Week 55

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Physics Name: ____________ Score: ______

1. The luminosity of a star is:
   - ☐ the total power it radiates
   - ☐ its surface temperature
   - ☐ its distance from Earth
   - ☐ its mass
2. Hotter stars have their spectral peak (Wien's law) at a ______ wavelength.

   ____

3. Redshift means a galaxy's spectral lines are shifted to:
   - ☐ longer wavelengths (it is moving away)
   - ☐ shorter wavelengths (it is approaching)
   - ☐ no change at all
   - ☐ a higher temperature
4. The flux received from a star falls as 1 over the distance ______.

   ____

5. A star's spectrum peaks at $\lambda_{\max} = 500$ nm. What is its surface temperature? ($b = 2.9 \times 10^{-3}$ m · K)

   ____________ K

6. A galaxy's lines show $\dfrac{\Delta\lambda}{\lambda} = 0.020$. What is its recession speed, as a fraction of c?

   ____

7. A star gives a flux of 100 $\dfrac{\mathrm{W}}{\mathrm{m}^2}$ at distance d. What is the flux at $3d$?

   ____________ $\mathrm{W/m^2}$

8. The Stefan–Boltzmann law gives a star's luminosity as:
   - ☐ $4\pi\sigma r^2 T^4$
   - ☐ $4\pi\sigma r T$
   - ☐ $\sigma r^2 T$
   - ☐ $4\pi r^2 T^2$

9. Almost all distant galaxies are redshifted, which shows the Universe is expanding.

☐ True ☐ False

10. A standard candle is an object whose ______ is known from its type.

☐ luminosity

☐ distance

☐ temperature

☐ mass

A-Level Physics

1. **the total power it radiates**

   Luminosity L is the energy radiated per second in all directions (watts).

2. **shorter**

   $\lambda_{\text{max}}T = b$, so a higher T means a smaller λ_{max} — toward the blue.

3. **longer wavelengths (it is moving away)**

   A receding source stretches the wavelengths — a redshift, with $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$.

4. **squared**

   $F = \dfrac{L}{4\pi d^2}$ — the inverse-square law.

5. **5800 K**

   $T = \dfrac{b}{\lambda_{\text{max}}} = \dfrac{2.9 \times 10^{-3}}{500 \times 10^{-9}} \approx 5800$ K — about the Sun.

6. **0.02**

   For $v \ll c$, $\dfrac{v}{c} = \dfrac{\Delta\lambda}{\lambda} = 0.020$.

7. **11.1 W/m^2**

   Inverse-square: $\dfrac{100}{3^2} = \dfrac{100}{9} \approx 11\ \dfrac{\text{W}}{\text{m}^2}$.

8. $4\pi\sigma r^2 T^4$

   $L = 4\pi\sigma r^2 T^4$ — strongly dependent on both radius and temperature.

9. **True**

   They are moving apart on average — the space between them is stretching.

10. **luminosity**

    Knowing L (without first knowing distance) lets you get the distance from the measured flux.

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:

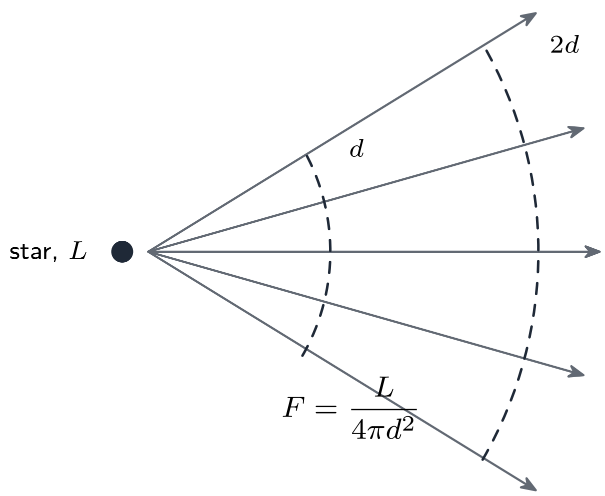
- use **luminosity** and the **inverse-square law** $F = \dfrac{L}{4\pi d^2}$
- explain how **standard candles** give distances

