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Understanding heat and temperature: Thermography learning activities

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1 Introduction

1.1 Rationale

The following examples illustrate two objectives we find useful and interesting within the framework of a MUSE contribution [1] for the International Year of Light (IYOL, [2]):

A) conceptual development: basic phenomena, current conceptual obstacles and learning difficulties[1]

B) cross-disciplinary connections: transfer and motivation

The activities below are of qualitative nature and on a difficulty level of secondary level I. This is completed by theoretically (also: mathematically!) deeper considerations such as proposed by Viennot & Décamp [5]

As for A) the Topic of thermography has much to do with the Topic of the last MUSE "production" (Prague and Nicosia workshops), viz. selective (differential) absorption, transmission and reflectivity [6]-[8]. This can by highlighted by the different behaviour in the IR and visible range, cf. the examples given below. One might systematically explore which conceptual obstacles might be addressed by thermography activities; some first examples, a list of conceptual obstacles (1.2), and some Sources are given below.

As for B) it is supposed to highlight the richness of physics concepts and theories, from live through technology to astronomy. Available evidence says that cross-disciplinary applications might have positive impact on both motivation and learning, in particular on transfer. It would be good if MUSE activities explore such kind of educational potential. Moreover, by the breadth of the possible IR examples, the universality of physics might be addressed, as an important issue of the nature of science issue.

1.2 Widespread conceptual obstacles related to heat and temperature

The following list contains important and widespread conceptual obstacles, but does of course not claim to be exhaustive (see [10], [11] for further Sources):

- Heat is the same as (or proportional) to temperature.
- A cold body contains no heat.
- Temperature is a property of a particular material or object.
- A hot object all by itself cools down, a cold object all by itself warms up.
- Skin or touch can determine temperature.
- Materials like wool have the ability to warm things up.
- Metal has the ability to attract, hold, intensify or absorb heat and cold.
- Energy is not transferred from one object to another unless those objects are in direct contact with each other.
- Only hot or warm objects transfer thermal energy.
- Objects of different temperature that are in contact with each other, or in contact with air at different temperature, do not necessarily move toward the same temperature. (Thermal equilibrium is not a concept.)

2 Thermography activities[2,3]

2.1 How to read thermographic images

Everything with a temperature above absolute zero emits electromagnetic radiation. Above 500°C, part of the emitted radiation becomes visible (glowing metal, fire,…). When the emitting matter is colder, it emits in the infrared range: this part of the electromagnetic spectrum is invisible because its wavelength is too long to be detected by the human eye. Instead, we perceive it as heat (as expressed in common language). Everything at ambient temperature emits in the infrared. Even very cold objects, such as ice cubes, emit infrared radiation.

A thermal camera works similarly to a video camera, but instead of recording light, it registers only infrared radiation. This type of camera allows the temperature of the surface of an object to be measured and recorded, to create a thermal image – a "thermograph".

In this kind of images, "temperatures", more precisely a measure of IR radiation, are associated to a false colours scale. Each image has its own scale and caution has to be taken when comparing different images so that no reading mistakes occur.. Readers of thermographs have also to be aware that measured temperatures depend of the

[1] The term „conceptual obstacle" instead of „misconception" is used her in order to avoid a discussion unnecessary for the present contribution. We would like to point out, however, that "misconception" is as term still widely used by authoritative Sources [3], [4], and that many of the examples considered here belong to the classical examples of misconceptions treated in this strand of research.

[2] There is a logical and pedagogical order in the activities below. Note, however that some examples contain redundant information below, in order to keep them usable independently.

[3] A document with hints for answers/solutions tot he questions in the activities below can be obtained from the authors

surfaces emissivity. Matt or reflective surfaces at thermal equilibrium will not emit the same amount of IR radiation.

To illustrate this principle, one can use a Leslie's cube. This is a device used to demonstrate the variations in emissivity of different surfaces at the same temperature. The cube is made of metal with a central cavity. The external faces are different from each other: one face is coated with black paint, a second with white paint, a third face has been polished and the last one is rough metal. The cube is generally filled with hot water, it is then waited till thermal equilibrium is attained, and faces are then studied using the IR camera.

Figure 1 shows infrared thermographs of the white and the polished faces. The face of the cube that has been painted white emits thermal radiation strongly. The polished metallic face of the cube emits much more weakly. Measured temperatures depend of selected emissivity, and by not taking account of its proper value large errors can occur as figure 1. Thus, for temperature readings, emissivity is essential, but in the activities presented below, this will not play a role (no temperature assessments).

