1 The Seat Buckle Sting: Why do Metals Feel Hot?

After a summer day spent swimming, fishing, or people-watching, you return to your car and realize you forgot to crack the window. You open the door and hot, humid air rushes out. While you were gone, your car became a sauna.

As you sit down, the cloth seats are pleasantly warm against the backside of your knees—just one more perk of weather warm enough for shorts. You automatically grab the dangling seatbelt terminal near your shoulder and ZING! The seatbelt buckle gives your hand a much more painful welcome than the seat gave your legs. The seats reminded you of a mild heating pad; the metal seatbelt hasp brings to mind a frying pan.

Why does the metal burn you when the cloth does not?

When this question comes up in the classroom, often the explanation is: *Metals are conductors, so they heat up faster.*

This narrative starts out on the right foot but then trundles into error—a different question should have been asked in the first place. Instead of asking why the buckle was hotter than the seat, we would do better to ponder why the buckle *felt* hotter than the seat. Your hand is not a thermometer. It cannot tell the temperature. Instead, nerves in your skin determine whether it is *gaining or losing heat*. (Scientists define "heat" differently than most people. *Heat*, strictly speaking, is thermal energy that is being transferred. It is not a reference to temperature. If this bothers you, simply pretend "heat energy" is written everywhere you see the word "heat.")

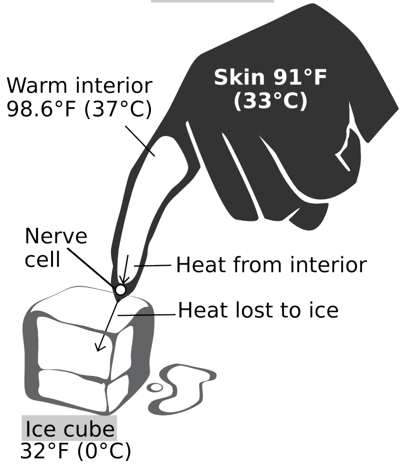
> Your hand is not a thermometer. It cannot tell the temperature. Nerves only determine whether the skin is gaining or losing heat.

Your internal body temperature is about 98.6° F (37° C), and your skin tends to stay around 91° F (33° C). *Because conduction moves heat from hotter objects to colder ones*, your body's metabolism is constantly warming your skin. It tends to lose energy to the outside air since you spend most of your time exposed to temperatures below 91° F (33° C). If the energy your skin is gaining from the inside is balanced by the amount it is losing to the outside, you are comfortable. However, if your skin cells are gaining thermal energy, your brain interprets this as "it's hot." Likewise, if your skin cells are losing thermal energy, your brain interprets this as "it's cold." This is how our nervous system reacts to short-term changes in our environment. Other factors, not discussed here, are involved for long-term, slow changes of temperature when core body temperature is affected.

> Heat flows from hotter objects to colder ones.

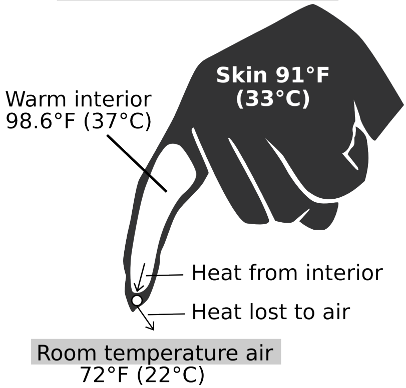
THE SEAT BUCKLE STING: WHY DO METALS FEEL HOT?

Ice Cube



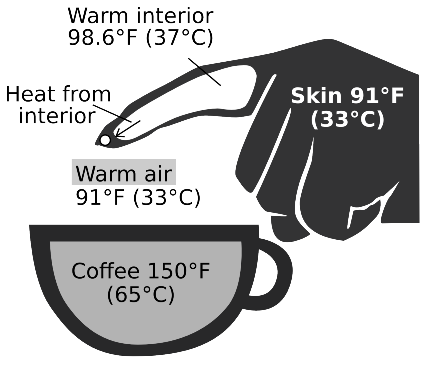
The ice pulls in more heat from the surface of your finger than is supplied by the warmth inside your body, so it feels cold.

Room Temperature Air



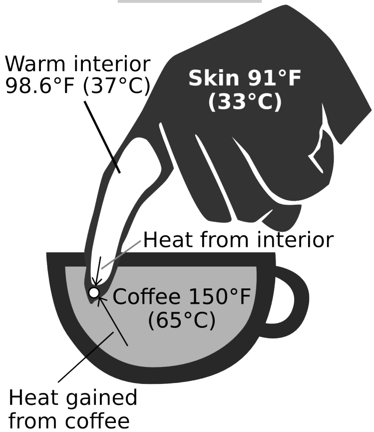
The heat lost by the skin to the cooler air approximately equals the heat supplied by the interior of the finger, so there is no net loss of heat. Even though the air is cooler than your skin, the nerve does not register it as cool.