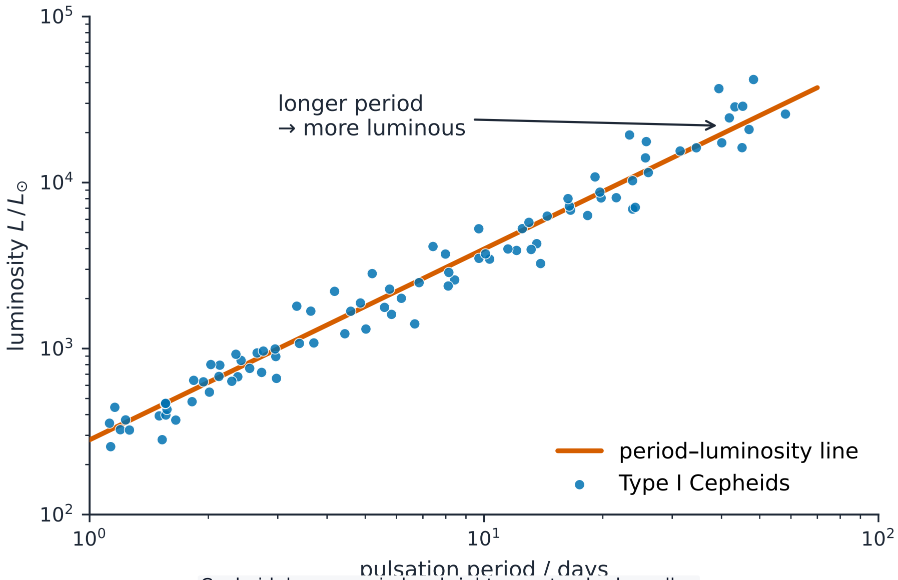
1 Worked examples

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

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.

10 **(a)** **(i)** State what is meant by the luminosity of a star.

....

.... [1]

(ii) Explain how standard candles are used to determine the distance to a galaxy.

....

....

....

....

....

.... [3]

(b) The Sun rotates on its axis. Points X, Y and Z are on the equator of the Sun as shown in Fig. 10.1.

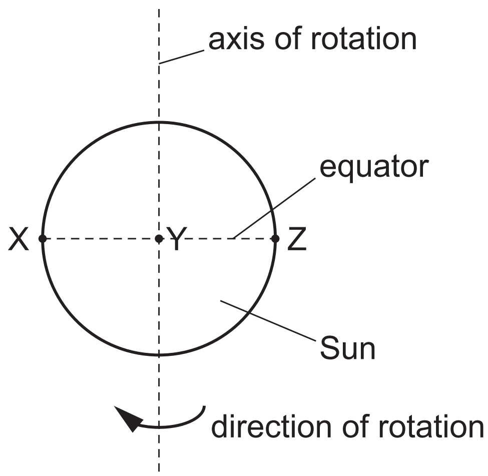


Fig. 10.1

The wavelengths of light from points X and Y are observed and recorded in Table 10.1.

Table 10.1

observed wavelength from X / nm	observed wavelength from Y / nm
656.2877	656.2831

(i) The Sun rotates with a period of 2.07×10^{6} s.

Show that the radius of the Sun is 6.93×10^{8} m.

[3]

(ii) State and explain how the expected wavelength of the light observed from Z compares with the emitted wavelength.

....

....

.... [2]

(iii) The luminosity of the Sun is 3.8×10^{26} W.

Use the information in **(b)(i)** to calculate the surface temperature of the Sun.

temperature = ... K [2]

[Total: 11]

25.2 Stellar radii

Name: ______________ Class: __________ Date: ____________ **Total: 26 marks**

KEY WORDS stefan–boltzmann law 斯特藩-玻尔兹曼定律 • wien's displacement law 维恩位移定律 • temperature 温度 • wavelength 波长 • blackbody 黑体

Objective

Build the skills to answer exam questions on **stellar temperature and radius**.

You must be able to:

