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On the thermal sensation when touching different materials that have the same temperature

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ABSTRACT

This work deals with the usual confusion when explaining the difference in the thermal sensation when touching materials of different natures that are at the same temperature. The description of some basic concepts such as heat, temperature, contact temperature, and thermal effusivity is given, which support the explanation of said difference from the point of view of scientific divulgation, accessible to the general public, avoiding complex mathematical expressions and specialized terms.

Este trabajo trata sobre la confusión habitual al intentar explicar la diferencia en la sensación térmica al tocar materiales de diferente naturaleza y que están a la misma temperatura. Se da la descripción de algunos conceptos básicos como calor, temperatura, temperatura de contacto, y efusividad térmica que fundamentan la explicación sobre dicha diferencia desde el punto de vista de la divulgación científica, accesible al público en general, y evitando expresiones matemáticas complejas y términos especializados.

I. INTRODUCTION

Sometimes, when we get out of bed and touch the tile floor with our bare feet, we feel cold on the soles of our feet. Then, when we step on the carpet or our indoor shoes, we feel a comforting warmth, Fig. 1. Likewise, at home, work, or school, we immediately perceive a sensation of coldness when touching a metallic object, such as a ruler, a tool, or a window. However, when we touch something made of wood, rubber, cardboard, or plastic, nearby or in contact with the first, we perceive it as warm. In these cases, objects and surfaces practically have the same temperature, so what is the difference in the thermal sensation due to?

In this work, the belief of some individuals from the general public is presented on how they explain the difference in the thermal sensation when they touch materials of different natures at the same temperature. The opinions of four groups of people interviewed with different degrees of preparation are given, showing the knowledge and management of concepts in each case and how they use them in their responses. In particular, the interviewees needed clarification on the meaning of heat and temperature and their differences. For this reason, the concepts of heat and temperature are briefly discussed from the point of view of scientific divulgation. Then, avoiding complex mathematical expressions and specialized terms, the concepts of contact temperature and thermal effusivity are presented, and their usefulness in explaining the difference in thermal sensation when materials of different natures but at the same temperature are touched.

Figure 1. We feel cold on the soles of our feet when we touch the tile floor with our bare feet and warm when we step on a carpet.

II. PROCEDURE

To know the opinion of people with different school degrees about the thermal sensation that is perceived when touching objects of different materials and at the same temperature, the following experiment was carried out (see Fig. 2): First, an aluminum plate and a wooden board of pine, both 30x30 cm in area and 1 cm thick, were put in contact one on top of the other at room temperature for 30 min to ensure a same temperature at the start of the experiment. Then, individually, each person interviewed was placed in front of the aluminum and the pine wood plates, separated and placed on a plastic table. Each person was asked to put his hand's palm on the aluminum plate for a few seconds and then remove it. After a few seconds, he was asked to put the palm of his hand on the wooden board for a few seconds and then remove it. Then, they were asked to answer the following questions:

Question 1: What difference between the plates did you perceive apart from the texture?
Question 2: What do you think is the reason for the difference?
Question 3: Do you think the temperatures of both plates are the same or different?

Figure 2. Placing the palm of the hand on a) an aluminum plate, and b) a wooden board.

The experiment was carried out with the following four groups (five people per group):

Group A: Elementary studies persons
Group B: High school studies persons
Group C: College students
Group D: College-level professors

III. RESULTS AND DISCUSSION

Tables I-III summarize the answers given by the four people groups in the experiment by placing the answers to the same question in a table. Each answer is representative of the opinion of each group.

TABLE I. Responses of the four people to question 1: What difference between the plates did you perceive apart from the texture?

Question	Person	Response
1	A	The metal is cold, and the wood is tempered
	B	Metal is colder
	C	The metal is colder
	D	The metal is colder

TABLE II. Answers of the four people to question 2: What do you think is the reason for the difference?

Question	Person	Response
2	A	By the material
	B	By the material
	C	Due to the type of material, they absorb heat differently
	D	Because the heat flux from the hand to the metal is greater

TABLE III. Answers of the four people to question 3: Do you think the temperatures of both plates are the same, or different?

Question	Person	Response
3	A	They are different. It's higher in wood.
	B	The metal is colder
	C	They are the same. They're in the same room
	D	They are the same.

