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

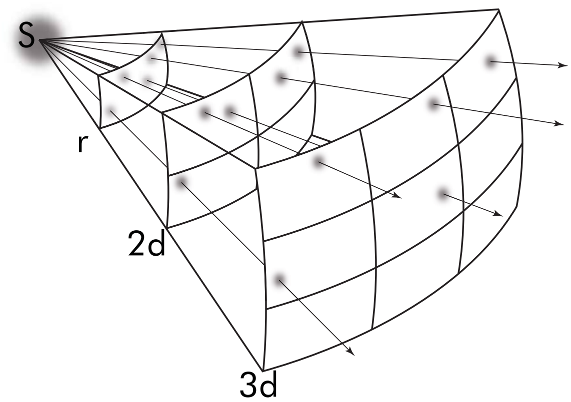
The habitable zone is usually defined as the region around a star within which an orbiting planet would be able to support liquid water at their surfaces. Colloquially it is also called the Goldilocks zone as it is neither too hot, nor too cold for life to evolve as we know it.

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

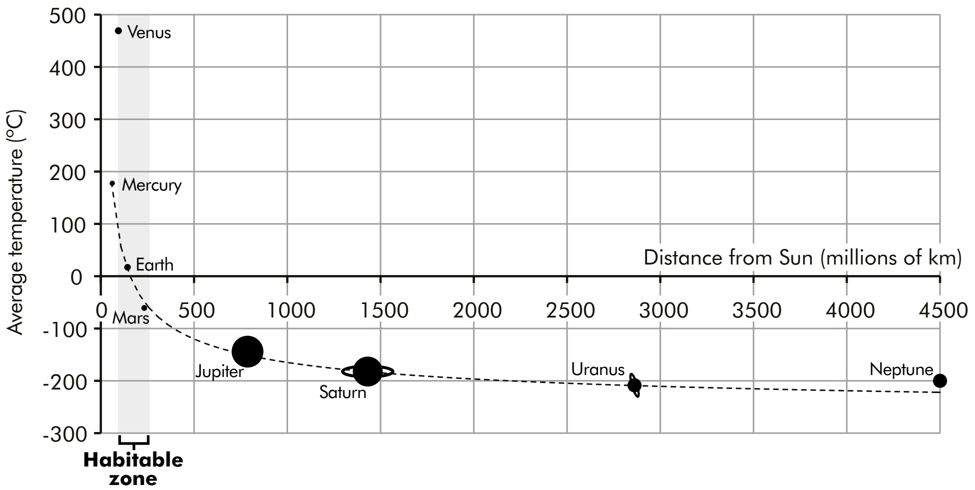
Student worksheet answers

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)

EXOPLANET PHYSICS

ESTIMATING TEMPERATURE: THE HABITABLE ZONE

If life is to exist on an exoplanet, it is likely to depend on liquid water. Water is liquid between 0°C and 100°C. If an exoplanet is too close to its star, it will be hotter than 100°C, and its water will boil away. Exoplanets that are colder than 0°C will be icy. For life to flourish, an exoplanet must be at just the right distance from its star, in the star's 'habitable zone'.



Note: The size of the planets is not shown to scale.

In this activity you will investigate how the temperature varies close to a radiant heat source. (This is your 'star'.) Find out how the temperature depends on its distance from the star for two thermometers (these are your 'planets').

What you'll need:

- Radiant heater or infrared light bulb
- 2 thermometers, one with a shiny bulb, the other with a blackened bulb.
- 2 clamps and stands
- Metre rule

Safety: Take care when working with a radiant heater. Do not get too close to it as you could be burned. If you are using a bulb do not look at it directly.

What you need to do:

1. Mount the shiny thermometer in a clamp. It should be vertical with its bulb at the same height as the heater/bulb. Repeat with the blackened thermometer.
2. Place each thermometer at a distance of 70 cm from the heater. Wait until the temperature has become steady. Record the distance and temperatures in a table.
3. Move the thermometers 5 cm closer to the heater. Record their temperatures when they are steady. Repeat at 5 cm intervals.

Safety: Take care that your temperature readings do not exceed 100°C (the limit of the thermometers)

4. Use the graph paper to draw a graph of temperature against distance for each thermometer. (Use the same graph axes for both.)

EXOPLANET PHYSICS

THE HABITABLE ZONE: TEMPERATURE-DISTANCE GRAPHS

1. The graph on the instruction sheet shows the average surface temperatures of the planets and their distances from the Sun.
   (i) How does temperature change with distance?

   (ii) Which planet does not fit this pattern?

   (iii) Explain why the Earth is the only planet likely to sustain life.

2. Your graph shows temperature and distance from a heater.
   (i) What was the lowest temperature reached in the experiment you carried out? What do you think the lowest temperature would be for temperature-distance graph for a star?

   (ii) Can you explain why the shiny and black thermometers give different results?

Taking it further A star's habitable zone changes over time. Use the internet to find out about the lifecycle of stars. What will happen to the Sun in the future? How will this change the habitable zone?