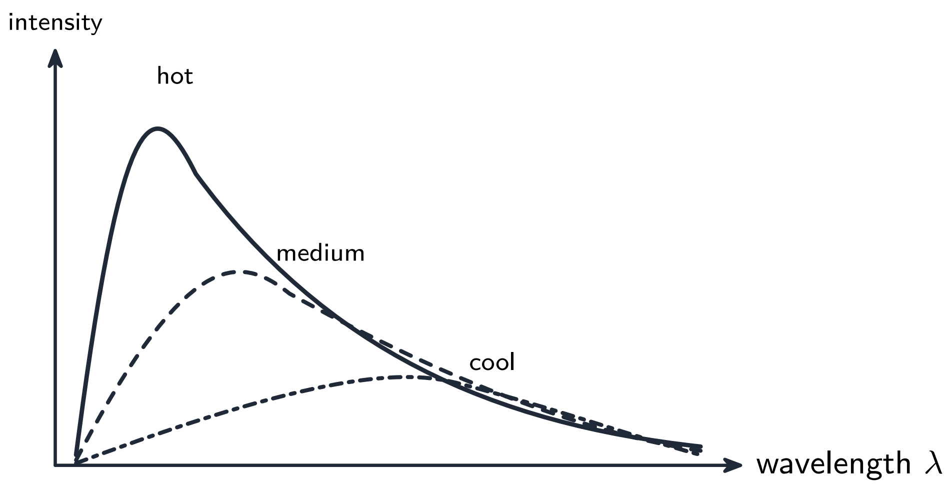
- use **Wien's law** $\lambda_{\max}T = \text{constant}$
- use the **Stefan–Boltzmann law** $L = 4\pi\sigma r^2T^4$
- combine them to estimate a star's **radius**

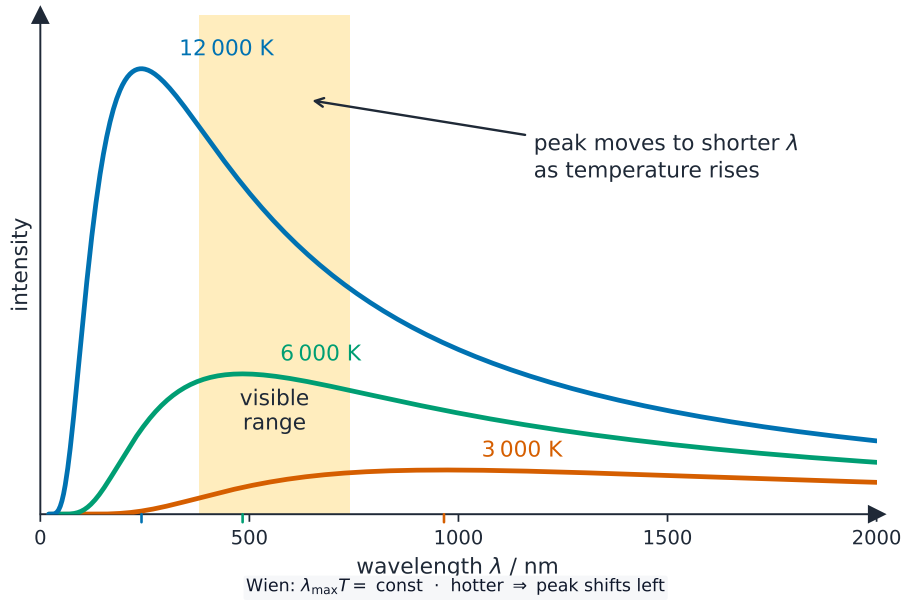
1 Worked examples

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.

■ Wien's law

A star radiates a **black-body** spectrum; a **hotter** star radiates more and peaks at a **shorter** wavelength:





A blackbody curve and Wien law

$$\lambda_{\text{max}} T = b, \qquad b = 2.90 \times 10^{-3} \text{ m K}.$$

■ Stefan–Boltzmann law and radius

$$L = 4\pi\sigma r^2 T^4, \qquad \sigma = 5.67 \times 10^{-8} \text{ W m}^{-2}\,\text{K}^{-4}.$$

Find T from Wien's law, then $r = \sqrt{\dfrac{L}{4\pi\sigma T^4}}$.

Worked example. $\lambda_{\text{max}} = 500$ nm: $T = \dfrac{2.90 \times 10^{-3}}{500 \times 10^{-9}} = 5800$ K.

2 Practice

Now apply the methods above.

2.1 Write **Wien's displacement law**. [1]

2.2 A star's spectrum peaks at 500 nm. Find its surface **temperature**. [2]

2.3 Write the **Stefan–Boltzmann law**. [1]

2.4 State how λ_{max} changes for a **hotter** star. [1]

3 Exam-style questions

3.1 A **hotter** star has its peak emission at a: [1]

- **A** longer wavelength
- **B** shorter wavelength
- **C** the same wavelength
- **D** no peak

3.2 A star's black-body spectrum peaks at 290 nm. Calculate its surface **temperature**. [2]

3.3 Star P has radius 7.0×10^8 m and surface temperature 5800 K. Star Q has the **same** surface temperature but **three times** the radius. ($\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}.)

