A-LEVEL PHYSICS • EXERCISE SHEET

# 25.1 Standard candles

Name: ______________ Class: __________ Date: ____________ **Total: 25 marks**

**KEY WORDS** luminosity 光度 • standard candle 标准烛光 • radiant flux intensity 辐射通量密度 • power 功率 • inverse-square law 平方反比定律

## Objective

Build the skills to answer exam questions on **luminosity** and **standard candles**.

**You must be able to:**

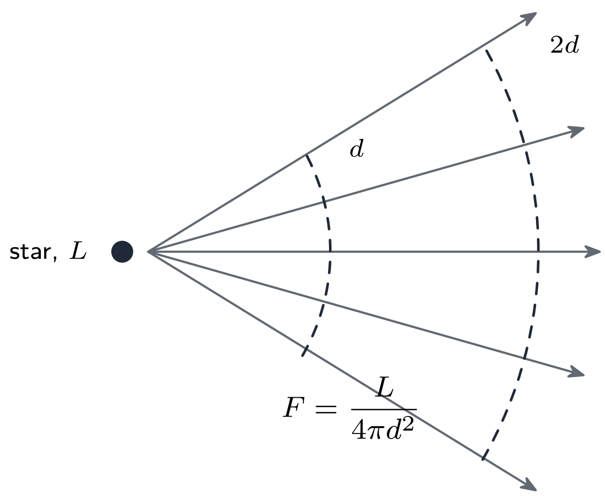
- use **luminosity** and the **inverse-square law** $F = \dfrac{L}{4\pi d^2}$
- explain how **standard candles** give distances

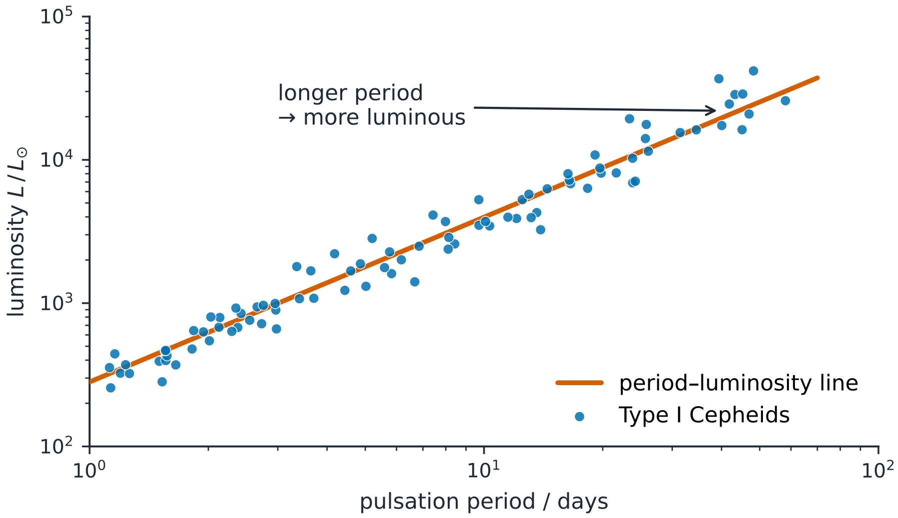
## 1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

### ■ Luminosity and flux

The **luminosity** $L$ is the total power a star radiates. At distance $d$ this power is spread over a sphere of area $4\pi d^2$, so the **radiant flux intensity** is:






Cepheid: longer period ⇒ brighter · standard candles

*Cepheids as standard candles*

$$F = \frac{L}{4\pi d^2}, \qquad d = \sqrt{\frac{L}{4\pi F}}.$$

A **standard candle** is an object of **known luminosity**; measuring its flux $F$ gives its distance.

**Worked example.** Sun $L = 3.8 \times 10^{26}$ W, $d = 1.5 \times 10^{11}$ m: $F = \dfrac{3.8 \times 10^{26}}{4\pi(1.5 \times 10^{11})^2} = 1.4 \times 10^3$ W m$^{-2}$.

