THE BEST WAITRESS: COOLING LIQUIDS

Núria is a college student who works as a part-time waiter at the university cafeteria. She has observed that customers have diverse opinions on what a perfect coffee is. She is faced with the following dilemma: One of her customers is not going to drink her hot coffee with milk for ten minutes, but wants it to still be as hot as possible. Núria asks herself the question: Is it better to immediately add the room-temperature milk, stir the coffee, and let it sit for ten minutes, or is better to let the coffee sit for ten minutes and then add and stir in the milk?

Your tasks in this activity will lead you to help the waitress to find the answer to this demand.

Before going on, write down your prediction, explain your reasoning and how you could design an experiment to help the waitress!

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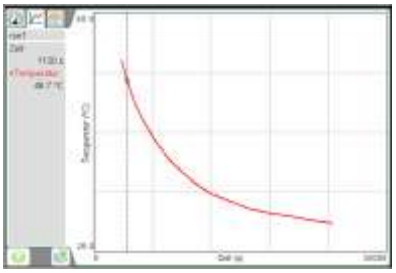
A. Preparation

1) Open the document "*temperature. tns*" and trace the graph which was obtained from an experiment with 100 ml hot water in a room at a temperature of 24.5°C.
2) Explore how long it takes the temperature of the water to decrease about five degrees, respectively from 50°C to 45°C, from 45°C to 40°C, from 40°C to 35°C, from 35°C to 30°C, and from 30°C to 25°C.



Describe what you found out by exploring the data and explain your reasoning!

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B. Observation of an experiment

Preliminary experiments: To complete this experiment in a short time, you will use a small quantity of hot water at least about 30°C above room temperature. Record the water's temperature as it cools with a temperature sensor connected to a calculator.

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C. Modeling the situation in the laboratory

1) Use a temperature sensor to record the cooling process of hot water (10 minutes).

2) Create a table to calculate the cooling rate ($\Delta T/\Delta t$) and the difference in temperature T_{diff} between the two bodies ($T_{diff} = T_{water} - T_{room}$) for selective time segments: [0min; 1min], [1min; 2min], ..., [9min; 10min].

t (min)	Temperature of water (°C)	Temperature of room (°C)	Temperature difference T_{diff} (°C)
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

3) Explore if your data support the following statement: The rate at which thermal energy moves from one body to another is proportional (by a constant k) to the difference in temperature between the two bodies. If applicable, find the value for the constant k.

   k = ……

4) Find a function that can be derived from the exponential equation $T_{diff} = T_0 \cdot e^{-kt}$, where T_0 is the initial temperature difference and test if it is in agreement with your data.

   T_{diff} = ……..

5) Now investigate the cooling process when you add a certain amount of water at room temperature to the hot water according to the dilemma of the coffee drinker.

   Complete the following sentences:

   If a certain amount of water at room temperature is added to the hot in the beginning, the temperature difference after ten minutes is …… Therefore, my advice for Núria is:

   ……

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Extension 1: Take data for a longer period of time so that the water cools to nearly room temperature. This may take more than 30 minutes. Does the exponential model still fit the data?

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6) **Extension 2**: Use the temperature sensor to experiment with containers made of different materials and analyze the following questions:

– Does a drink cool faster in a ceramic cup than in a Styrofoam cup?

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– What variables must you hold constant in order to guarantee that the difference in the data is due to the cup?

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– What part of the exponential equation is related to the cup?

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D. Evaluating the data obtained

1) Explain why the equation $T_{diff} = T_0 \cdot e^{-kt}$ correctly produces the temperature difference at t = 0s.

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2) When t is very large, what value of temperature difference do you expect? What is the corresponding temperature of the water at that time?

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3) How can you influence the value of k, for example, to decrease the value of k? What quantity does k measure and how does it relate to the cooling process?

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4) Use your equation to calculate the temperature after 500 seconds. Compare your calculated value with the actual data value.

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5) Use your equation to predict the time it takes the water to reach a temperature 3°C above the room temperature and if possible, check the calculated value with the actual data value.

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E. Show your results

Thinking about your observations, discuss the correctness of the following statements:

Do not forget to explain your reasoning!

a) If the temperature difference is cut in half, it takes half as long to get 1°C above room temperature.

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b) The value of k measures how rapidly the temperature is changing. ……

c) The addition of milk at room-temperature reduces the rate of heat loss during the waiting period of the coffee drinker in the example above.

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d) When the value of k increases, the water will cool more slowly.

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e) Systems in which a rate of change is proportional to the changing quantity show exponential behavior.

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Write general conclusions

Returning to the main question of this activity:

How can we explain that it makes a difference if the room-temperature milk is immediately added to the hot coffee or alternatively not until after ten minutes? ……

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Questions

a) It was easy for our group to design our own experiment and find an appropriate solution to the given task. Tick a number 1, 2, 3, 4 or 5 (1: strongly agree 5: strongly disagree)

Please explain your answer……

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b) The guidance in the worksheet helped us to perform the experiment and analyze the data in order to understand the physics behind and apply physics concepts to everyday life situations. Please, tick a number 1, 2, 3, 4 or 5 (1: strongly agree 5: strongly disagree) and explain your answer: ……

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