Leslie cube

ACTIVITY

In this activity you will investigate how well an object's surface radiates or absorbs heat depending on the coating on its surface.

BACKGROUND INFORMATION

Today, we're familiar with the fact that a white car sitting in the sun is cooler than a black car. We say that the white car is good at reflecting the Sun's heat away, but the black absorbs it. But is it that simple?

In 1804 Sir John Leslie, a Scottish mathematician and physicist, published a paper called *'An Experimental Inquiry into the Nature and Propagation of Heat'*. This paper was the result of his experiments using a device that he invented, now known as the Leslie cube. The cube was of a relatively simple design, and yet displayed some unexpected behaviour.

He used metal to make a hollow cube. Each of the four vertical faces was coated differently: one was polished and shiny, one was covered with soot, the third was covered with a sheet of paper, and the fourth was painted with variable option ('Leslie's canisters', Chemistryworld.com, https://www.chemistryworld.com/opinion/leslies-canisters/4012476.article (2 October 2020). The cube could be filled with hot water through a hole in the top of the cube.

The clever part was what happened next. When Sir Leslie measured the temperatures of the different sides of the cube (from the outside), he noticed that the temperatures all differed. In fact, the dark, rough surface was hotter. This must have meant that it was a better emitter of heat. Let's explore what's meant by that.

Thermal radiation

When something heats up, it emits infrared light. This is true of everything that we encounter in our everyday lives.

How well something emits that radiation is dependent on various properties of the material. In this experiment, we're looking at the properties of the different coatings on the vertical faces of the cube.

The black, matte surface (i.e. the soot-covered one) is much better at emitting heat. So if you stand next to a black wall that is in the sunshine, you would feel warmer because the wall is radiating its heat at you.

BACKGROUND INFORMATION - cont'd

Thermal absorption

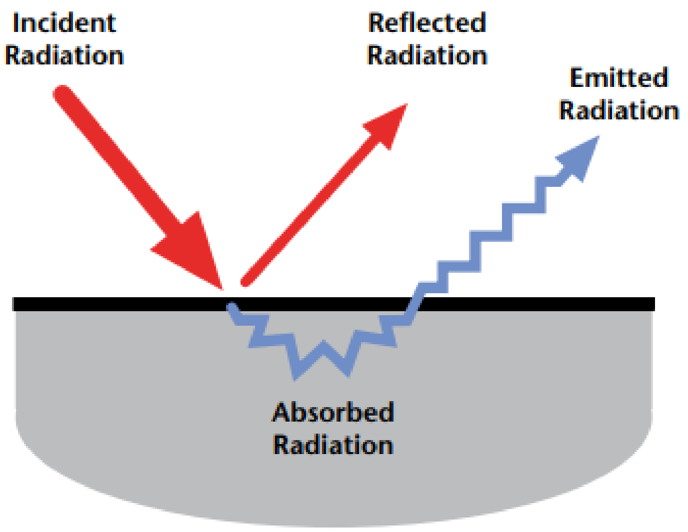
But where did the black wall get its heat from in the first place?

That's where thermal absorption comes in. As with emission, how well something absorbs heat is also dependent on its properties. It turns out that when something is good at emitting heat, it is also good at absorbing it. Therefore, if we return to our example of a black wall, not only is it good at absorbing heat, and it is also good at emitting it.

At the other end of the scale is a shiny surface. It is not good at absorbing heat, and not good at emitting it, either.

Figure 1

Incident Radiation on an Opaque Surface



For any particular wavelength of radiation striking an opaque material, the sum of radiation that is reflected and that absorbed must equal the incident radiation. The radiation emitted and the radiation absorbed must equal each other at steady state.

https://www.energy.wsu.edu/documents/aht_principles%20of%20heat%20transfer.pdf

Figure 1 shows what happens when light is shone at an opaque surface (incident radiation). Some is absorbed and heats up the surface. Some of this absorbed light is released as the blue wiggly line. The remaining light is reflected as the smaller red arrow. In our experiment, the sizes of the right hand arrows will vary for each surface with its different coating

Thermal reflection

Now here's the kicker: if something is good at absorbing, and good at emitting, how good is it at reflecting?

To answer this question, let's think about a matte black surface. We know it is good at absorbing heat, and that it is good at emitting heat. Can you see your reflection in a matte black surface? No. This means it's poor at reflecting visible light, and will also be poor at reflecting heat.

Then, think about a shiny metal surface. It does not absorb heat well, and neither does it emit heat well, but it does reflect heat (or visible light) really well.

BACKGROUND INFORMATION - cont'd

Cooling down

There are three ways in which objects can cool down, in other words, three ways in which objects disperse their heat.

1. Convection. This works by the movement of fluids such as air or heat that carry the heat away. e.g., a saucepan of liquid warming on the stove – the heat from the hotplate warms the liquid from the bottom of the pan, the warm liquid rises taking that heat higher, while the cooler liquid at the top sinks.

2. Conduction. This is where heat is transferred by two things of different temperatures touching each other. e.g., your cold hand touching a warm mug – your hand warms up as heat is conducted out of the mug into your skin.

3. Radiation. This happens when heat is lost by the emission of infrared radiation, and can even happen in the vacuum of space.

What does all of this have to do with astronomers?

Telescopes are very sensitive to temperature changes. Modern telescopes are constructed out of glass, metal and are full of complicated electronics. The glass and metal will expand and contract with changes in temperature, and the electronics need to stay cool (sometimes extra, extra cool).

