The infrared camera as a pedagogical tool in science education

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Abstract The infrared camera, or thermal imaging camera, can be used to complement the teaching of a number of topics in high school science. Here, we provide seven examples of its application in teaching physics, chemistry and biology concepts at high school level. We also discuss its strengths for such applications and provide some pointers for science educators.

Infrared thermal imaging, or thermography, is a powerful tool that brings visualisation of the temperature of an object or scene to life. It makes use of the fact that every object at a temperature above absolute zero (0 K or −273.15 °C) gives off electromagnetic radiation according to radiation laws. An infrared camera detects the infrared radiation emitted by the object, converts these into electrical signals, and displays the temperature distribution in a false-colour image that gives users an intuitive appreciation of the temperature distribution. As a highly visual tool, it has found many uses in fields as diverse as education, research and development, inspection of buildings, and gas detection (Vollmer and Möllmann, 2010).

For science education, the infrared camera has been shown to be highly useful (Vollmer *et al.*, 2001). Every science educator needs a repertoire of approaches to engage students and spice up lessons. The infrared camera is ideal for this purpose in certain contexts as it renders the invisible visible and allows students to ‘see things in a different light’ in both the literal and metaphorical sense of the phrase. Abstract science concepts can be grasped by students more easily using this tool. With significant reduction in costs in recent times due to the widespread use of the infrared camera in different fields, there is even more reason for science educators to use it in their lessons. A basic model can now be purchased for around £400.

The infrared camera can be used to demonstrate concepts in physics, chemistry and biology (Short, 2012; Xie, 2012). Our previous works (Wong and Subramaniam, 2018a, 2018b) demonstrate its use for teaching introductory college physics. We find that the full repertoire of the use of the infrared camera in teaching physics, chemistry and biology has not yet been fully exploited. Therefore, this article serves to extend the diversity and scope infrared camera applications with the aim of providing busy science teachers with ready and feasible ideas to implement in their classes.

Examples of the use of the infrared camera in teaching science concepts

Rubbing an eraser across a surface (sliding friction)

When an object slides across a surface, work is done against frictional forces. The relevant equation is $F_s = \mu_s F_n$, where F_s is the force of sliding friction, μ_s is the coefficient of sliding friction, and F_n is the normal force with which each surface presses on the other. The work done is converted to thermal energy – the temperature of the two surfaces in contact will thus increase. This demonstration can be easily done using readily available resources (eraser and table). The minute changes in temperature of the surfaces involved can be captured readily using the infrared camera. This phenomenon cannot be easily demonstrated using other methods of temperature measurement. Notice from Figure 1 that a small temperature rise of 0.5 K of the table top can be distinguished using this method of just rubbing across the surface. Students can vary the speed of rubbing and the contact pressure to see what happens to the temperature.

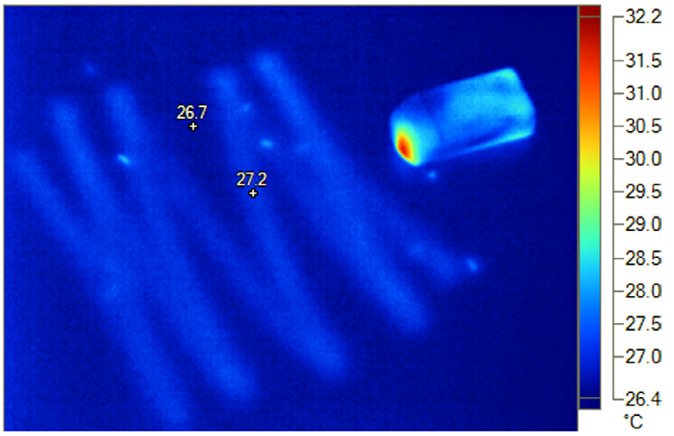

Figure 1 Infrared thermal image related to rubbing an eraser on a table top; work done against sliding friction causes a temperature rise at the rubbed surfaces of the table top and the eraser

Joule heating

Joule or ohmic heating forms the basis for the operation of a myriad of electrical appliances, where its direct effect is useful. In other cases, it is an unwanted effect. It is a phenomenon whereby passing an electrical current through a resistor generates heat. For our experiment, we connected three wire-wound resistors (12 Ω, 27 Ω and 100 Ω) in parallel to a 10 V supply. Using an infrared camera, the joule-heating effect was observed readily, as shown in Figure 2. The power dissipated for each resistor is given by $P = V^2/R$. As can be seen in Figure 2(b), the smaller the resistance, the greater the power dissipated and the higher the temperature. (Relating the power dissipated to the actual temperature is not straightforward though, and is not in the scope of this article.)