## 2 Practice

Now apply the methods above.

**2.1** Define the **luminosity** of a star. [1]

**2.2** Write the **inverse-square law** for radiant flux intensity. [1]

**2.3** The Sun's luminosity is $3.8 \times 10^{26}$ W. Find the flux at Earth ($d = 1.5 \times 10^{11}$ m). [2]

**2.4** State what a **standard candle** is. [1]

## 3 Exam-style questions

**3.1** If the distance to a star **doubles**, the radiant flux intensity becomes: [1]

- **A** twice as large
- **B** half as large
- **C** one quarter as large
- **D** four times as large

**3.2** A standard candle has luminosity $4.0 \times 10^{28}$ W. Its measured flux is $2.0 \times 10^{-9}$ W m$^{-2}$. Calculate its **distance**. [3]

**3.3** An astronomer wants the distance to a galaxy several million light-years away. Explain how a **standard candle** in that galaxy makes this possible, giving the quantity that must be measured, the quantity that must be known in advance, and the assumption the method depends on. [4]

**3.4** A star has a luminosity of $6.5 \times 10^{27}$ W. Its radiant flux intensity measured at the Earth is $2.9 \times 10^{-9}$ W m$^{-2}$.

(a) **Define** the **luminosity** of a star and the **radiant flux intensity** received from it. [2]

(b) **Determine** the distance of the star from the Earth. [3]

(c) The star's surface temperature is 9600 K. Taking $\sigma = 5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$, **determine** its radius. [3]

(d) A second star at the same distance has the same radius but **half** the surface temperature. **Determine** the flux intensity received from it, as a fraction of that from the first star. [2]

(e) **Suggest** why the flux intensity actually measured at the Earth may be **lower** than the calculation predicts. [2]

## Solutions

**2.1** The **total power** of radiation emitted by the star (in all directions).

**2.2** $F = \dfrac{L}{4\pi d^2}$.

**2.3** $F = \dfrac{3.8 \times 10^{26}}{4\pi(1.5 \times 10^{11})^2} = 1.4 \times 10^3\ \mathrm{W\ m^{-2}}$.

**2.4** An object of **known luminosity**.

**3.1** **C** — one quarter.

**3.2** $d = \sqrt{\dfrac{L}{4\pi F}} = \sqrt{\dfrac{4.0 \times 10^{28}}{4\pi(2.0 \times 10^{-9})}} = 1.3 \times 10^{18}$ m.

**3.3** Find an object in that galaxy whose **luminosity is known in advance** from its type — a Type Ia supernova or a Cepheid variable — which is what ”standard candle” means. **Measure** the radiant flux intensity $F$ arriving at Earth. Then $F = \dfrac{L}{4\pi d^2}$ gives $d = \sqrt{\dfrac{L}{4\pi F}}$. The method assumes the radiation spreads out evenly and nothing absorbs it on the way, so the inverse-square law holds over that distance.

**3.4** (a) **Luminosity** is the total power radiated by the star in all directions; **radiant flux intensity** is the power received per unit area at the observer, perpendicular to the direction of the star.
(b) $F = \dfrac{L}{4\pi d^2}$, so $d = \sqrt{\dfrac{L}{4\pi F}} = \sqrt{\dfrac{6.5 \times 10^{27}}{4\pi \times 2.9 \times 10^{-9}}} = 4.2 \times 10^{17}$ m.
(c) $L = 4\pi r^2 \sigma T^4$, so $r = \sqrt{\dfrac{L}{4\pi\sigma T^4}} = \sqrt{\dfrac{6.5 \times 10^{27}}{4\pi(5.67 \times 10^{-8})(9600)^4}} = 3.3 \times 10^7$ m.
(d) At the same radius and distance, $F \propto T^4$, so halving $T$ gives $\left(\frac{1}{2}\right)^4 = \dfrac{1}{16}$ of the flux intensity.
(e) Interstellar dust and gas **absorb and scatter** some of the light on the way; and the Earth’s atmosphere absorbs part of it too, so a ground-based measurement is lower still.