(a) Calculate the luminosity of star P. [2]

(b) Without further calculation, state and explain the luminosity of star Q. [2]

3.4 Outline how a star's **radius** can be estimated from its spectrum. [2]

3.5 The light from a distant star is analysed. Its intensity is greatest at a wavelength of 580 nm, and its radiant flux intensity at the Earth is 3.6×10^{-10} W m^{-2}. The star is 8.4×10^{17} m away. Take Wien's displacement constant as 2.90×10^{-3} m K and $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}.

(a) **State** Wien's displacement law. [2]

(b) **Determine** the surface temperature of the star. [2]

(c) **Determine** the luminosity of the star. [2]

(d) **Determine** the radius of the star, and **compare** it with the Sun's radius of 7.0×10^8 m. [3]

(e) A second star has the **same** luminosity but a surface temperature twice as high. **Determine** the ratio $\dfrac{\text{radius of the second star}}{\text{radius of the first}}$, and **state** what kind of star that suggests. [3]

Solutions

2.1 $\lambda_{\max}T = \text{constant}$ (or $\lambda_{\max} \propto 1/T$).

2.2 $T = \dfrac{b}{\lambda_{\max}} = \dfrac{2.90 \times 10^{-3}}{500 \times 10^{-9}} = 5800$ K.

2.3 $L = 4\pi\sigma r^2 T^4$.

2.4 It is **shorter** ($\lambda_{\max} \propto 1/T$).

3.1 **B** — shorter wavelength.

3.2 $T = \dfrac{2.90 \times 10^{-3}}{290 \times 10^{-9}} = 1.0 \times 10^4$ K.

3.3 (a) $L = 4\pi r^2\sigma T^4 = 4\pi(7.0 \times 10^8)^2(5.67 \times 10^{-8})(5800)^4 = 4.0 \times 10^{26}$ W.
(b) $L \propto r^2$ at fixed temperature, so tripling the radius makes the luminosity $3^2 = 9$ times larger: 3.6×10^{27} W.

3.4 Find T from $\lambda_{\max}$ (Wien's law) and measure L; then use the Stefan–Boltzmann law $L = 4\pi\sigma r^2 T^4$ to solve for r.

3.5 (a) The wavelength at which the emitted intensity is a **maximum** is **inversely proportional** to the thermodynamic temperature of the body: $\lambda_{\max}T = \text{constant}$.
(b) $T = \dfrac{2.90 \times 10^{-3}}{580 \times 10^{-9}} = 5.0 \times 10^3$ K.
(c) $L = 4\pi d^2 F = 4\pi(8.4 \times 10^{17})^2 \times 3.6 \times 10^{-10} = 3.2 \times 10^{27}$ W.
(d) $r = \sqrt{\dfrac{L}{4\pi\sigma T^4}} = \sqrt{\dfrac{3.19 \times 10^{27}}{4\pi(5.67 \times 10^{-8})(5000)^4}} = 7.6 \times 10^8$ m; that is about 1.1 times the Sun's radius, so it is a star of very similar size.
(e) At fixed luminosity r^2T^4 is constant, so $r \propto \dfrac{1}{T^2}$; doubling T gives a radius $\dfrac{1}{4}$ as large, i.e. a ratio of 0.25. A star of the same luminosity packed into a quarter of the radius and much hotter suggests a **white dwarf** rather than a main-sequence star.

10 **(a)** State Hubble's law.

....

....

.... [2]

(b) A star in a distant galaxy emits radiation that has a maximum intensity of emission at a wavelength of 4.62×10^{-7} m.

Observations of the galaxy made on the Earth detect the maximum intensity of emission from the star at a wavelength of 4.91×10^{-7} m.

(i) Explain why the observed wavelength and the emitted wavelength have different values.

....

....

.... [2]

(ii) Calculate the speed of the star relative to the Earth.

speed = ... $m\,s^{-1}$ [2]

(iii) The wavelength of maximum intensity of emission is used to determine a value for the surface temperature of the star.

Explain how the temperature determined using the observed wavelength compares with the true value of temperature determined using the emitted wavelength.

....

....

.... [2]

(c) A value for the Hubble constant is $2.3 \times 10^{-18}\,s^{-1}$.

Use your answer in **(b)(ii)** to determine the distance of the star in **(b)** from the Earth.

distance = ... m [2]

[Total: 10]

10 **(a)** State Hubble's law.

....

....

.... [2]

(b) A star in a distant galaxy emits radiation that has a maximum intensity of emission at a wavelength of 4.62×10^{-7} m.

Observations of the galaxy made on the Earth detect the maximum intensity of emission from the star at a wavelength of 4.91×10^{-7} m.

