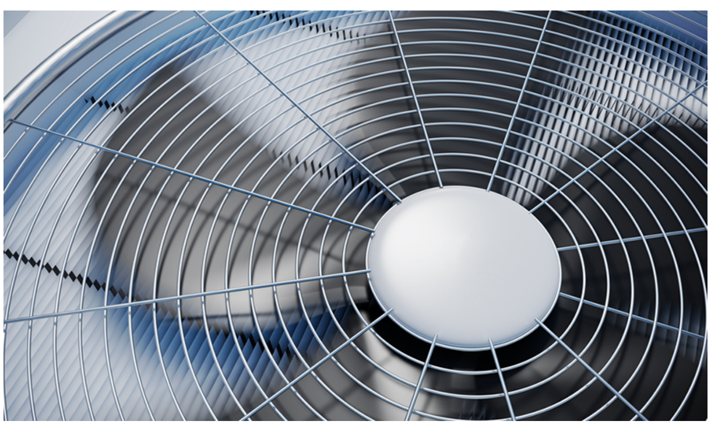
Electricity Generated from Coils and Globules

Researchers transform heat into useable electricity using a polymer phase transition, a behavior they say could be used to improve the energy efficiency of devices such as air conditioners.

By **Katherine Wright**

Air-conditioning units guzzle energy, such that—in the summer months—they come in first place for electricity use among household appliances. Now Teppei Yamada and his colleagues at the University of Tokyo have developed a material that could help reduce air-conditioning energy needs by turning waste heat from these systems into electricity [**1**]. The material could also be used in wearable devices that need to generate their own electricity. "Technologies that turn heat into electricity are in their beginning stages," Yamada says. "Here for the first time, we do that using a [polymer] phase transition."

The material that Yamada and his colleagues use is a thermoresponsive polymer called PNV, a water-absorbing polymer developed by others. In solution, at room temperature, PNV sucks in water such that each polymer strand takes on the shape of a bloated coil. Heat the mixture to above about 40 °C and the chains expel this water and shrink into compact globules.



The waste heat from an air conditioner could be transformed into electricity using a new polymer battery.
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PNV's "coil–globule" transition can also be induced through a redox reaction, which is a reaction that involves the transfer of electrons between two materials. As synthesized, each strand of the PNV Yamada and his group use is positively charged, with a net charge of +2 (PNV^{2+}). This charge can be reduced by one through various methods. PNV^{+} undergoes the same coil–globule transition as PNV^{2+} but at around 20 °C instead of 40 °C. Thus, if a redox reaction happens in a sample held at 30 °C, the electron transfer will trigger a phase transition.

The team's calculations show that this redox-triggered phase transition can—under certain conditions—be used to generate a voltage in a battery-like device. Broadly speaking, the process goes as follows: At one electrode, globule PNV^{+} donates an electron to the electrode. This donation oxidizes PNV^{+}, which then turns into PNV^{2+} and swells into a bloated coil. At the other electrode, coiled PNV^{2+} takes an electron. This action reduces PNV^{2+} into PNV^{+} and shrinks the polymer into a globule. The cycle then repeats.

For this reaction to generate a voltage, the electrodes must have different temperatures. In this case the cold electrode needs to be at a temperature just above the coil-to-globule transition temperature of PNV^{+} and the hot electrode at a temperature just below the coil-to-globule transition temperature of PNV^{2+}. This temperature gradient causes an imbalance in the

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distribution of coils and globules across the device, which in turn induces an electrochemical potential difference between the electrodes. This difference is a prerequisite for voltage generation in any system, even normal batteries, says team member Hongyao Zhou. “If there was no temperature gradient, we wouldn’t get any voltage because the phase transitions would occur equally at the two electrodes, which would then have the same electrochemical potential,” he adds.

For their demonstration, the researchers built a battery from two layers of platinum, between which they placed their PNV mixture. Initially, half of the PNV was in the oxidized form (PNV^{2+}) and half in the reduced form (PNV^{+}). They set the cold electrode to 25 °C and increased the hot electrode from 25 °C to 45 °C while measuring the voltage output.

For the 50:50 mixture, the researchers found that the voltage output jumped suddenly when the temperature difference exceeded 10 °C. The maximum output they recorded for their battery was about 20 millivolts, a voltage Zhou says they could increase by connecting multiple devices. The temperature difference required to get this voltage jump was adjustable, going to both higher and lower values when the team altered the ratio of PNV^{+} to PNV^{2+} in the initial mixture. Only a tiny voltage output was found when they replaced the PNV with a molecule that undergoes the redox reaction but has no polymer chain associated with it, indicating that the polymer phase transition was indeed behind the electricity generation, Zhou says.

Yamada, Zhou, and their colleagues also performed the reverse experiment, where they applied a current and measured the induced temperature change in the system, a phenomenon that could be used to cool electronic devices. This effect was smaller, but they did see a temperature change of a few millikelvin. Zhou says that this is the first time a temperature change has been obtained from the phase transition of the polymer.

In the team’s demonstrations, the temperature gradient was set using laboratory instruments. In real-world applications, Zhou envisions that this could be done using waste heat from other devices, such as an air conditioner unit. The heat could also come from the human body. “The ideal temperature to operate this device is near body temperature, so we could use body heat and air to generate electricity,” Yamada says. “There are lots of opportunities there.”

This work provides a novel route to using polymer materials in energy applications, says Javier Carretero-González at the Institute of Polymer Science and Technology, Spain, who develops functional polymer materials for sustainable energy technologies. “The implementation of new and more sustainable polymer materials in energy storage and conversion could open an alternative to inorganic and metallic systems that are usually more expensive,” he says. That would offer a clear advantage over current technologies.

Katherine Wright is the Deputy Editor of ***Physics Magazine***.

REFERENCES

1. H. Zhou *et al.*, “Direct conversion of phase-transition entropy into electrochemical thermopower and the Peltier effect,” **Adv. Mater. (2023).**