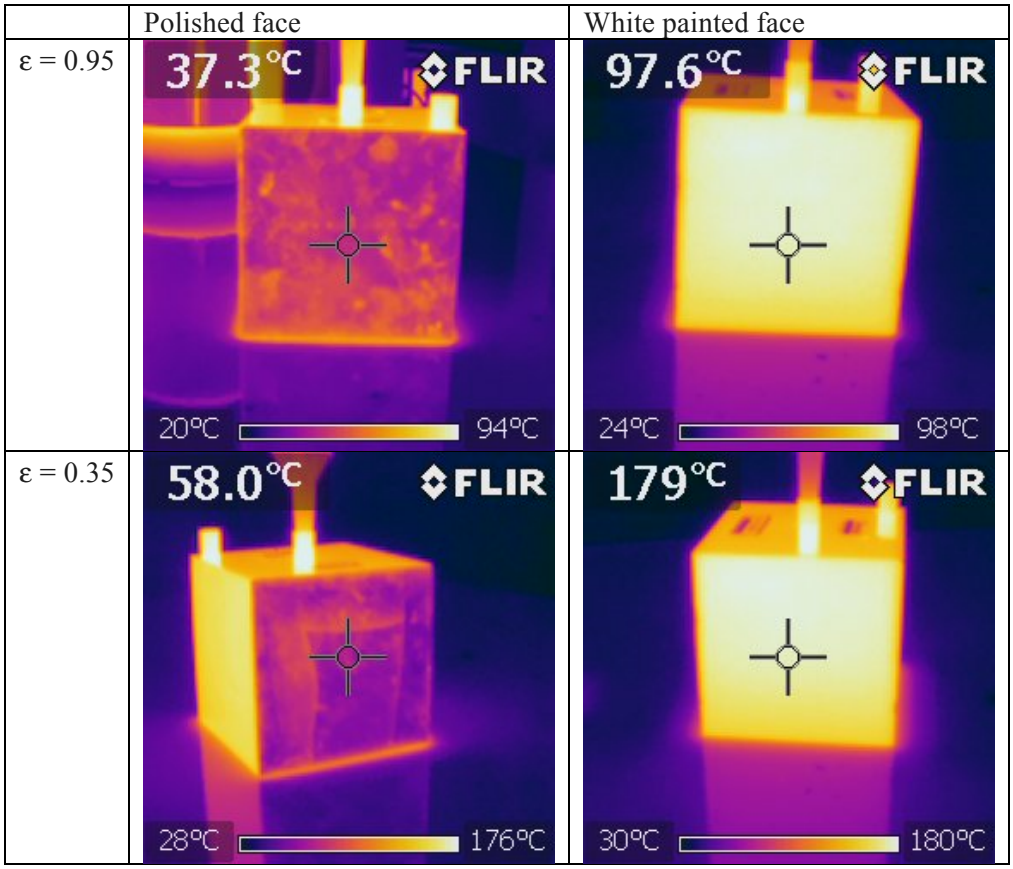


Figure 1: Thermographs of a Leslie's cube filled with hot water: white painted face and polished metal face measured with different ε (ε is the selected emissivity on the camera setup).

2.2 Conceptual development (basic phenomena, conceptual obstacles)

2.2.1 *Heat conduction and conductivity*

2.2.1.1 Temperature and its sensation: metal is cold, wool is warm

Title	Metal is cold, wool is warm
Topic	– Heat conduction and conductivity – Physiological sensation of cold and warm by contact (conduction)
Conceptual obstacle(s)	Temperature as property of a particular material or object ("metal is cold, wood is warm")
Comment(s)	With a short "fingertip" contact, both objects appear to have the same temperature
Image Source(s)(s)	Estelle de Chambrier

Introduction

Thermal sensations by contact with an object depend of the object material. This activity's purpose is to differentiate between temperature, independent of the material, and conductivity, dependant on the material.

Situation and questions
For this activity, objects made of different matter (wool, polystyrene, plastic, glass, metal, water, wood) are to be investigated by the pupils.

To do: Touch one after the other the objects put in front of you.

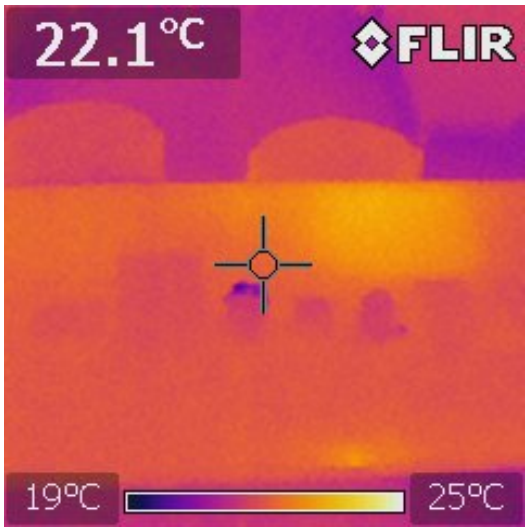
Questions:
a) Rank the objects from the hottest to the coldest and associate each of them with a temperature assessment in common language words (very cold, cold, warm, very warm, etc.).

Matter	Wool	Polystyrene	Water	Wood	Metal	Plastic	Glass
Assessed temperature							

My order:

……

b) An IR thermal image of different objects has been taken using an IR camera.



1. By using this thermograph image, give estimations of both metallic and woollen objects temperatures.

T_{metal}=
T_{wool} =

2. Compare these temperatures to the assessed temperatures during part a). What do you notice?

3. Could you find an experimental way to confirm the real temperature of the objects surface?

2.2.1.2 Heat conduction

Title	Heat conduction
Topic	Heat conduction and conductivity
Conceptual obstacle(s)	
Comment(s)	
Image Source(s)	Estelle de Chambrier

Introduction

To stir a tea, one can use plastic or metal spoon. Metal spoons may become rapidly very hot if let too long in the hot water. Plastic spoons do not show this disadvantage. The activity below allows to investigate the reason for this difference in terms of thermal conductivity.

Situation and questions
Two cylinders made of different materials, eg plastic and copper (or aluminium and copper) are put on a table with container full of very hot (just boiled) water.

To do: Put the bottom of each cylinder in the water and put a fingertip on top of each. Stay that way for approximately one minute.

Questions:
a) Describe your sensations:

……

……

b) Based on your previous sensations, predict how an IR thermograph of the total system (water, cylinders, fingers) would look like after approximately one minute. Sketch a image using various colours (red for warm, blue for cold[4]).

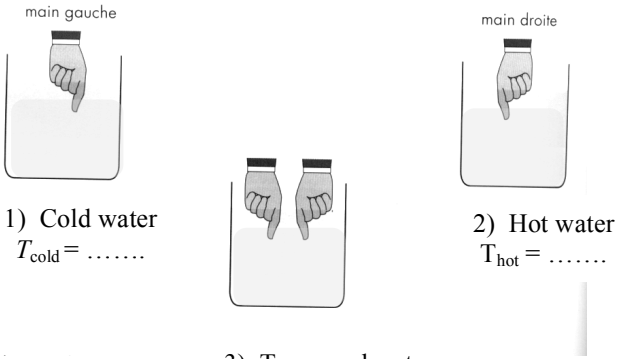
2.2.1.3 What you feel…fingers and water

Title	What you feel…fingers and water
Topic	– Heat conduction and conductivity – Physiological sensation of cold and warm by contact (conduction)
Conceptual obstacle(s)	– Difference between physiological sensation of warm and cold and physical temperature – Taking account of heat conduction and temperature as two distinct factors at work
Comment(s)	
Image Source(s)	Estelle de Chambrier

Introduction
Cold or warm sensations are related to the rate and the direction of thermal transfers,

Situation and questions
Three containers with water : cold water in the first, hot water in the second and tempered water in the third.