(i) Explain why the observed wavelength and the emitted wavelength have different values.

....

....

.... [2]

(ii) Calculate the speed of the star relative to the Earth.

speed = ... $m\,s^{-1}$ [2]

(iii) The wavelength of maximum intensity of emission is used to determine a value for the surface temperature of the star.

Explain how the temperature determined using the observed wavelength compares with the true value of temperature determined using the emitted wavelength.

....

....

.... [2]

(c) A value for the Hubble constant is $2.3 \times 10^{-18}\,s^{-1}$.

Use your answer in **(b)(ii)** to determine the distance of the star in **(b)** from the Earth.

distance = ... m [2]

[Total: 10]

A-LEVEL PHYSICS • EXERCISE SHEET

25.3 Hubble's law and the Big Bang theory

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

KEY WORDS redshift 红移 • hubble's law 哈勃定律 • big bang 大爆炸 • recession 退行 • spectral lines 谱线

Objective

Build the skills to answer exam questions on **redshift**, **Hubble's law** and the **Big Bang**.

You must be able to:

- use the **redshift** $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$
- use **Hubble's law** $v \approx H_0 d$
- explain how redshift and Hubble's law support the **Big Bang**

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.

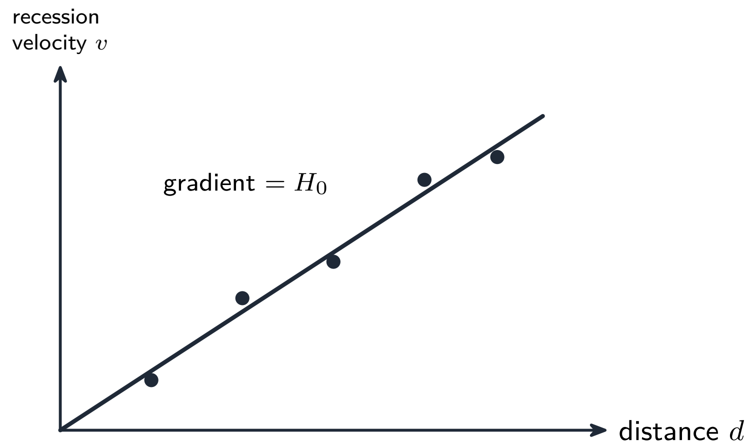
Redshift

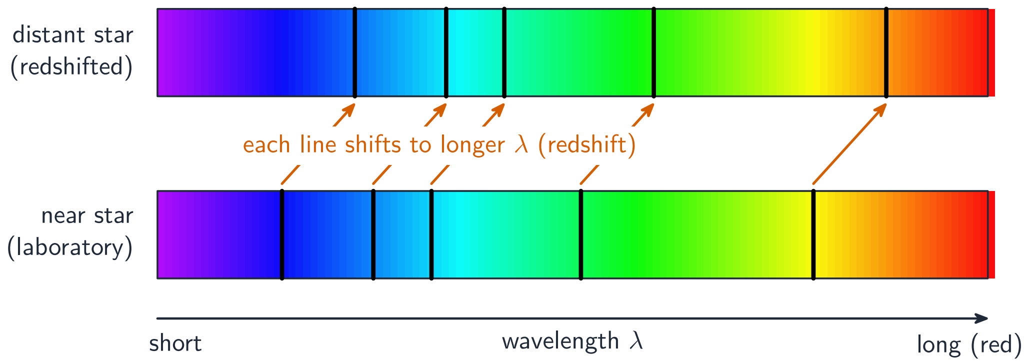
The spectral lines of distant galaxies are at **longer** wavelengths than in the lab — a **redshift**, showing the galaxy is moving **away**. For $v \ll c$:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}, \qquad \Delta\lambda = \lambda_{\text{observed}} - \lambda_{\text{emitted}}.$$

Hubble's law

The recession speed is **proportional to distance**:





Redshift in a galaxy spectrum

$$v \approx H_0 d.$$

Every galaxy moving away (faster if further) means the Universe is **expanding** — so in the past it was smaller and denser, leading to the idea that it began from a single point: the **Big Bang**.

2 Practice

Now apply the methods above.

