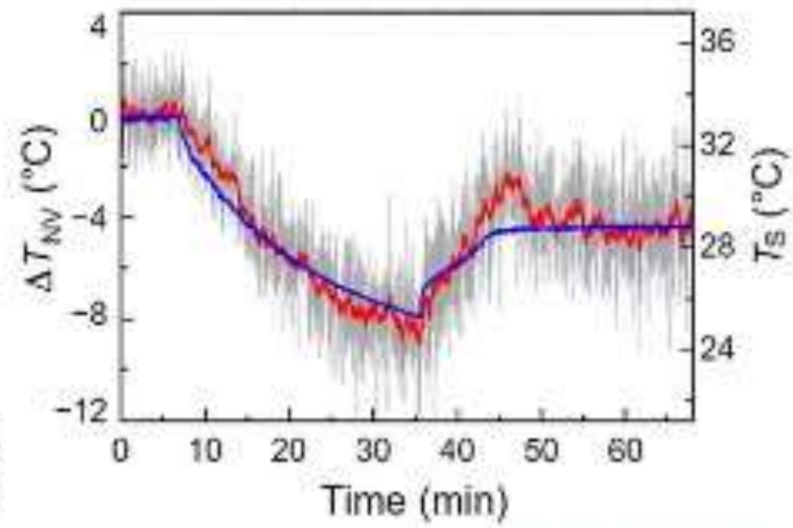
Once in a while, a nitrogen atom steals the place of a carbon atom next to an empty carbon site in the crystal lattice of diamond. Researchers call those impurities nitrogen–vacancy (NV) centers. They occur in nature, and researchers often deliberately add them to a diamond lattice for various applications, including as a component in quantum information technology or as a microscopic biological sensor. (See the article by Lilian Childress, Ronald Walsworth, and Mikhail Lukin, *Physics Today*, October 2014, page 38.)

NV centers in nanodiamonds have already been used as thermometers for *in vitro* cells. Now Masazumi Fujiwara at Osaka City University in Japan and his colleagues have demonstrated that NV centers in nanodiamonds can measure minute temperature changes *in vivo*. The particle tracking method the researchers paired with their microscope apparatus provides micrometer-scale spatial resolution.



Credit: Image courtesy of Masazumi Fujiwara

Fujiwara and his colleagues first injected nanodiamonds (red dots in the image above) into a *Caenorhabditis elegans* worm and then followed the nanodiamonds by measuring the fluorescence intensity generated by excitation with a green laser. Applying spin-resonant microwave radiation in combination with the laser pulse splits the NV center's ground state sublevel with spin quantum number 0 from the degenerate −1 and +1 sublevels. The transition between the sublevels is temperature dependent and can be optically detected because the NV center fluoresces as the excited electrons relax back to the ground state.



Credit: Adapted from M. Fujiwara et al., *Sci. Adv.* **6**, eaba9636 (2020)

To test the sensitivity of their nanodiamond thermometer, the researchers induced a thermal shock to the worm by varying its body temperature between 25 °C and 33 °C. The time series shows the agreement between the worm sample temperature (blue line in the second figure) and the estimate from the nanodiamond thermometer (red line).

The measured temperature variations should help researchers learn more about how *C. elegans* regulates its body heat. What's more, the nanodiamond thermometer may be applicable to other animals such as zebrafish, which are studied for drug development and their regenerative abilities. (M. Fujiwara et al., *Sci. Adv.* **6**, eaba9636, 2020.)

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Classical physics allows the atom to have heat capacity at the macroscale, the conservation of heat proceeding by an increase in temperature. However, the Planck law of quantum mechanics denies the atoms in nanoscale diamonds the heat capacity to conserve heat by a change in temperature suggesting small temperatures do not occur at the nanoscale. The heat thought to cause a small temperature difference is actually conserved by the emission of non-thermal EM radiation observed as nitrogen-vacancy fluorescence.