Warm Air



The air is about the same temperature as the skin, so no heat is exchanged, but the skin is still warmed by the inside, so your brain thinks “warm,” even though no actual heat is entering your skin from the outside air.

Hot Coffee



Your finger receives a great deal of heat from the liquid coffee and some from inside. This could easily be enough to cause damage to your skin, and your brain registers “HOT!”

How Your Skin Feels Hot or Cold: Four Examples

This explains why it can be 86° F (30° C) outside and feel warm even though the air is cooler than your body! Your skin is losing a little energy to the air, which is slightly cooler. But your blood delivers more energy than is lost to the air. *Your skin is gaining more heat from the inside than it is losing to the outside, so you feel hot.*

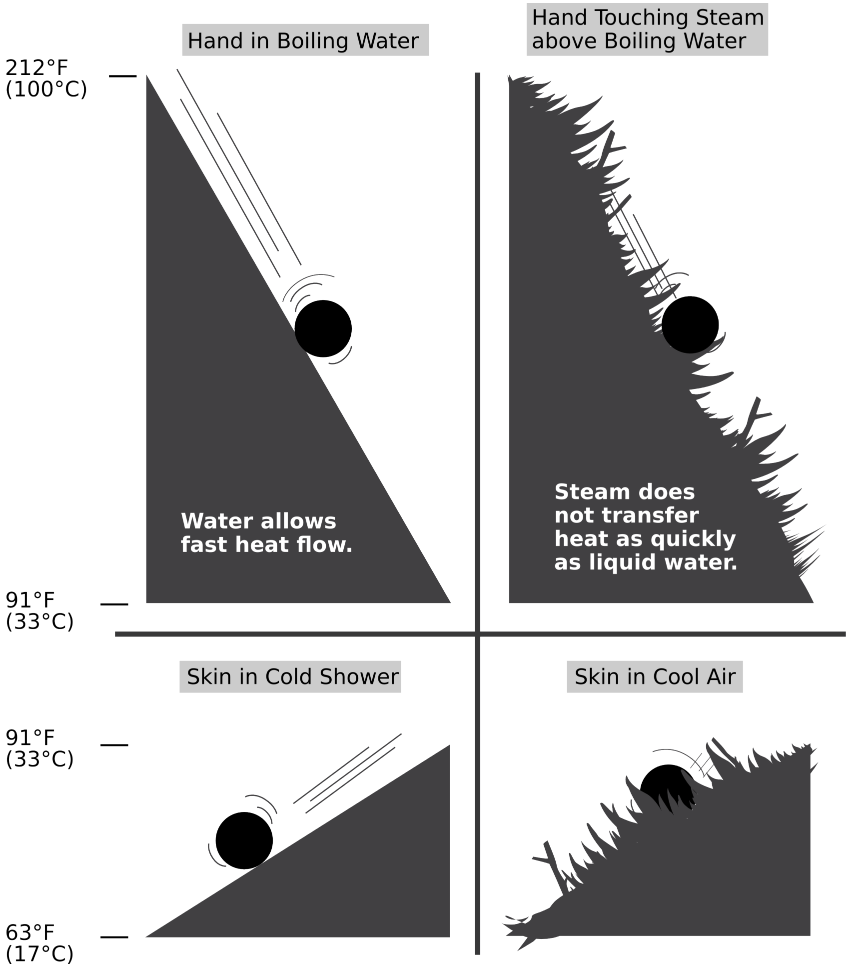
> The rate of heat loss (or gain) depends on both the temperature difference and the material you are touching. Your skin loses heat four times faster to water than to air at the same temperature.

The import or export of heat does not depend solely on the relative temperature, and that's where things get interesting. Heat flows from hotter objects to colder ones, but the compositions of the objects affect how quickly heat is transferred.

To understand how temperature and composition combine to determine the flow of energy, an analogy may help. Imagine a ball rolling down a hill. Temperature is represented by the ball's height in the analogy while the composition of the material is comparable to the roughness of the surface and the condition of the ball. Let's see how this works.

We know the ball tends to roll downhill rather than uphill. That is like knowing heat moves from hotter objects to colder ones, regardless of the materials in question. The temperature determines which direction the heat flows just like the slope determines which direction a ball rolls. Balls roll downhill. Period.

However, the ball's speed depends on both its composition and the steepness of the hill. A ball of putty will take longer to roll down the hill than a tennis ball. Balls roll more quickly down a steep hill than a gentle one, and they roll more slowly down a rough, grassy hill than a cement ramp. Thus, while the relative temperature determines which object gains thermal energy from the other, the *rate* of that flow also depends on the composition of the objects.



