The cooking egg

(exp. id 20210110-2-v1)

An experiment proposed by:
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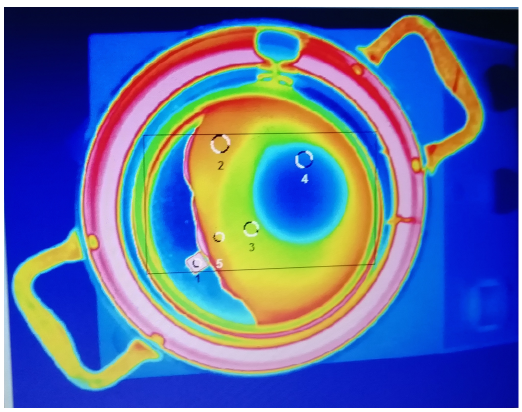
Overview

We propose to investigate the cooking process of a fried egg with a thermal camera. The experiment is remarkable because, through a familiar example, it allows to introduce many different phenomena, from the laws of heat transmission to phase transitions. It is an engaging activity that can be carried out both with high school and undergraduate students, as it involves a large amount of non-trivial physics that can be proposed with an approach far from a typical textbook one.



Materials

- Thermal camera (there are low-cost devices that can be implemented on smartphones)
- Easel
- Electric heater
- Tablet or computer
- Aluminum frying pan
- Egg

Making the measurements

A thermal camera is used to monitor the temperature increase of an egg fried in a hot pan. Special care is to be used when interpreting thermal images, as thermal cameras do not simply convert surface temperatures into different colors. They give a measurement of radiance W in an infrared band; this can be converted into reliable temperature values, thanks to the Stefan-Boltzmann law

$$W = \epsilon_\lambda \sigma T^4 \tag{1}$$

but only when the spectral emissivity ϵ_λ of the material is known (σ is the Stefan Boltzmann constant). ϵ_λ is the ratio between the energy at wavelength λ emitted by the real body and that emitted by an ideal black body at the same temperature. For a water-based body, as food is, a value of $\epsilon_\lambda = 0.96$ can be assumed, which is very close to 1, that of an ideal black body.

When an egg is poured into a hot pan, its temperature starts growing. The temperature of different areas of the egg can be plotted as a function of time. The yolk surface heats slowly and irregularly due to gas bubbles that easily form inside it. Moreover, it is difficult to model the heat transfer inside the yolk, both because of its shape and the high surface area exposed to ambient air. In contrast to the yolk, the white may be approximated as a slab o dense liquid with flat boundaries in a temperature gradient, the upper and the bottom temperatures being that of air and pan, respectively. This is an easier situation to approach quantitatively. The temperature is seen initially grows to grow rapidly, and then remains constant for a long interval. After that, it starts growing again. If the temperature is plotted as a function of the squared root of time t, the initial and final trends are well fitted by straight lines, which indicates that heat transmission occurs basically via conduction and, consequently, $T \propto \sqrt{t}$. Particularly interesting is the region where temperature no longer increases despite that the heater continues to provide energy. The behaviour is typical of phase transitions. The case of egg involves ‘soft matter’, and the transition occurs from a fluid phase towards a denser gelly phase. During the transition, all the incoming energy is used by the system to unfold albumen proteins. This process, at the molecular scale, brings some charged groups towards the outside of the protein structures. The unfolded structures then attract each other and aggregate until a macroscopic connected structure is formed, and the albumen has become a rigid gel. Heat transmission now occurs via conduction with a heat conductivity smaller than for the liquid albumen, as evidenced by the smaller slope of T versus $\sqrt{t}$.

The results of this experiment have been recently published in a paper that can give further hints and ideas to teachers [1].

General remarks

The experiment is particularly intriguing as it deals with an everyday life example. It allows facing soft matter properties and phase transformations in a non-trivial way. It aims to stimulate the interest of students in physical sciences, giving teachers the chance to introduce new themes of thermodynamics and heat propagation. Moreover, thermal cameras are fascinating tools, increasingly popular in schools, with a principle of operation that offers the opportunity to discuss concepts like emission and reflection with practical and surprising examples. The Kirchhoff law allows relating the emission and the reflection of objects in thermal equilibrium with the environment:

$$R_\lambda + \epsilon_\lambda = 1, \tag{2}$$

where R_λ is the ratio between the reflected energy and the incident one, at wavelength λ.

Metals, like the aluminum of the pan, have a low emissivity and a high reflectance, therefore their temperature can be measured with a thermal camera only if their ϵ_λ is properly accounted for. In fact, due to reflection, a thermal camera in its default mode shows hot metal of the same colour as room temperature.

Further details and experimental can be found in Ref. [1]

References

[1] N. Ludwig and M. Carpineti; "Frying an egg to study heat transport: an engaging and didactic experiment"; (2020) Phys. Educ. 55, 025016

For the instructor

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1. The experiment should be proposed to students with an inquiry-based approach. Teachers could ask them to perform the experiment and try to use their physics knowledge to find an explanation for the time dependence of the egg's surface temperature.
2. Performing experiments using food and everyday objects has a double advantage to engage students and to stimulate them to think about physics also in their private time, by appreciating that physics is everywhere.

Objectives

1. Primary objective: Enjoyment and practice in empirical experiments.
2. Primary objective: Development of scientific investigating skills
3. Primary objective: Modeling heat conduction
4. Primary objective: Understanding the concepts of phase transition and latent heat
5. Suitable for: High school and undergraduate students
6. Duration: Approximately 3 hours

Further Info Online

Please leave feedback, suggestions, comments, and report on your use of this resource, on the channel that corresponds to this experiment on the Slack workspace "smartphysicslab.slack.com".
Instructors should register on the platform using the form on `smartphysicslab.org` to obtain login invitation to the Slack workspace, and/or to request being added to the mailing list of smartphysicslab.