1) Measure the water temperature in each vessel.
2) Put a finger in the cold water and a finger of your other hand in the hot water. Stay for approximately 15 seconds.
3) Put then rapidly your two fingers in the tempered water.



1) Cold water
T_{cold} = …….

2) Hot water
T_{hot} = …….

3) Tempered water
$T_{tempered}$ =…….

Describe what you feel at step 3.

……

……

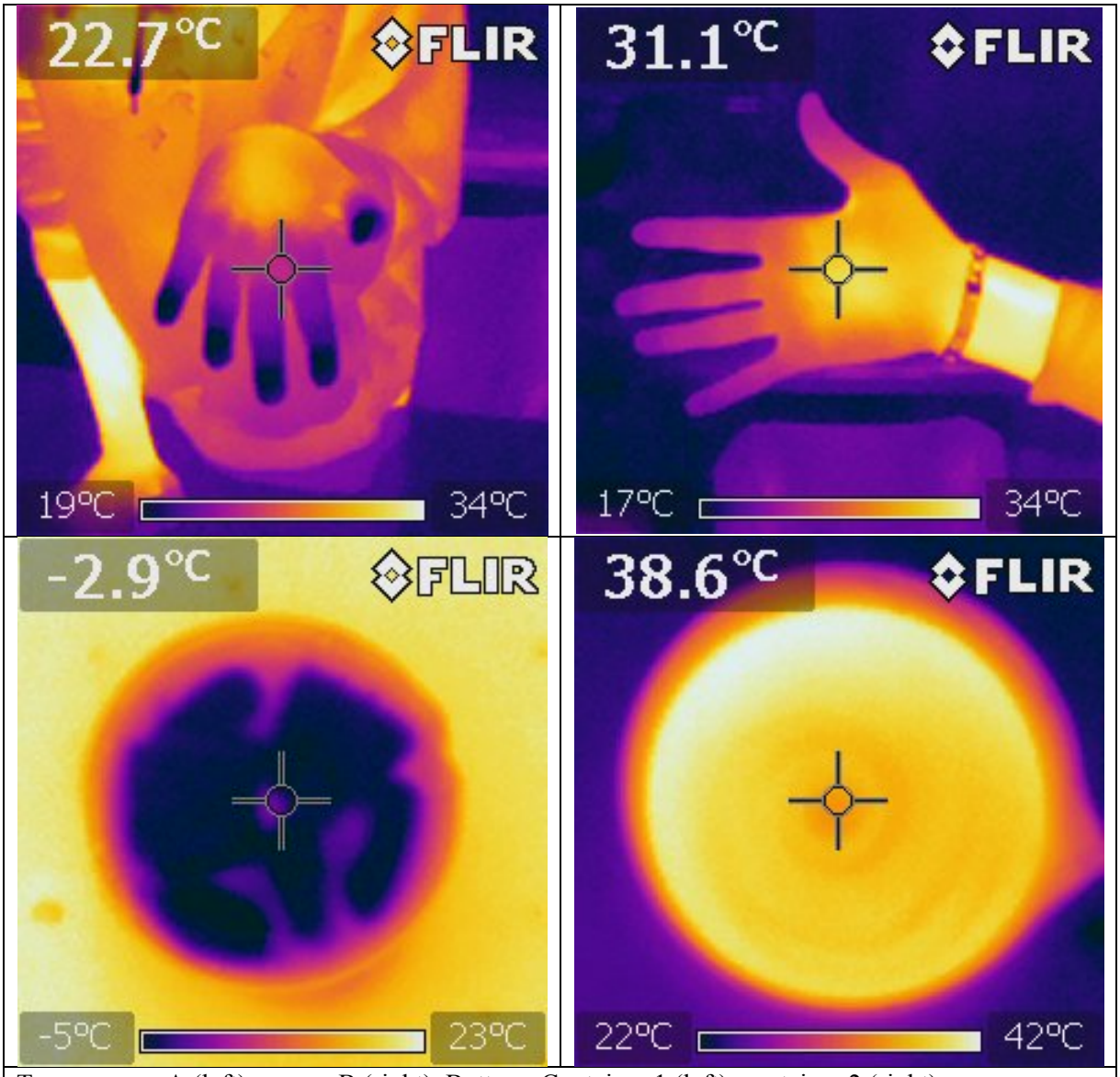
……

……

[4] We will use this temperature coding throughout the learning sequence: red for "warm", blue for cold

2.2.1.4 What you feel…hands and water

Title	what you feel…hands and water
Topic	– Heat conduction and conductivity – Physiological sensation of cold and warm by contact (conduction)
Conceptual obstacle(s)	– Difference between physiological sensation of warm and cold and physical temperature – Taking account of heat conduction and temperature as two distinct factors at work
Comment(s)	
Image Source(s)	Estelle de Chambrier



Top : person A (left), person B (right). Bottom: Container 1 (left), container 2 (right).
Source: Estelle de Chambrier

Introduction

The sensation of cold or warm is related to the rate and the direction of thermal transfer (actually it is the local temperature of the skin which depends on both and which is perceived by our receptors).

Situation and questions

Two persons (A and B) have taken IR thermal images of their hands.
Answer the following questions by using those images.

a) If you had to shake hands successively with those two persons, would you experiment something different regarding thermal sensations? Explain your answer.

b) Both persons A and B dip their hands in the liquid of container 1. Do you think that their sensations will be the same? Why?

c) Same question if the persons dip their hands in container 2.

