Cambridge IGCSE · Physics 0625 · Notes

Stars and the Universe

Read online at **pastopic.com/cambridge/physics-0625/notes/stars-and-the-universe**

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Read first: **General properties of waves**, **Electromagnetic spectrum**, **The Earth and the Solar System**

What you need to know

This topic zooms out from the Solar System to stars, galaxies and the whole Universe. It uses wavelength from General properties of waves, the regions of the electromagnetic spectrum, and $\text{speed} = \text{distance} \div \text{time}$ with the speed of light from The Earth and the Solar System. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

The Sun as a star

1. **Know that the Sun is a medium-sized star**, made mostly of **hydrogen and helium**, and that it gives out most of its energy as **infrared, visible light and ultraviolet**.
2. **Extended only:** know that stars are powered by **nuclear reactions** that release energy, and that in a stable star these reactions are the **fusion of hydrogen into helium**.

Stars and galaxies

3. **State that** each galaxy is made of many billions of stars; the Sun is one star in the galaxy called the **Milky Way**; the other stars of the Milky Way are much further from the Earth than the Sun is.
4. **State that** astronomical distances can be measured in **light-years**, where one light-year is the distance light travels in (the vacuum of) space in one year.
5. **Extended only:** know that one light-year is 9.5×10^{15} m.
6. **Extended only:** describe the **life cycle of a star**: cloud of gas and dust → protostar → stable star → red giant or red supergiant → planetary nebula and white dwarf, or supernova, nebula and neutron star or black hole → new stars and planets.

The Universe

7. **Know that the Milky Way is one of many billions of galaxies** in the Universe, and that it is about **100 000 light-years** across.
8. **Describe redshift** as an increase in the observed wavelength of electromagnetic radiation from stars and galaxies that are moving away (receding).
9. **Know that light from distant galaxies is redshifted** compared with light given out on the Earth, and that this is evidence that the Universe is **expanding** and supports the **Big Bang Theory**.

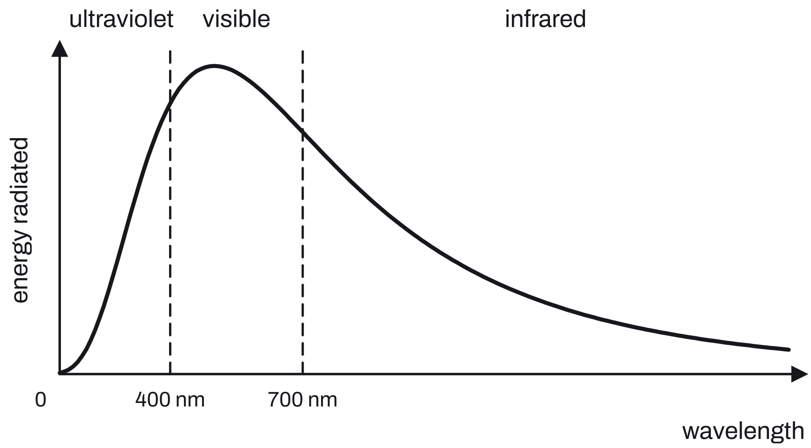
10. **Extended only:** know that **cosmic microwave background radiation (CMBR)**, microwaves of a particular frequency, is observed at all points in space around us; explain that it was produced shortly after the Universe formed and has been stretched into the microwave region as the Universe expanded.
11. **Extended only:** know that a galaxy's speed v away from the Earth is found from the **change in wavelength** of its starlight (redshift), and its distance d from the **brightness of a supernova** in it.
12. **Extended only:** define the **Hubble constant** $H_0 = \dfrac{v}{d}$, recall and use it, and know that its current estimate is 2.2×10^{-18} per second.
13. **Extended only:** know that $\dfrac{d}{v} = \dfrac{1}{H_0}$ is an estimate of the **age of the Universe**, and that this is evidence that all the matter in the Universe was once at a single point.