To question 1, the four groups answered practically the same, noting that they perceived the metal colder. Regarding question 2, groups A and B answered the same, “By the material”. In addition to that same answer, Group C added, "they absorb heat differently", introducing the concepts of absorption and heat, demonstrating greater knowledge and management of the concepts. Group D introduced the concept of heat flow in his answer, adding that heat goes from hand to metal, demonstrating a higher degree of academic preparation. For question 3, the responses of groups A and B were similar, indicating a higher temperature for wood and a lower temperature for metal. The responses of groups C and D are also similar, responding correctly and demonstrating a greater understanding of the experiment.

Because people used the concepts of heat and temperature in their answers, they were asked the following two additional questions:

Question 4: When you measure the temperature of an object, what property of the object are you measuring?
Question 5: What is heat for you?

Tables IV and V summarize the answers the four groups gave by placing the answers to the same question in a table.

TABLE IV. Answers of the four groups to question 4: When you measure the temperature of an object, what property of the object are you measuring?

Question	Group	Response
4	A	We measure the temperature it has, the heat or the cold
	B	how cold is it
	C	We measure body heat
	D	It is the lack of cold. heat is energy

TABLE V. Responses of the four groups to question 2: For you, what is heat?

Question	Group	Response
5	A	It is the temperature that the body has.
	B	It's hot. It is difficult to explain.
	C	An equilibrium of thermal energy.
	D	It's temperature. No, it is an instantaneous measure of equilibrium.

From the answers to questions 4 and 5, confusion in the concepts of heat and temperature can be seen in the four groups, and none of their answers was correct. Groups C and D used more elaborate concepts such as “equilibrium” and “thermal energy” in their answer to question 5 but without concluding an idea.

To help clear up this confusion, a general description of the concepts of temperature and heat is presented in the following section.

IV. HEAT AND TEMPERATURE

Temperature measures the state of internal movement (vibrations, rotations, and translations) of the atoms and molecules that make up matter. An instrument called a thermometer is used for its measurement, which gives a comparison reading with a reference and on a certain scale (the mode common are the Celcius, the Fahrenheit, and the Kelvin temperature) (Smorodinski, 1983).

Heat is the energy transferred from one point to another between which there is a temperature difference (Zemansky, 2011). This energy transfer can take place by three mechanisms: conduction, convection, and radiation. They are illustrated in Fig. 3.

In the conduction mechanism, a kinetic energy transfer occurs between two points until a thermal equilibrium is reached between them. The convection mechanism is produced by moving a fluid (air, water, etc.) that transports energy between regions at different temperatures. Heat can also be transferred between two bodies at different temperatures, even though there is no means of physical contact between them, propagating in the form of thermal radiation, even through empty space. It is how we perceive the heat coming from the Sun. This is the so-called radiation mechanism (Cengel, 2020).