2.2.1.5 Palm prints

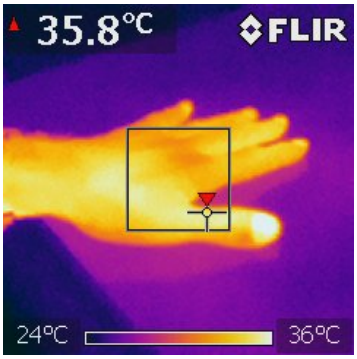
Title	Palm „prints“
Topic	– Heat conductivity of different materials – Physiological sensation of cold and warm by contact (conduction)
Conceptual obstacle(s)	– Temperature as property of a particular material or object (“metal is cold, wood is warm”) – Taking account of heat conduction and temperature as two distinct factors at work
Comment(s)	
Image Source(s)	Estelle de Chambrier

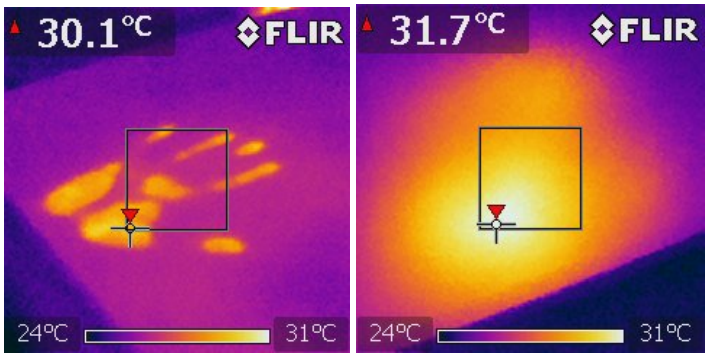
Situation and questions

Consider two surfaces, one made of wood, one made of metal. Imagine you put your palm on both (at two well separated moments, so that the first contact cannot have an effect on the second) and leave it there for a while. How would a thermographic image look like in both cases? Make a schematic drawing around the indicated contour with the usual temperature coding[4], and explain your answer.

	
wood	metal
Your drawings of the form of warm areas left by you palm on a wooden (left) and metal (right) surface	

Images (below: left wood, right aluminium)





2.2.1.6 Metal is cold, wood is warm (II)? Think twice – with thermography

Title	Metal and wood
Topic	– Heat conductivity of different materials – Physiological sensation of cold and warm by contact (conduction)
Conceptual obstacle(s)	– Temperature as property of a particular material or object ("metal is cold, wood is warm") – Taking account of heat conduction and temperature as two distinct factors at work
Comment(s)	
Image Source(s)	Estelle de Chambrier

Introduction

This activity focuses on the relation between thermal transfer, decrease (or increase) of temperature and body sensations.

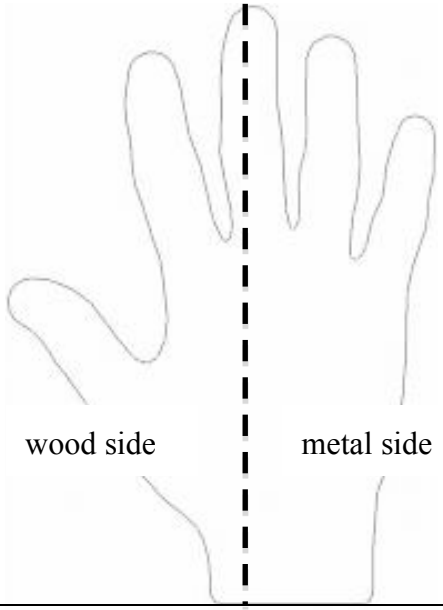
Situation and questions

a) Now that we have understood

(i) that metal and wooden objects in equilibrium with their environment have the same temperature,

(ii) that metal and wood are, however, distinguished by their thermal conductivity.

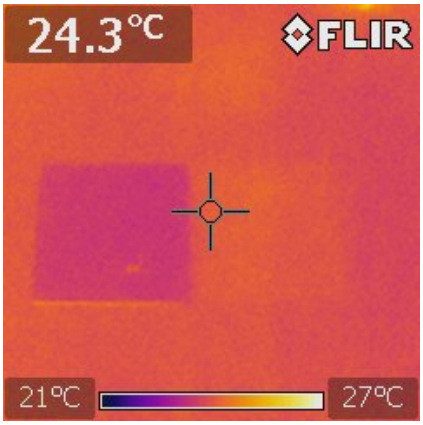
We consider again two surfaces, one made of wood, one made of metal, but this time neighbouring each other. Put your palm on this arrangement, one half on the wooden side, the other on the metal one, and leave it there for a while. How would a thermographic image look like now? Make a schematic drawing, with the usual thermography coding[4].



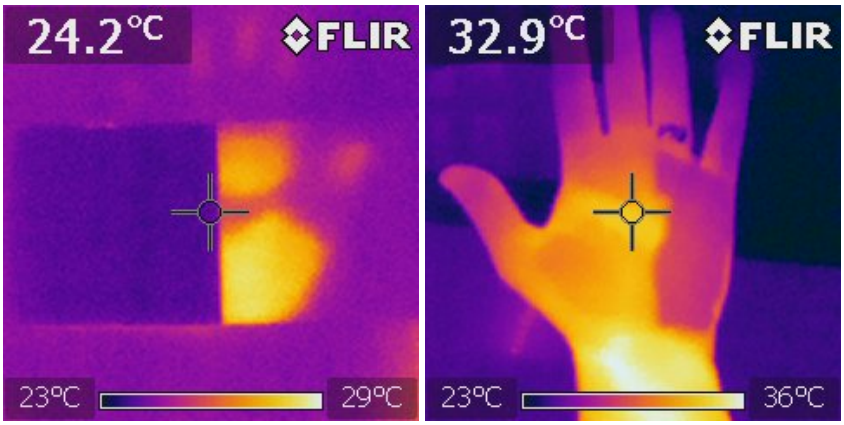
Your drawing of what thermographic image you expect, after your palm having been placed on surface with adjacent metal and wooden areas.

b) In light of the thermographic images below (and your drawing, possibly corrected), how would you reconcile
(i) the fact of equal equilibrium temperature, regardless of the material,
(ii) the perceptually correct statement "metal is cold, wood is warm"?

c) Will your hand be, just after experiment, in (internal) thermal equilibrium?



surface (before contact)



surface and palm (after contact)

2.2.2 *Radiative heat transfer*

2.2.2.1 Hot water, cold water: C'mon feel the heat…

Title	Hot water, cold water
Topic	Physiological sensation of cold and warm: by radiation
Conceptual obstacle(s)	Heat is transmitted by other means than direct contact or by heating surrounding air. Heat is also transferred by radiation from the hot water to the hand or from the hand to the cold water.
Comment(s)	
Image Source(s)	Estelle de Chambrier

Situation and questions

Two (closed) containers are put on a table. The first one is full of hot water (≈ 80°C) and the second one of cold water (≈ 10°C).