Understand it

The Sun is an ordinary star

A **star** is a huge ball of hot gas that gives out its own light. The Sun is a star of **medium size**: many stars are much bigger, many much smaller. It is made mostly of **hydrogen** (most of its mass) and **helium**, with small amounts of heavier elements.

The Sun gives out electromagnetic radiation across the spectrum, but almost all of its energy is in three neighbouring regions: **infrared**, **visible light** and **ultraviolet**. Only tiny amounts come out as radio waves, microwaves, X-rays or gamma rays.



On a graph like this, ultraviolet is always on the **short-wavelength** side of visible light and infrared on the **long-wavelength** side, because that is their order in the electromagnetic spectrum. The Sun gives out more energy as infrared than as ultraviolet.

Extended only: what powers a star

Deep in the centre of a star the temperature is millions of degrees. There, **hydrogen nuclei join together (fuse) to form helium nuclei**. This is **nuclear fusion**, and it releases a great deal of energy, which travels out to the star's surface and is radiated into space as electromagnetic radiation. It is **fusion** (small nuclei joining), not fission (a large nucleus splitting), and it is **not burning**: no oxygen is involved.

Galaxies, the Milky Way and the Universe

- A **galaxy** is a huge collection of **many billions of stars**, held together by gravity.
- Our Sun is one star in the galaxy called the **Milky Way**. The Milky Way is about **100 000 light-years** in diameter.
- All the other stars in the Milky Way are **much further away** from us than the Sun is. The nearest one is a few light-years away; the Sun is about 8 light-*minutes* away.
- The **Universe** is made of **many billions of galaxies**; the Milky Way is just one of them.

From smallest to largest: planet → star (with its planets, a solar system) → galaxy → Universe.

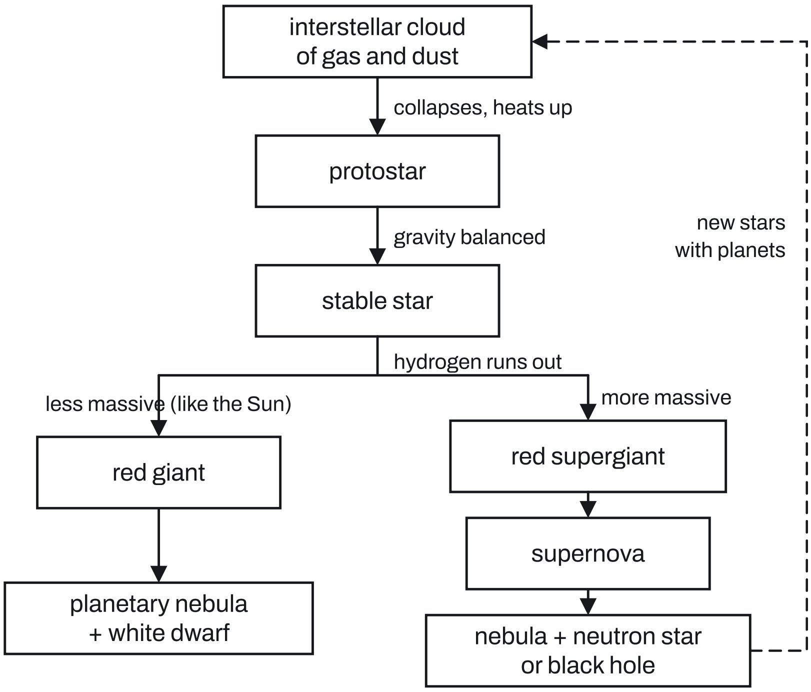
Light-years

Distances between stars are so large that metres are awkward. Astronomers use the **light-year**: the **distance** light travels through (the vacuum of) space in **one year**. Despite the "year" in its name, it is a distance, not a time.

$$1 \text{ light-year} = c \times t = 3.0 \times 10^8 \text{ m/s} \times (365 \times 24 \times 3600 \text{ s}) = 9.5 \times 10^{15} \text{ m}.$$

That is 9.5×10^{12} km. Because light takes one year to cross each light-year, light from a star 50 light-years away left it 50 years ago: we see the star **as it was** 50 years ago.