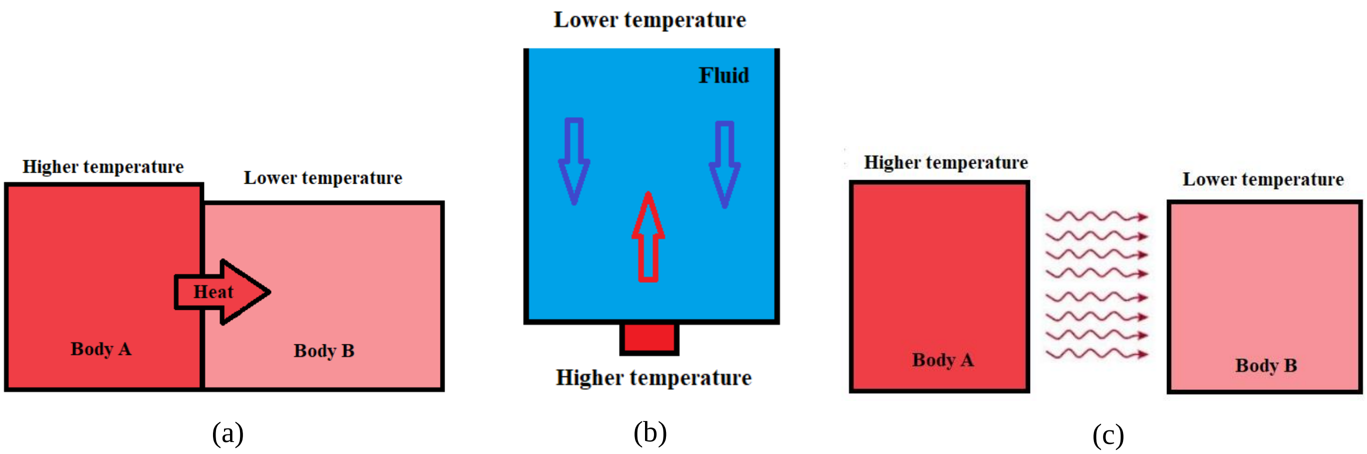

Figure 3. Heat transfer by a) conduction, b) convection, and c) radiation.

Heat has units of energy and temperature does not. Unlike heat, which is energy in motion, temperature gives a measure of the state of internal movement of matter compared to a reference.

V. CONTACT TEMPERATURE AND THERMAL EFFUSIVITY

When two sufficiently large bodies, *A* y *B*, with uniform initial temperatures T_{Ao} y T_{Bo}, are brought into contact, the temperature T_c at their contact surface instantly reaches equality, as given by (Bein & Pelz, 1989):

$$T_c = \frac{e_A T_{Ao} + e_B T_{Bo}}{e_A + e_B} \tag{1}$$

It is called the contact temperature, which reaches an intermediate value between T_{Ao} y T_{Bo}, and it is dominated by the body with the highest value of the parameter *e*, called thermal effusivity. The dependence of T_c on *e* shows that thermal effusivity is the property that determines the contact temperature between two bodies when they touch. Thermal effusivity can be interpreted as the heat exchange capacity of a surface with its surroundings (Almond & Patel, 1996). Although thermal effusivity is not a well-known thermal parameter outside the field of heat transfer, its importance is evident in applications in other areas. Knowledge of the thermal effusivity of the materials used in bone and dental implants is fundamental in determining thermal compatibility with human tissue. Another example occurs in the pharmaceutical industry, where measuring the effusivity of pills is an established quality criterion (Clemens, 2007). In the aerospace industry, the phenomenon described plays a very important role when designing the materials of the fuselage of rockets so that it does not melt by friction with the atmosphere at high speeds. Due to its units, $Ws^{1/2}/m^2K$, thermal effusivity gives the idea of being a more abstract quantity than it is. Indeed, we are all very familiar with it in our daily lives. This explains why metal feels cooler than wood, even though both are at the same temperature.

For example, at room temperature, e = 24,643 $Ws^{1/2}/m^2K$ for aluminum, e ~ 470 $Ws^{1/2}/m^2K$ for wood, and e ~ 1,332 $Ws^{1/2}/m^2K$ for human tissue (Almond & Patel 1996, Blaine 2018, Cengel 2020). Using Eq. (1), it follows that when a person with a hand temperature of 35 ºC touches, for a few seconds, an aluminum and then a wooden object, both at 15 ºC, the temperature of the contact surface takes the value of 16.0 ºC in the case of aluminum, and 29.8 ºC in the case of wood. In the case of aluminum, the contact temperature is 19 ºC lower than the temperature of the skin. In the case of wood, it is only 6.2 ºC lower. The heat flux from the skin to the aluminum object is much greater than in wood. The thermal sensation is cold in the first case and warm in the second. Of course, if we touch the objects for a long time, we will feel them at the same room temperature, which they are (Marín 2006, Marín 2007), but the explanation of this can be the subject of future work.

IV. CONCLUSIONS

We present the different opinions of four groups of persons with different degrees of preparation on the difference in the thermal sensation that each one perceives when touching materials of different nature and at the same temperature. We used an aluminum plate and a pine wood board in our experiments. Even though the two most highly educated people, a college student and a collage-level professor, used more elaborate concepts in their responses, all four groups needed clarification on the concepts of heat and temperature and their use to explain the different thermal sensations in the experiment. They did not mention the concepts of contact temperature and thermal effusivity. Product of these results, we briefly describe the concepts of heat and temperature, explaining their differences. Finally, we described the concepts of contact resistance and thermal effusivity and their usefulness in explaining the difference in the thermal sensation when touching different materials with the same temperature.

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