Approach your open hands close to the containers but without touching their surface.

a) Describe your sensations.

……

……

b) Give an estimation of the air temperature at the location of both your hands (compare to the temperature of you hand, and circle one of the options given

$T_{\text{air near container 1}}$ = much colder / colder / equal / hotter / much hotter

$T_{\text{air near container 2}}$ = much colder / colder / equal / hotter / much hotter.

c) Measure the temperatures with the help of a thermometer.

$T_{\text{air near container 1}}$ = …….. $T_{\text{air near container 2}}$ = ……..

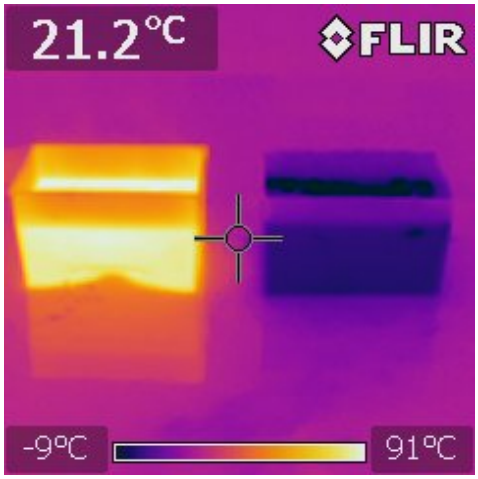
d) Find a way to explain both your sensations and the contradiction between estimated and measured temperatures.

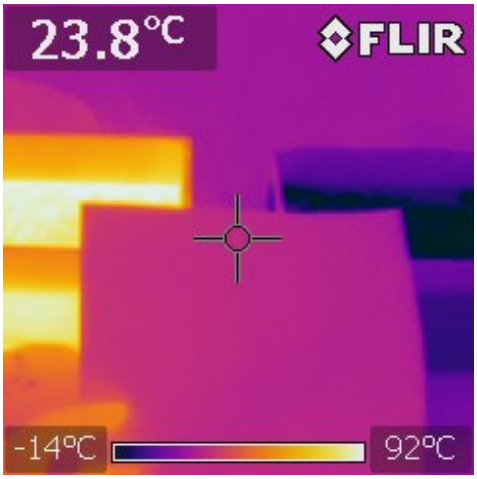
……

……

2.2.2.2 Radiation: Heat transfer without contact

Title	Radiation: Heat transfer without contact
Topic	– IR transmission of different materials – Physiological sensation of cold and warm: by radiation
Conceptual obstacle(s)	Energy is not transferred from one object to another unless those objects are in direct contact with each other
Comment(s)	Concerning activity and answer c): Actually, the paper would block heat transfer by radiation *as well* as by convection; however, the prediction that the physiological perception will be considerably less hot stays the same
Image Source(s)	Estelle de Chambrier





Plastic containers with hot (left side in each image) and cold water (right side in each image): without and with a sheet of paper about midway in between. (Position is not important as long as the sheet is not too close to the hot container, where it would heat up itself, and the picture would not be so effective in showing that paper can stop heat transmission by radiation.) .

Situation and questions

a) Explain the difference in colours between both containers.

b) Based on this image, can you explain the warm/cold sensations that you experiment by approaching your palms?

c) On the right image, a sheet of paper is put between the containers and the camera. Based on this image, predict what you would feel by doing the same experiment than before but with a sheet of paper put between your palms and the containers. Explain your answer.

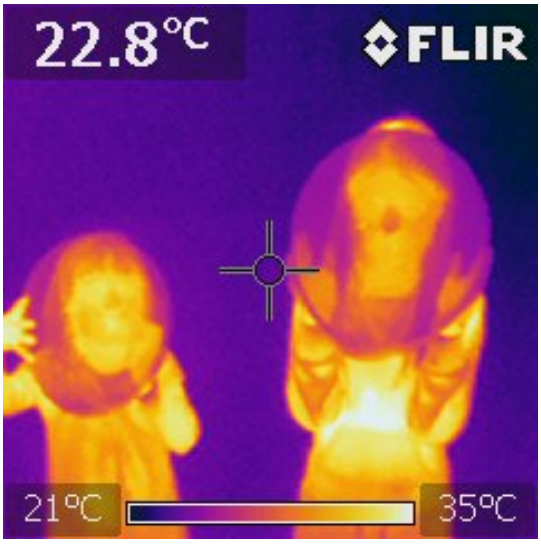
2.2.3 *Spectral selectivity*

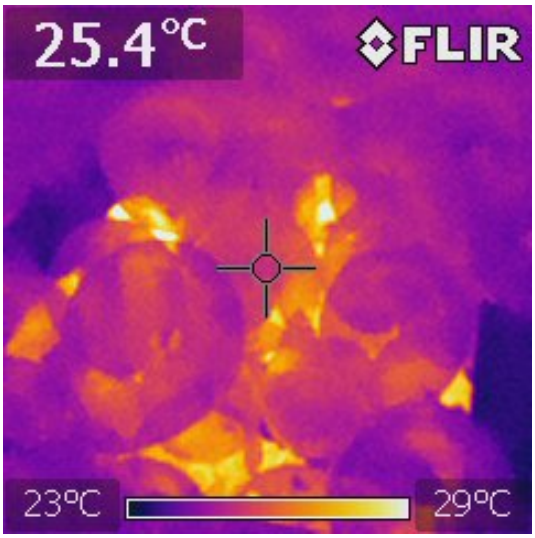
2.2.3.1 Spectral selectivity: balloons

Title	Spectral selectivity: balloons
Topic	IR transmission of different materials
Conceptual obstacle(s)	
Comment(s)	
Image Source(s)	Estelle de Chambrier