2.1 State what is meant by **redshift**. [1]

2.2 Write the **redshift** equation linking $\Delta\lambda$, λ and v. [1]

2.3 Write **Hubble's law**. [1]

2.4 State what the redshift of distant galaxies tells us about the Universe. [1]

3 Exam-style questions

3.1 The redshift of distant galaxies is evidence that: [1]

- **A** the Universe is static
- **B** the Universe is expanding
- **C** galaxies are approaching us
- **D** light slows down over distance

3.2 A spectral line emitted at 4.62×10^{-7} m is observed at 4.91×10^{-7} m. Calculate the **recession velocity** of the source. [3]

3.3 A galaxy recedes at 2.0×10^{7} m s^{-1}. Taking $H_0 = 2.2 \times 10^{-18}$ s^{-1}, calculate its

distance. [2]

3.4 Explain how **Hubble's law** leads to the **Big Bang** theory. [3]

3.5 A spectral line emitted at 486.1 nm in the laboratory is observed at 492.6 nm in the light from a distant galaxy. Take $c = 3.00 \times 10^{8}$ m s^{-1} and the Hubble constant as 2.3×10^{-18} s^{-1}.

(a) **State** Hubble's law. [2]

(b) **Explain** why the observed and emitted wavelengths differ. [2]

(c) **Determine** the speed of the galaxy relative to the Earth, and state whether it is approaching or receding. [3]

(d) **Determine** the distance of the galaxy from the Earth. [2]

(e) **Suggest** why an estimate of the age of the Universe can be made from the Hubble constant, and **state** one assumption that estimate depends on. [3]

Solutions

2.1 The **increase in wavelength** of light from a source moving **away** from the observer.

2.2 $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$.

2.3 $v \approx H_0 d$.

2.4 It is **expanding** (galaxies are moving apart).

3.1 **B** — the Universe is expanding.

3.2 $\Delta\lambda = 4.91 \times 10^{-7} - 4.62 \times 10^{-7} = 0.29 \times 10^{-7}$ m; $v = \dfrac{\Delta\lambda}{\lambda}c = \dfrac{0.29 \times 10^{-7}}{4.62 \times 10^{-7}}(3.0 \times 10^{8})$ $= 1.9 \times 10^{7}$ m s^{-1}.

3.3 $d = \dfrac{v}{H_0} = \dfrac{2.0 \times 10^{7}}{2.2 \times 10^{-18}} = 9.1 \times 10^{24}$ m.

3.4 All galaxies are moving **away**, faster the further they are, so the Universe is **expanding** — in the past it was smaller and denser; extrapolating back, everything began from a single point/event — the **Big Bang**.

3.5 (a) The **recession speed** of a galaxy is **directly proportional to its distance** from us, $v = H_0 d$, for galaxies far enough away.
(b) The galaxy is **moving away** from us, so each wave takes slightly longer to reach us than the one before; the waves are stretched, the observed wavelength is longer, and the light is **redshifted**.
(c) $\dfrac{\Delta\lambda}{\lambda} = \dfrac{492.6 - 486.1}{486.1} = 0.01337$; $v = \dfrac{\Delta\lambda}{\lambda}c = 0.01337 \times 3.00 \times 10^{8} = 4.0 \times 10^{6}$ m s^{-1}, **receding** — the wavelength has increased.
(d) $d = \dfrac{v}{H_0} = \dfrac{4.01 \times 10^{6}}{2.3 \times 10^{-18}} = 1.7 \times 10^{24}$ m.
(e) If every galaxy has been moving apart at a constant speed since the beginning, the time since they were all together is $\dfrac{d}{v} = \dfrac{1}{H_0}$, which gives about 4.3×10^{17} s, roughly 14 billion years. It assumes the expansion rate has **not changed** over that time.

10 **(a)** State Hubble's law.

....

....

.... [2]

(b) A star in a distant galaxy emits radiation that has a maximum intensity of emission at a wavelength of 4.62×10^{-7} m.

Observations of the galaxy made on the Earth detect the maximum intensity of emission from the star at a wavelength of 4.91×10^{-7} m.

(i) Explain why the observed wavelength and the emitted wavelength have different values.

....

....

.... [2]

(ii) Calculate the speed of the star relative to the Earth.

speed = ... $m\,s^{-1}$ [2]

(iii) The wavelength of maximum intensity of emission is used to determine a value for the surface temperature of the star.

Explain how the temperature determined using the observed wavelength compares with the true value of temperature determined using the emitted wavelength.

....

....

.... [2]

(c) A value for the Hubble constant is $2.3 \times 10^{-18}\,s^{-1}$.

Use your answer in **(b)(ii)** to determine the distance of the star in **(b)** from the Earth.

distance = ... m [2]

[Total: 10]