Infrared transmission characteristics of a black bin bag

In addition to studying temperatures of objects, the infrared camera can also be used to bring out the infrared transmission characteristics of certain materials. One interesting example is that of a black bin bag, which has low transmission for visible light but is highly transparent to infrared radiation (Figure 3). Bin bags are made of polythene, which has high transmission in the infrared region (Tsilingiris, 2003). This usually surprises people, as we are accustomed to seeing only in the visible. A similar 'see-though' effect in the infrared region can be demonstrated using a blown-up balloon or a silicon wafer. In contrast, a piece of Perspex or Plexiglas demonstrates the opposite effect – they are highly transparent in the visible but almost opaque to infrared in the range of typical infrared cameras (Wong and Subramaniam, 2018a).

Crystallisation of saturated sodium ethanoate (exothermic process)

This is a popular and highly visual demonstration in chemistry. Using an infrared camera with video output function and a projector, a large class can view the crystallisation process and the temperature rise captured when a small seed crystal of sodium ethanoate trihydrate ($NaC_2H_3O_2{\cdot}3H_2O$) is added to a supersaturated solution of the same substance at room temperature (Figure 4). See Shakhashiri (1983) for more details on the procedure. The process is fairly rapid, and the contents of the bottle turn

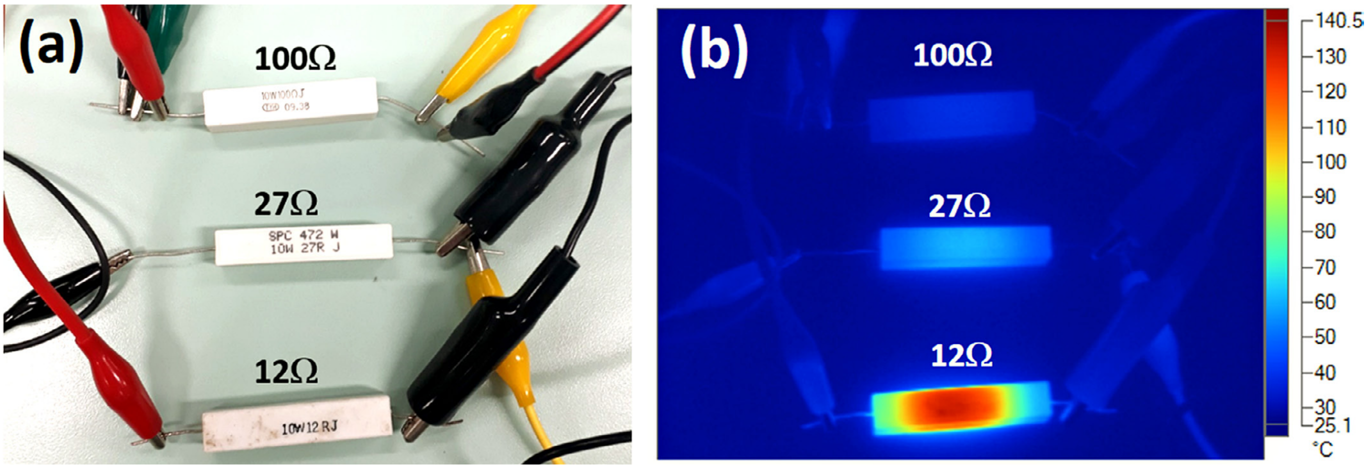

Figure 2 Resistors connected in parallel to a 10 V supply: (a) visible light image and (b) corresponding infrared thermal image, taken around 90 s after turning on the power