Situation and questions

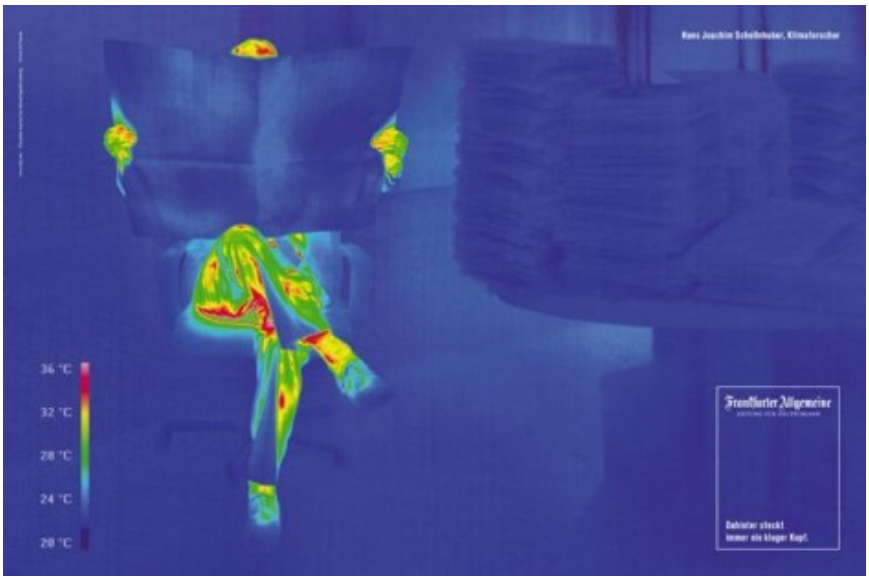
Two children are playing hide-and-seek under a huge amount of latex balloons. Their mother is looking for them and, being allergic to latex, can't touch the balloons. She decides thus to use an IR thermal camera in order to find her children.





a) Can you imagine why she thinks that this will be useful? Use the images above to justify your answer.

b) Would the same physics trick have worked if the children have chosen to hide under a pile of papers and cardboards? Use the image below to justify your answer. Relate your answer to one of the preceding experiments.



2.2.3.2 Spectral selectivity: transmission – from man to Milky Way, and back to everyday life

Title	Spectral selectivity: transmission
Topic	– Transmission: IR vs. visual range – IR transmission of different materials
Conceptual obstacle(s)	
Comment(s)	The concept of selective absorption is shown across several states and types of matter (PE, solid; dust, solid granular; vapour/smoke; gaseous; for the liquid state and other examples, see [7], [8])
Image Source(s)	upper row: Estelle de Chambrier middle row: http://www.ipac.caltech.edu/outreach/Edu/Regions/irregions.html lower row : Cool Cosmos/IPAC, http://coolcosmos.ipac.caltech.edu/

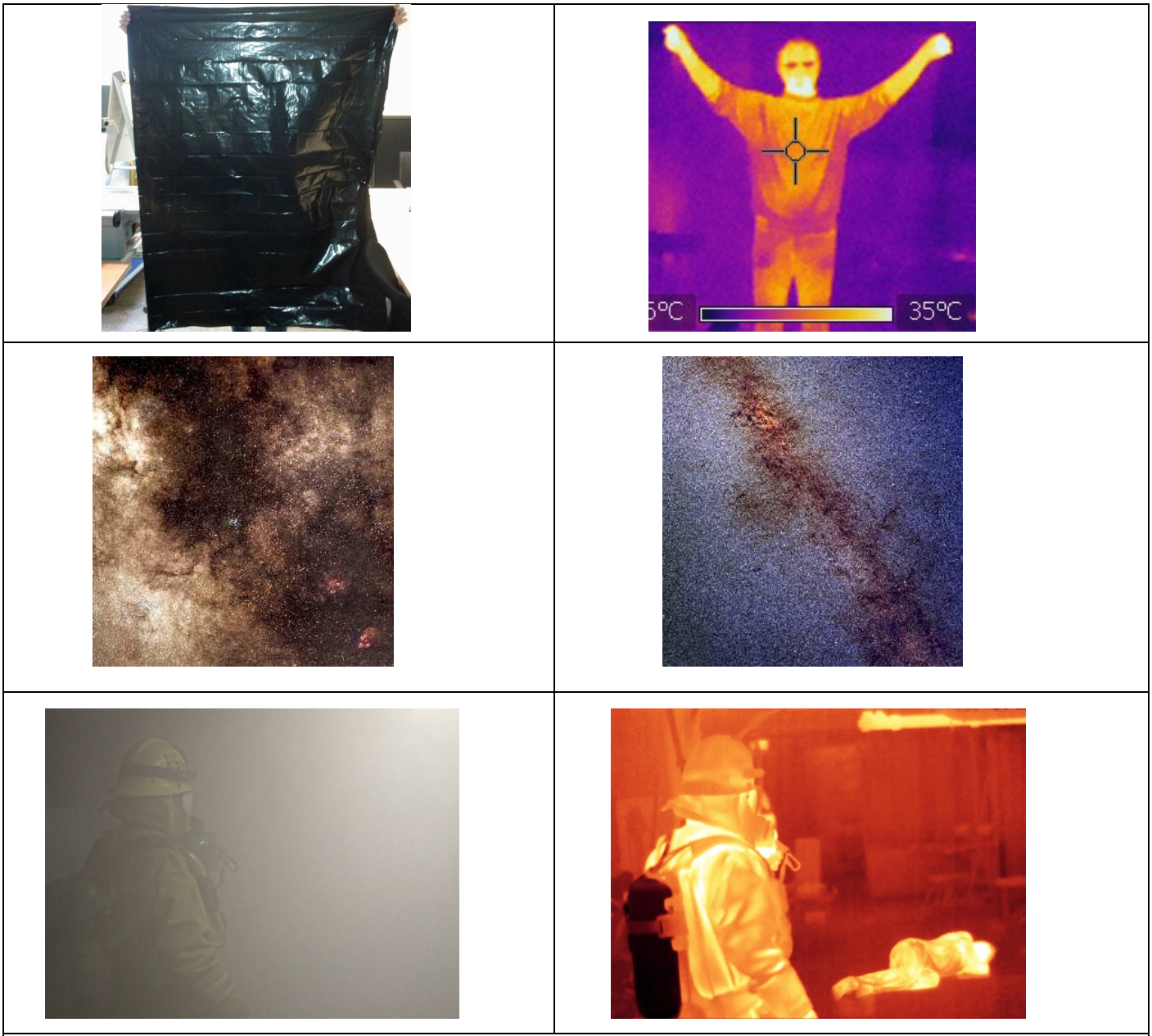


Fig. 1. Looking behind the curtain: Infrared images from man to milky way, and back to everyday life
1) Top: Behind a plastic "curtain" (PE): person in visual range invisible (left), in infrared range visible (right).
2) Middle: Behind the dust "curtain" (interstellar dust): galactic centre in visual range invisible (left), in infrared range visible (right).
3) Bottom : Behind the smoke "curtain": Firefighter seraching for a victim: invisible in the visual range (left), visible in infrared range (right).

