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:

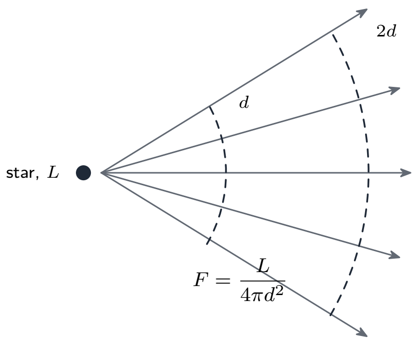
- use **luminosity** and the **inverse-square law** $F = \dfrac{L}{4\pi d^2}$
- explain how **standard candles** give distances

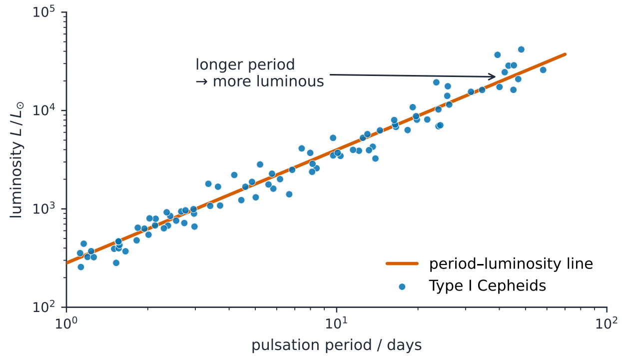
1 Worked examples

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 3.8×10^{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 4.0×10^{28} W. Its measured flux is 2.0×10^{-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 6.5×10^{27} W. Its radiant flux intensity measured at the Earth is 2.9×10^{-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 $\sigma = 5.67 \times 10^{-8}$ 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

Each answer shows the steps, then the **result**.

2.1

- the **total power** of radiation emitted by the star (in all directions)

2.2

- $F = L/(4\pi d^2)$

2.3

- $F = L/(4\pi d^2)$

$$F = \frac{3.8 \times 10^{26}\ \text{W}}{4\pi(1.5 \times 10^{11}\ \text{m})^2} = \mathbf{1.4 \times 10^3}\ \text{W m}^{-2}$$

2.4

- an object of **known luminosity**

3.1 C

- $F \propto 1/d^2$, so doubling d makes F **one quarter**

3.2

- $d = \sqrt{L/(4\pi F)}$

$$d = \sqrt{\frac{4.0 \times 10^{28}\ \text{W}}{4\pi(2.0 \times 10^{-9}\ \text{W m}^{-2})}} = \mathbf{1.3 \times 10^{18}}\ \text{m}$$

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
- **measure** the radiant flux intensity F arriving at Earth
- then $F = L/(4\pi d^2)$ gives $d = \sqrt{L/(4\pi F)}$
- the method assumes the radiation spreads out evenly and nothing absorbs it on the way

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) $F = L/(4\pi d^2)$, so $d = \sqrt{L/(4\pi F)}$

$$d = \sqrt{\frac{6.5 \times 10^{27}\ \text{W}}{4\pi \times 2.9 \times 10^{-9}\ \text{W m}^{-2}}} = \mathbf{4.2 \times 10^{17}}\ \text{m}$$

(c) $L = 4\pi r^2 \sigma T^4$, so $r = \sqrt{L/(4\pi\sigma T^4)}$

$$r = \sqrt{\frac{6.5 \times 10^{27}\ \text{W}}{4\pi(5.67 \times 10^{-8}\ \text{W m}^{-2}\,\text{K}^{-4})(9600\ \text{K})^4}} = \mathbf{3.3 \times 10^9}\ \text{m}$$

(d) at the same radius and distance, $F \propto T^4$

- so halving T gives $(1/2)^4 = \mathbf{1/16}$ 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