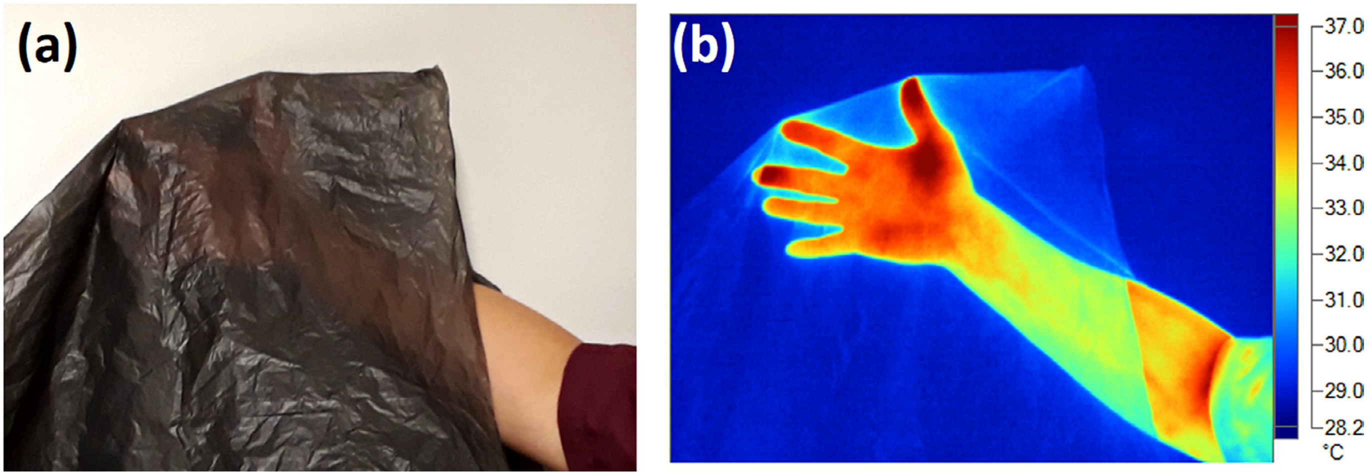

Figure 3 A person's hand inside a black bin bag: (a) visible light image and (b) corresponding infrared thermal image

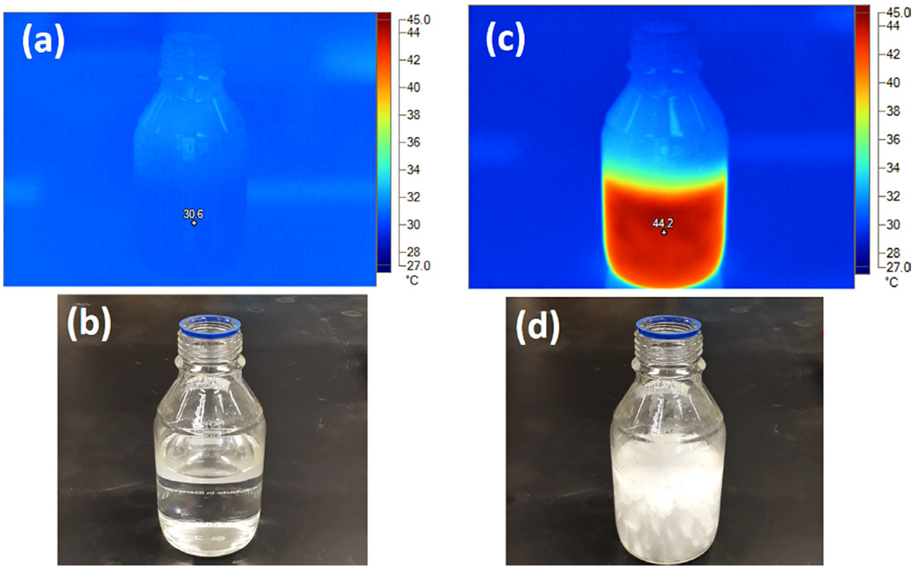

Figure 4 Before crystallisation: (a) infrared thermal image and (b) visible light image; after crystallisation: (c) infrared thermal image and (d) visible light image

completely white gradually but quickly, with the temperature rising above 40 °C. Without the infrared camera, students will only be able to see the contents of the bottle turning white during crystallisation but cannot 'witness' the temperature change taking place. One point to note is that the temperature captured by the infrared camera is that of the bottle, rather than that of the contents, as glass absorbs the infrared radiation emitted from the contents. However, it should be essentially the same as that of the contents, with thermal conduction taking place rapidly.