The image pairs above show that the same physical phenomenon can be at work in very different situations, viz. that the same object might be opaque for visible light, yet transparent for IR (or selective transmission, as scientists put it).
a) Name the fundamental difference regarding the materials of the situations 1), 2), 3).
b) Name another fundamental difference regarding the location of situation 1) and 2).
c) Do you find something noteworthy in this similarity across differences?

2.3 Transfer/cross-disciplinary connections

2.3.1 *Thermal insulation*

2.3.1.1 Clothes keep warm

Title	Clothes keep warm
Topic	Thermal insulation
Conceptual obstacle(s)	(i) Temperature (cold or warm) is a property of a particular material or object (ii) Materials like wool have the ability to warm things up (iii) Distinction between indicated temperature of thermograms and thermal sensations.
Comment(s)	A current misconception related to thermograms is the confusion between temperature measurements and thermal sensations. The measured temperature at the surface of the skin or the clothes will be the larger, the larger the thermal transfer from the (warm) body to the (cold) surroundings. A low temperature (e.g. on the jacket) shows that radiative transfer between the body and the surroundings is low. The child will thus feel warmer at these places.
Image Source(s)	http://thermal-imaging-blog.com/index.php/2010/12/08/bundle-up-your-overcoats/#.UoPql5H0gQR

Situation and question(s)
In everyday language the words “heat” , “warm” and “cold” often don’t have the same meaning as in physics and thus may induce conceptual obstacles in thermodynamics.
For example, when told to put a warm sweater, a child will attribute the heat as something provided by the sweater. The sweater thus becomes the source of the thermal energy.

1. Think about another common expressions and what conceptual obstacle might come from their use.
2. Based on the thermogram above, order the children’s body parts from the lowest to the highest temperature.
3. Nor order the children’s body parts according their sensations of cold and warm (from coldest to warmest sensation, most probable answer according to your experience).
4. Now compare the order of temperatures you found (question 2) and that of sensations of cold and warm (question 3)? Which conceptual obstacle might appear from this comparison?

5. Formulate a brief explanation about thermograms which would help to avoid this conceptual obstacle.

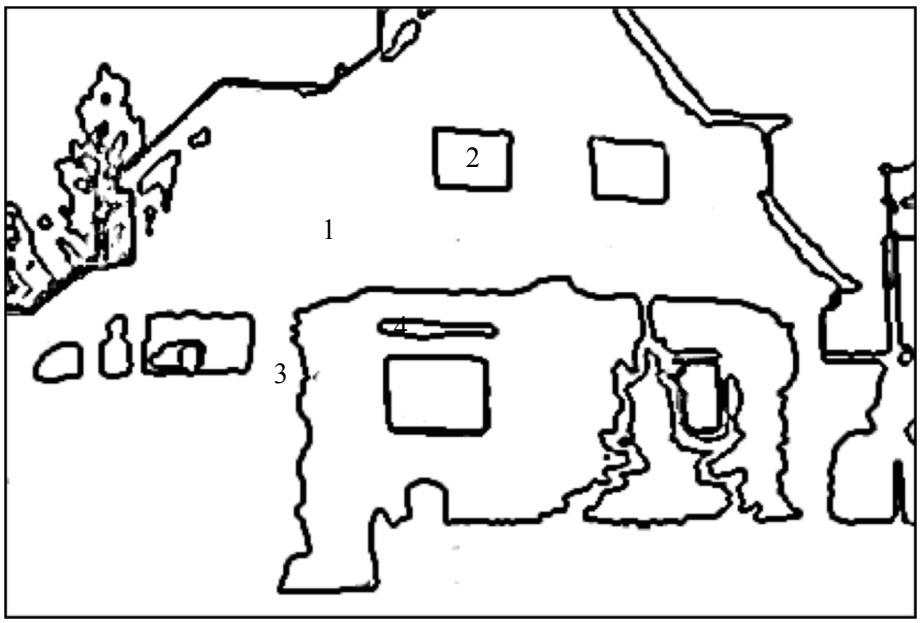
2.3.1.2 Thermal insulation of buildings

Title	Thermal insulation of buildings
Topic	Thermal insulators, thermal conductors
Conceptual obstacle(s)	
Comment(s)	
Image Source(s)	

Situation and question(s)

The image below shows a thermal image of a house front. The image has been taken in winter and the outside temperature is below zero.

+



Building materials are classified from well insulating to well conducting heat depending on their ability to limit thermal energy losses. Insulating materials are thus creating kind of a resistance to thermal energy transfers.

a) Order the different areas in the image from the coldest to the warmest (i.e. from lowest to highest temperature)
b) Assuming that the inside temperature is uniformly 20 °C, estimate the temperatures differences between the inside and outside in the areas 1 to 4.
c) Can you explain those differences? Think about the energy losses.

d) Based on your previous answers, order material from areas 1 to 4 from the most to the least insulating knowing that:
- first floor's windows are made of a double glazing
- ground level's windows are made of a single glazing
- ground level's wall is made of bricks
- first floor's level is made of a multilayer of bricks and rock wool.

