THE HABITABLE ZONE

Students investigate how temperature changes with distance from a heat source and relate this to planetary temperatures.

Apparatus and Materials

(per group of 2 to 4 students)

- Radiant Heater or 250 W infrared bulb mounted in a holder
- 2 thermometers (one with a shiny bulb, the other with a blackened bulb)
- 2 clamps and stands
- Meter rule
- Graph paper

Each student will require a photocopy of the instructions and worksheet (pages 8 and 9 respectively).

Health & Safety and Technical Notes

Old mains powered radiant heaters with bowl-fire elements are no longer recommended for use in schools. Refer to CLEAPSS Laboratory Handbook 11.9.2 for safety information and alternatives. A 240 W infrared bulb works well.

Beware of burns: tell students to stop as soon as they feel anything. If a lamp is used, warn students not to look directly into the light as it will be very bright.

Learning objectives

After completing this activity, students should be able to:

- understand that the temperature of a planet depends on its distance from its star, surface reflectively and atmosphere
- understand that the habitable zone is the region of space around a star where the average surface temperature of a planet will allow liquid water to exist.

Introducing the activity

Introduce the idea of an exoplanet and explain that we are interested to know whether life might exist on any of the observed exoplanets.

Explain that liquid water is likely to be necessary for life. There are two reasons for this: many substances can dissolve in liquid water, and many of the chemical reactions necessary for life take place most efficiently in the temperature range around 0°C to 50°C. That's why our body temperature is maintained close to 37°C.

Discuss the graph on the student instruction sheet; planets close to the Sun are hottest, those furthest away are coldest. Ask them to explain this, given that the surface temperature of the Sun is about 5500°C and the temperature of deep space is -270°C (almost absolute zero).

Students may not appreciate that the temperature of a planet arises from a balance between energy absorbed from the star and energy radiated into space. You may want to discuss a planets energy balance at the end of the activity.

The practical activity

Students use thermometers to measure the temperature at different distances from a radiant heater. They should start at a good distance (around 70 cm) from the heater and move towards it. Warn them not allow their thermometers to get hotter than 100°C.

Students will probably realise that the temperature will rise as they approach the heater. It is more interesting if you can provide two thermometers per group: one with its bulb blackened using soot or vegetable black, the other with its bulb made shiny using aluminium leaf or foil. If this is not possible ask half the class to work with black thermometers and the other half with shiny thermometers and then pool results at the end.

The shiny bulb thermometer should show lower temperatures as it reflects radiation away. The blackened thermometer will absorb radiation better.

After the students have drawn their graphs, discuss their results and explain why temperature decreases with distance from the star/heater; the radiation 'spreads out' as it travels and so becomes less intense (see figure 2a). Also ask students how they think the graph would change for a more powerful heater/star. Other questions to help students link their results to planetary temperatures and habitable zones are provided on the worksheet. Answers to these questions are shown in Figure 2b.

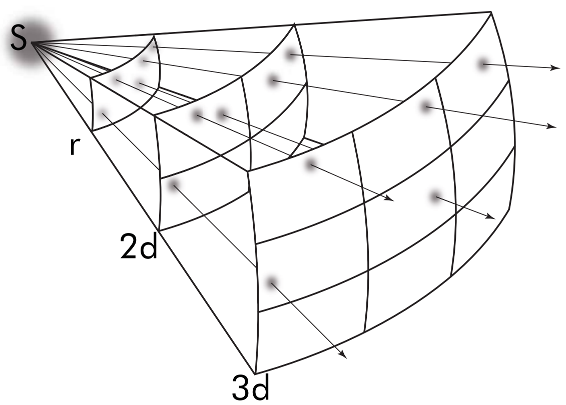
About the habitable zone

The habitable zone is usually defined as the region around a star within which an orbiting planet would be able to support liquid water at their surfaces. Colloquially it is also called the Goldilocks zone as it is neither too hot, nor too cold for life to evolve as we know it.

You could explain how astronomers are able to estimate the size of a star's habitable zone. Refer students to the planetary temperatures on the instruction sheet, both predicted and actual. Explain that the predicted temperatures (the dotted line) were calculated by assuming that the planets absorb all the radiation that falls on them; this is the (theoretical) equivalent of an ideal black thermometer. Ask them if they think treating the planets as black objects is a good model? Students should conclude that for most of the planets in the Solar System this seems to be a reasonable approximation. The differing results they obtained for black and silver thermometers should help them provide at least one reason why planets may be not be at the predicted temperature; planets that reflect more light absorb less of the incident solar energy. Another complication is a planet's atmosphere; particularly if it contains a high concentration of greenhouse gases.
For the Earth the (natural) greenhouse effect means it is about 30°C warmer than predicted. Venus has a much thicker atmosphere and the greenhouse effect is more extreme. Venus is 500°C warmer than predicted by black-body radiation calculations.

> ### Taking it further
> Once students have developed a better understanding of the habitable zones, you could ask them to use the internet to find out about how stars evolve over time. What implications does this have for the Sun's habitable zone? (As the Sun enters it red giant phase towards the end of its life it will become larger and brighter.
> The habitable zone will move further out.)

Figure 2a



The intensity of the radiation emitted by a source decreases with distance. For a star (a spherical source) doubling the distance results in a fourfold decrease in intensity.

Figure 2b

Student worksheet answers

1. (i)	Temperature decreases/goes down
(ii)	Venus
(iii)	Earth has a temperature between 0°C and 100°C / it is in the habitable zone
2. (i)	20°C (or whatever room temperature is).
	For a star lowest temperature will be -270°C (accept anything below -200°C)
(ii)	The shiny thermometer reflects (more infrared-radiation)