Dissolution of D(+)-glucose monohydrate (endothermic process)

Glucose is highly soluble in water. The dissolution process is endothermic. Here, we used D(+)-glucose monohydrate, a naturally occurring simple carbohydrate. The infrared thermal image shown in Figure 5 was taken immediately after dissolving the glucose in water in the respective beakers. As can be seen, the glass beakers containing solutions of different concentrations of glucose exhibit a temperature drop with respect to that containing pure water – the higher the concentration, the lower the temperature.

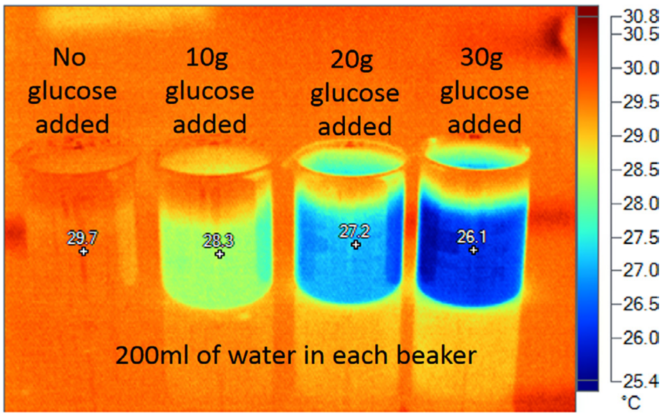

Figure 5 Infrared thermal images of beakers of water with different amounts of D(+)-glucose monohydrate dissolved in them

Poikilotherms

The infrared camera can be used to study the body temperatures of animals (Kastberger and Stachl, 2003). An interesting topic is how a 'cold-blooded' animal will show up under the infrared camera. Here, we propose using frogs to study this as they can be quite readily procured because of their use in dissection in biology lessons in school. Also, they are farmed for their meat in many places around the world. (The frogs in our article were found in a frog farm in Singapore.) The common frog is a poikilotherm – an animal whose internal body temperature varies considerably. Unlike homeotherms that maintain thermal homeostasis, the body temperature of poikilotherms fluctuates according to the surroundings. Here, we took images of frogs partially submerged in water in their pen. The wall of the pen (seen at the top of Figure 6) is warm because the other side of the wall faced the Sun on a sunny day. As can be seen, the temperatures of the entire bodies of the frogs are almost the same as that of the water that they are partially submerged in.

Warm-blooded but with cold hands

Humans are warm-blooded homeotherms with a stable internal body temperature. The skin temperature, however, varies with different parts of the body and with ambient temperature, and also from person to person. Here, we compare the temperatures of the hands of two people who have been in the same air-conditioned room with an ambient temperature of around 26 °C for a similar duration (around an hour or longer). As can be seen in Figure 7, the hand of Person A is colder than that of Person B. It is possible that there could be problems with blood circulation in the hands of Person A. The fingertips of Person A are also colder than the other regions, because heat loss through the fingertips is most pronounced.

Conclusion

We have provided some examples here of how the infrared camera can complement the teaching of certain topics in physics, chemistry and biology. In some cases, such as the case of studying heat produced by sliding friction, an infrared camera seems to be the only feasible way of