2.3.2 *Life sciences*

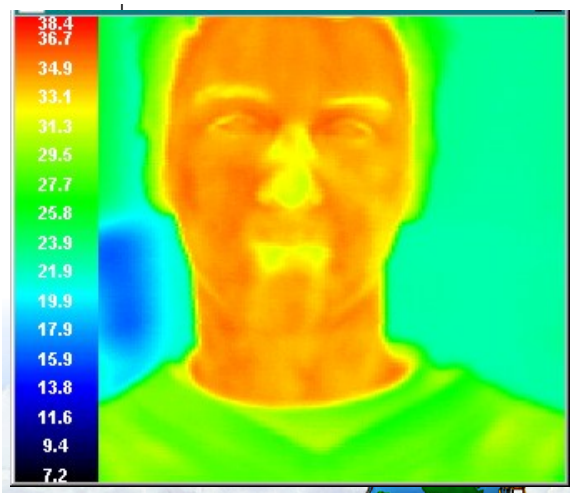
2.3.2.1 Illness detection

Title	Illness detection
Topic	
Conceptual obstacle	
Comments	– External body temperature is approximately 2°C below internal body temperature. – Temperature scales are in Celsius degree and each colours panel is specific for each image.
Image Source(s)	http://thermal-imaging-blog.com/index.php/2010/12/08/bundle-up-your-overcoats/#.UoPql5H0gQR

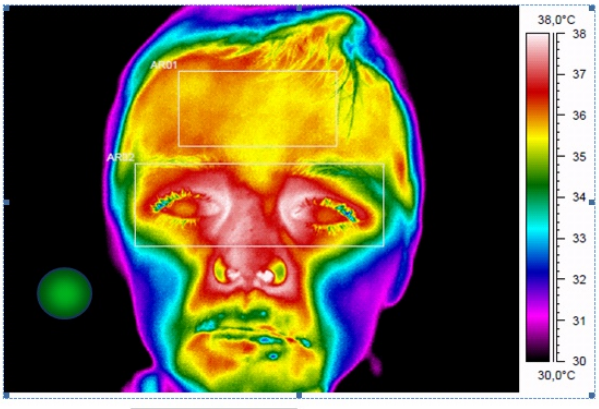
Situation and question(s)
During the H1N1 flu pandemics, infrared thermal imaging were used in the airports to detect potentially infected people. Images of passengers' faces were taken in order to know if they had fever.

a) Following thermal images show the faces of travellers departing from Bali. On each image A and B:

1) Give the temperatures of the different areas of the faces
2) Deduce if the travellers A and B will be authorised to board in the plane.



A



B

b) Why do you think that this method was chosen instead of direct temperature measurements? Find at least two advantages.

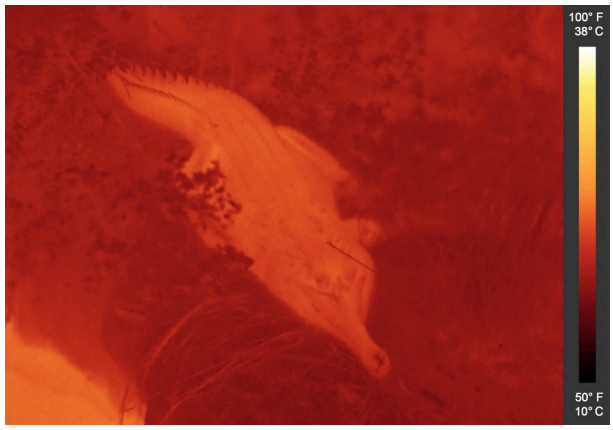
Situation and question(s)

2.3.2.2 Crocodiles

Title	Crocodiles
Topic	– Cold-blooded animals – Thermoregulation
Conceptual obstacle	
Comment(s)	The background information given below can be omitted if provides elsewhere in the teaching unit (eg. in biology classrooms about poikilothermic organisms etc.)
Image Source(s)	[12]

Background

Unlike mammals and birds, crocodiles are not able to maintain a constant internal body temperature. Their ideal temperature is between 30°C and 33°C. In order to maintain it, they move from the cold to the warm parts of their surroundings (or vice versa). However, if the environmental temperature is too low, the crocodiles actions will slow down considerably, and if the low temperature last for too a long time, they cannot survive. This is by the way one of the reasons discussed for the extinction of dinosaurs, which had the same temperature regulation behaviour as crocodiles (in fact, this is true for the entire larger class of reptiles, to which both crocodiles and dinosaurs belong to).



Situation and question(s)

a) By using the images above, do an estimation of the crocodile's surroundings average temperature.

b) Make an estimation of the crocodile's average temperature then compare it with the estimated surroundings temperature.

c) Are the temperatures the same? By observing carefully the images, can you formulate a plausible explanation of the findings? Is it the only one?

d) From the above, can you give the scientific reason why crocodiles are also called "cold-blooded animals" and why it is not plausible to find them in cold regions?

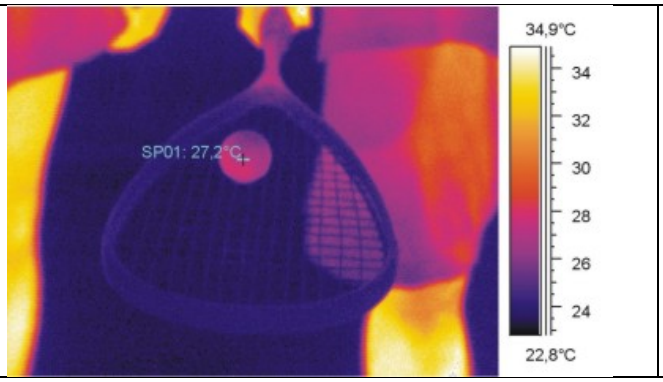
2.3.3 *Diverse*

2.3.3.1 Squash ball heating

Title	Squash ball heating
Topic	– Internal friction heating – Energy conservation
Conceptual obstacle	
Comment(s)	
Image Source(s)	M. Vollmer, http://www.fh-brandenburg.de/~piweb/projekte/thermo_galerie.html

Situation and question(s)

Have a look at the thermographies of a squash ball below. Is it possible to understand the order of magnitude of the temperature rise? See [13] for a detailed treatment of this question.



Heating of a squash ball after some minute of playing

3 References

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[10] Viennot, L. (2001). Reasoning in physics: The part of common sense . Dordrecht: Kluwer ; ch 4.1 - 4.4

[11] AAAS (American Association for the Advancement of Science) : Science Assessment: http://assessment.aaas.org/Topics; access 11-10-04

[12] Cool Cosmos, http://coolcosmos.ipac.caltech.edu/infrared_worl.

[13] Müller, A. (2015). Squash ball heating, see [1]