

Why does metal feel colder than wood?

Juan Segurola · All Rights Reserved

QUE · Article 001 · Simple Questions, Deep Answers · Version 0.2 EN

A wooden table and a metal object can have the same temperature yet feel different when touched. This does not force a choice between a faulty thermometer and a deceptive hand. They respond to different conditions. A properly used thermometer allows us to estimate temperature; touching an object starts an exchange that changes the temperature of the skin itself.

The precise question is therefore how two objects initially at the same temperature can cool the skin differently. Stating it this way reveals a condition that is easily overlooked: the objects must initially be cooler than the surface of the hand. The familiar contrast is not an unchanging property of metal, independent of circumstances.

1. The observation to be explained

Suppose two objects have remained in a stable environment and their surfaces have been checked to have the same temperature. That check matters. An object near a window, heat source or draught need not share the conditions of another object simply because both occupy the same room.

Once the starting conditions have been established, touching an object changes the system. Previously the hand and object were separate; now there is a contact through which energy can pass. The object's initial temperature remains relevant, but it no longer describes the process by itself. Material properties, geometry and contact duration also matter.

Three distinct outcomes could be recorded: the object's initial temperature, the skin's temperature over time, and the person's response. A difference in one does not automatically establish the same difference in the others. Sensation must not become a circular definition of temperature. Saying that an object is colder because it feels colder is precisely the inference under examination.

2. Transferring energy and changing temperature

Thermal conductivity relates conductive heat flux to a temperature gradient. In a simple one-dimensional description, Fourier's law is $q = -k \, dT/dx$. Here q is heat flow per unit area, k is conductivity, and the negative sign specifies transfer towards lower temperature.

The equation does not say that metal contains a substance called cold or that cold enters the hand. Nor does it say that bodies at the same temperature contain the same internal energy. Internal energy also depends on amount of matter, composition and state.

A second property enters the temperature change: heat capacity. When a region receives energy, its rise in temperature depends on how much energy is required to warm it. For a homogeneous solid over a range where properties can be approximated as constant, heat capacity per unit volume is ρc , the product of density and specific heat capacity.

Conductivity and heat capacity therefore answer different questions. One describes transport; the other relates energy received to temperature change. Saying that metal conducts heat well identifies an important part of the mechanism, but leaves out what happens as the receiving region warms.

3. A model that separates the variables

Consider an idealised comparison. Two homogeneous bodies initially have uniform temperatures and are placed in perfect contact along a flat surface. During a sufficiently short interval, the thermal disturbance does not reach their opposite faces. Treating them as semi-infinite means ignoring those distant boundaries, not claiming that real objects extend indefinitely.

A useful combination in this model is thermal effusivity, $e = \sqrt{k\rho c}$. If T_s is the skin's initial temperature and T_o the object's, the ideal contact temperature is:

$$T_c = (e_s T_s + e_o T_o) / (e_s + e_o).$$

This is a weighted average. An object with high effusivity relative to skin draws the contact temperature towards its own initial temperature. Low relative effusivity leaves it closer to the initial skin temperature. Ho's review discusses this formulation and its limits for contact with the hand [2].

The objects in the question differ in their relative effusivity. Common metals such as aluminium have much higher effusivity than skin, while wood generally has lower effusivity [2,3]. As a concrete comparison, applying $e = \sqrt{k\rho c}$ to the conductivity, density and specific heat values tabulated by Rykaczewski [3, Table 1] gives approximately 24,300 for aluminium, 1,180 for skin, and 700–920 for wood, in $J/(m^2 K s^{1/2})$. These are calculated effusivities from published material parameters, not measurements of sensation. Aluminium is about 21 times the skin value; the wood values are about 0.59–0.78 of it. These particular wood parameters do not define every wood or contact. They establish the relevant ordering: for objects initially cooler than the hand, the ideal model places the aluminium contact temperature much closer to the object's temperature, while wood leaves it closer to the skin's. The model thus connects the named materials to the different cooling effects.

An intentionally hypothetical example makes the consequence visible without presenting calculations as material measurements. Let $T_s = 32^\circ C$ and $T_o = 22^\circ C$. For $e_o/e_s = 1$, the expression gives $27^\circ C$; for a ratio of 9, it gives $23^\circ C$; for $1/9$, it gives $31^\circ C$. The initial object temperature has not changed. What has changed is the relative weighting of its properties in the exchange.

These numbers are neither measured hand temperatures nor a table describing particular metals and woods. They are calculated outcomes under specified assumptions. Their purpose is to show why equal initial temperature does not require an equal response during contact.

4. What experiments with people contribute

Ho and Jones conducted two experiments on material discrimination and localisation using thermal cues. Participants could discriminate materials when thermal differences were large; localisation among fingers was limited. Measured skin-temperature changes were smaller than theoretical predictions [1].

This result prevents an excessive conclusion. A useful thermal cue does not make the hand an infallible material identifier. Likewise, predicting the direction of a contrast does not establish that a model predicts its magnitude accurately. Comparing the physical record with the perceptual response is part of the test, not an afterthought.

Discrimination and identification are also logically different. Choosing which of two contacts produces more cooling is a comparative task. Recognising a material requires associating a response with a category. Different combinations of properties and

circumstances could generate similar signals, so perceptual similarity does not establish chemical identity.

5. Where the idealisation ends

Actual contact involves thermal resistance at the interface, finite geometry and living skin. Ho's review discusses how these factors and physiological heat supply limit simple models [2]. Adding decimal places to a formula cannot compensate for assumptions that fail to represent the contact being described.

Geometry provides a particularly clear conceptual check. A thin sheet and a thick piece of the same material share intensive properties but not the same amount of matter available for exchanging energy. A model that ignores the rear surface may work over one interval and fail later. There is no universal validity time independent of material and thickness.

The direction of the effect can also be checked without introducing new data. If the object starts warmer than the skin, the weighted average lies above the initial skin temperature: the model predicts warming rather than cooling. If both initial temperatures are equal, the temperature difference driving conduction vanishes in this model. "Metal is always cold" is therefore not a physical explanation.

6. What is secure and what remains to be specified

The distinction between initial temperature and temperature evolution during contact is secure. So is the joint role of heat transport and heat storage. These facts do not supply a universal function converting object temperature into an exact sensation for every person and contact.

A quantitative prediction for a particular situation requires boundary conditions, appropriate properties and measurements against which the model can be tested. If the model fails, incorrect parameters must be distinguished from unsuitable assumptions or an oversimplified connection to perception. These are different sources of uncertainty.

The everyday answer is brief: under familiar conditions, contact with metal can cool the skin more than contact with wood at the same initial temperature. The fuller explanation must preserve the phrase "under those conditions". An object has thermal properties; the sensation arises through an interaction.

Related reading

IDE-014, Measurement, develops how a measurement operation determines which quantity can be compared. It is optional background, not a prerequisite.

References

- [1] Ho, H.-N.; Jones, L. A. Contribution of thermal cues to material discrimination and localization. *Perception & Psychophysics* 68, 118–128 (2006). <https://doi.org/10.3758/BF03193662>
- [2] Ho, H.-N. Material recognition based on thermal cues: Mechanisms and applications. *Temperature* 5(1), 36–55 (2018; first published online 2017). <https://doi.org/10.1080/23328940.2017.1372042>
- [3] Rykaczewski, K. Modeling thermal contact resistance at the finger-object interface. *Temperature* 6(1), 85–95 (2019; online 2018). <https://doi.org/10.1080/23328940.2018.1551706>