Terrestrial telescopes: Down here on Earth, telescopes are built in high, exposed places where the heat from the Sun can be extreme. White paint is used to coat the outside of domes to reflect as much heat as possible, and also emit infrared heat efficiently. There are many other engineering tricks used to cool down a telescope and the air inside the dome, but it all starts with the coating on the outside.

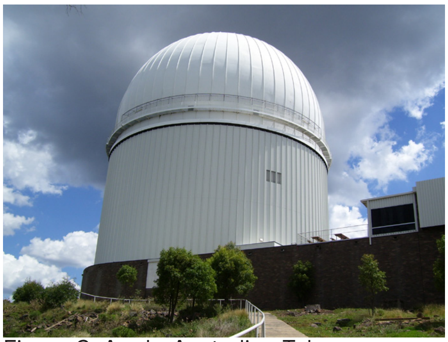


Figure 2: Anglo-Australian Telescope, Coonabarabran, NSW, Australia. By Diceman Stephen West - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6176165

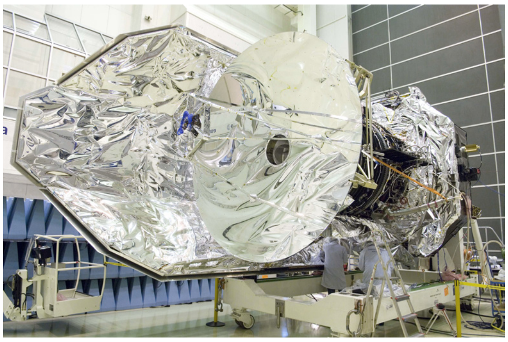


Figure 3: Herschel spacecraft. Credit: ESA.

Space telescopes: With no atmosphere to protect them, space telescopes are exposed to the Sun's rays directly. The side facing the Sun can reach 120 degrees C. Engineers carefully choose both a highly-insulating material and an appropriate colour that is poor at absorbing heat (e.g. white). The side facing away from the Sun is cold, but can be coated with a material and colour that is good at absorbing the heat that comes from the Sun (e.g. black).

FURTHER READING

Read about why this is important to astronomers:

'About the sunshield', NASA, Goddard Space Flight Centre website, https://jwst.nasa.gov/content/observatory/sunshield.html

Tomaswick, Andy, 'James Webb telescope going through cooling process', Universe Today, Phys.org website, https://phys.org/news/2022-02-james-webb-telescope-cooling.html (16 February 2022)

Read about thermal radiation:

'How exactly does light transform into heat--for instance, when sunlight warms up a brick wall? I understand that electrons in the atoms in the wall absorb the light, but how does that absorbed sunlight turn into thermal energy?', Scientific American website, https://www.scientificamerican.com/article/how-exactly-does-light-tr/ (21 October 1999)

All websites accessed 17/3/2022.

EQUIPMENT

You will need the following to complete this activity.

- Leslie cube (these can be purchased from school science suppliers, or maybe you could build your own *)
- Non-contact infrared thermometer
- Heat source (dependent on the type of Leslie cube you have: hot water for some, or a hot light for others)
- Heat proof mat
- Ruler
- Pen or pencil

EQUIPMENT - cont'd

* BUILD YOUR OWN SUBSTITUTE LESLIE DEVICE

Instead of building your own Leslie cube, use painted aluminium cans.

- Obtain four identical cans that have a small opening, e.g. soft-drinks cans, or soup cans with a ring-pull. Strip the paint or remove the labels from the cans.
- Paint each of them as follows: one with matte black paint, one with shiny black paint, one with matte white paint, and leave one as the raw, shiny metal.
- Hot water
- Non-contact infrared thermometer
- Heat proof mat
- Ruler
- Pen or pencil

EXPERIMENT

1. Place your Leslie cube or your cans on the heat proof mat, on top of a bench.

2. Measure ten centimetres away from each of the surfaces of the cube, or from each of the cans.

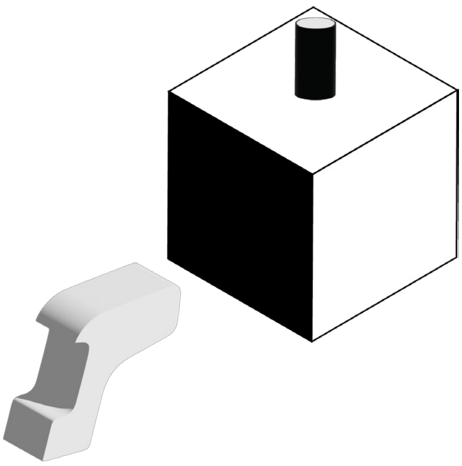
3. Fill your Leslie cube or each of your cans with hot water until they are full.

4. From ten centimeters away, use the thermometer to measure the surface temperature of each of the surfaces, or from each of the cans.

5. Record your results in the table below.

6. Dispose of the hot water carefully.

7. Plot your results in a column graph with temperature on the y-axis and the coating on the x-axis.



RESULTS

Surface coating	Temperature (deg C)
Matte, black	
Matte, white	
Shiny, smooth white	
Shiny, smooth metal	

FOLLOW-UP QUESTIONS

1. Which surface (or can) stayed the coolest? Which surface (or can) was the hottest?

2. Explain in terms of radiation why your measurements had to be taken from the same distance each time.

3. Using your results, propose a reason for why vacuum flasks are shiny and silver on the inside.

FOLLOW-UP QUESTIONS

4. Suggest how this experiment could be adjusted to measure how well each coating reflects heat. Mention variables, dependents and constants, and what equipment might be needed. Use the space below to draw any equipment set-up you think might work.