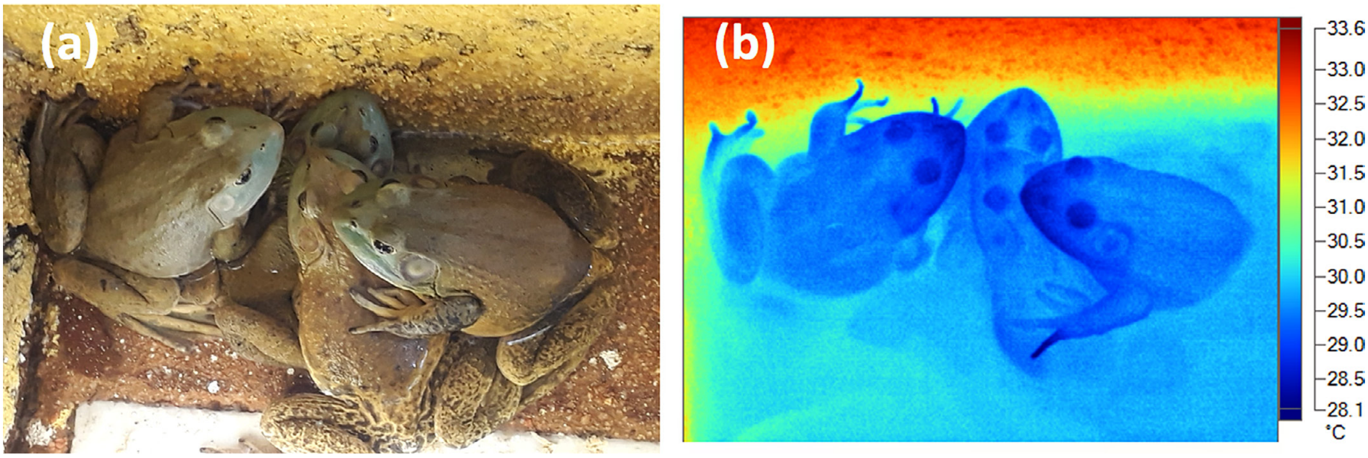

Figure 6 Frogs in their pen: (a) visible light image and (b) infrared thermal image

visualising the temperature increase. In other cases, such as monitoring the temperature change due to exothermic or endothermic reactions, a thermometer can do the job. However, we would argue that an infrared camera with video capture and output can show this temperature change to a much larger class. It is also much more visually captivating. Indeed, we believe that engaging students' interest is the first step to effective learning, and the infrared camera is ideally suited for this purpose.

While a basic infrared camera is easy to use, here are some reminders for science educators. You need to bear in mind, for example, how the emissivity of different materials affects the readings. Emissivity refers to the effectiveness with which a body emits thermal radiation, compared to a perfect emitter with an emissivity value of 1. The emissivity setting needs to be correct as otherwise the temperature reading will be inaccurate. This issue can generally be addressed by selecting the appropriate emissivity value for the material of concern in the database of the camera's software. The science educator should also have a general knowledge of how much a particular medium transmits infrared radiation in the wavelength range of the camera – this means you need to also understand why we cannot 'see' the temperature of the eyes behind a pair of glass spectacles. (This is because glass has low transmission for infrared, so the infrared radiation of the eyes cannot pass through the glass to reach the camera.) All these should not deter you from using the infrared camera though, as the advantages of the infrared camera over other traditional methods of teaching are significant indeed.

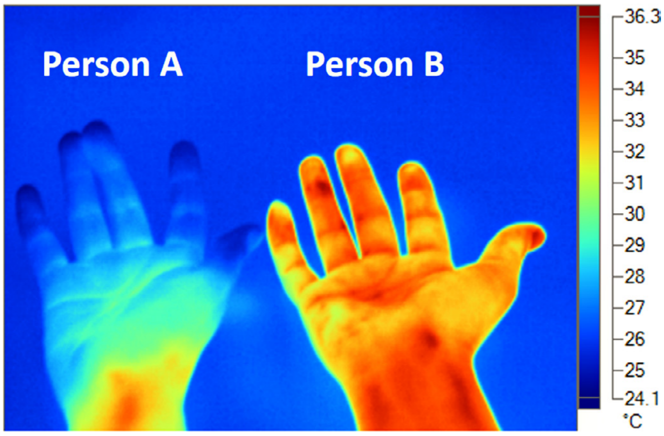

Figure 7 Infrared thermal image of the hands of two people at 26 °C

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