*The relative temperature determines which direction heat flows, like the relative height determines which way a ball rolls down a mountain. But the **rate** of heat flow is determined by not just the difference in temperature but also the materials in contact. Some materials allow heat to flow very quickly, just as some surfaces allow balls to roll very quickly. Metals and water are analogous to concrete ramps in this regard while cloth and air are like grassy, bumpy slopes.*

You can do a quick experiment to see this. Leave a glass of tap water sitting on your kitchen counter for half an hour. No matter what temperature the water was originally, it should be room temperature after being out that long. Put your finger in the water. The water feels cold, yet it is the same temperature as the glass, the counter, and the air around the rest of your body.

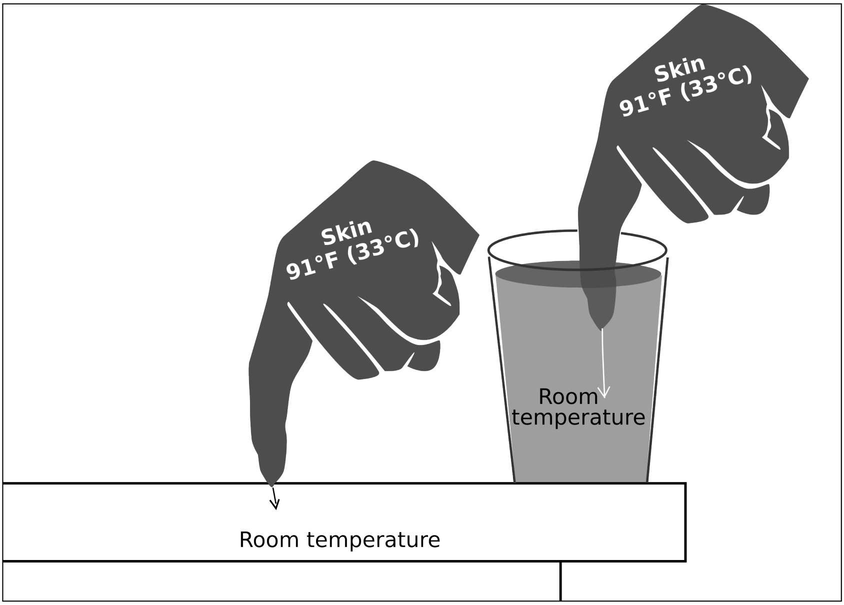
Metal, like water, conveys heat to or from your skin very rapidly, so metals in a hot car burn you for the same reason that the first shower burst always feels cold.

To understand why the water feels colder than the air, recall that your skin loses heat to the air but gains heat from your internal metabolism. At comfortable temperatures these balance and your skin does not register a net change. However, your skin loses energy to water four times faster than to air, so your finger is losing much more energy to the water than the rest of your body is, more than the skin in your finger is gaining from the blood running through it.

The finger-in-water demonstration indicates why staying dry is so important when exposed to cold. Wet skin loses much more heat to a wintry environment. Also, it explains why the first burst of water from a shower head feels so frigid. The water in the pipes feels much colder than air of the same temperature.

How does this apply to the original question? Why does the seatbelt buckle burn you?

The “metals are conductors” part of the standard explanation is correct and relevant, but not because conductors heat up more quickly than insulators. Rather, metals feel hotter than cloth for the same reason that room temperature water feels much colder than room temperature air. Consider the metal in your oven at home. The metal trays are *heated by the air around them*, so their temperature cannot surpass the temperature of the air. Yet the trays feel much, much hotter than the surrounding air.



Even though the water and counter are the same temperature, your body gives up heat much more quickly to the liquid water than the wooden counter.

Conclusion

Metals typically conduct heat quickly, so touching them can cause rapid movement of energy, either into your body (if the metal is hotter than your skin) or from it (as when someone's tongue gets frozen to a flag pole). If the clasp on your car's safety belt is even a few degrees hotter than your skin, a great deal of heat can flow from the buckle to your hand. As to *why* the items in your car can get extremely hot, see the chapter on *The "Greenhouse Effect."* However, don't make the mistake of claiming the metal is actually hotter than the other items in your car. *Everything* will be hot in the car, but the metal will communicate that "hot-ness" much more quickly to your hand.

Addendum: Why Doesn't Foil Burn You?

As a side note to this topic, you might wonder why aluminum foil does not burn you. Indeed, I'm surprised this question does not come up more often as an oddity common to everyday experience. You can put a pizza in an oven set to 400° F (200° C) and ten minutes later tug on the foil without feeling any significant distress. . . unless your fingers graze the steel rack below, in which case your hand is likely to jerk back involuntarily.

Is aluminum an insulator instead of a conductor? No. In fact, aluminum generally conducts heat faster than the steel composing the oven rack. However, the foil is about 100 times thinner than the rack. This means the amount of heat available to send into your hand is extremely small. The foil does not hurt you for the same reason that a small ice fleck does not cool your cola much and a spark with a temperature of 8300° F (4600° C) poses little risk of burn.