Extended only: the life cycle of a star



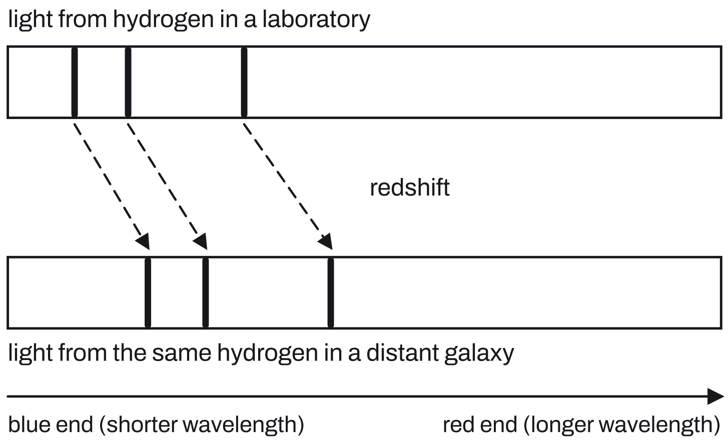
1. **Birth.** A star forms from an **interstellar cloud of gas and dust** that contains **hydrogen** (a stellar nebula).
2. **Protostar.** Gravity between the particles pulls the cloud inwards. As it **collapses**, it **heats up**. A collapsing, warming cloud like this is a **protostar**.
3. **Stable star.** When the centre is hot enough, hydrogen fusion starts. The star becomes **stable** when the **inward force of gravity** is **balanced** by an **outward force due to the high temperature** in its centre. It stays like this for most of its life (the Sun is at this stage).
4. **Running out. Every** star eventually runs out of hydrogen fuel in its centre.
5. **Giant.** When most of the hydrogen in the centre has become helium, the star **expands**. Most stars become **red giants**; more massive stars become **red supergiants**.
6. **The end of a less massive star (like the Sun):** the red giant throws off its outer layers as a **planetary nebula**, leaving a small, hot **white dwarf** at its centre.
7. **The end of a more massive star:** the red supergiant **explodes as a supernova**. This forms a **nebula** containing hydrogen and **new, heavier elements**, and leaves a **neutron star** or a **black hole** at its centre.
8. **Recycling.** The nebula from a supernova may collapse again to form **new stars with orbiting planets**.

Only red **supergiants** become supernovae. A red giant never does, and a white dwarf never becomes a black hole.

Redshift

When a source of waves moves away from you, the waves you receive are stretched: their **wavelength is longer** than when they were given out. For light this moves every line in the spectrum towards the **red** end, so it is called **redshift**.

Redshift is an increase in the **observed wavelength** of electromagnetic radiation from stars and galaxies that are **moving away** (receding). The speed of light does not change; the wavelength goes up and so the frequency goes down.



Astronomers compare the lines in a galaxy's light with the same lines from the same element (such as hydrogen) in the laboratory. Light from **distant galaxies** is **always redshifted**, so they are all moving away from us. And the **further away** a galaxy is, the **bigger its redshift**, so the **faster** it is moving away.

The simplest explanation is that **the Universe is expanding**: space itself is stretching, carrying the galaxies apart from each other. Run the expansion backwards and everything gets closer and closer, until all the matter was together at a single point. That is the **Big Bang Theory**: the Universe began from a single point and has been expanding ever since. Redshift is evidence for it.

Extended only: cosmic microwave background radiation (CMBR)

Wherever astronomers point a microwave telescope, at every point in the sky, they detect faint **microwave radiation of a particular frequency**. This is the **cosmic microwave background radiation** (CMBR).

It was produced **shortly after the Universe formed**, when the Universe was very hot and dense and the radiation had a very short wavelength. As the Universe **expanded**, the radiation was **stretched** with it (redshifted), so its wavelength **increased**, until it reached the **microwave** region we detect now. Its speed has stayed the same the whole time; its frequency has fallen. The CMBR is further evidence for the Big Bang.

Extended only: the Hubble constant and the age of the Universe

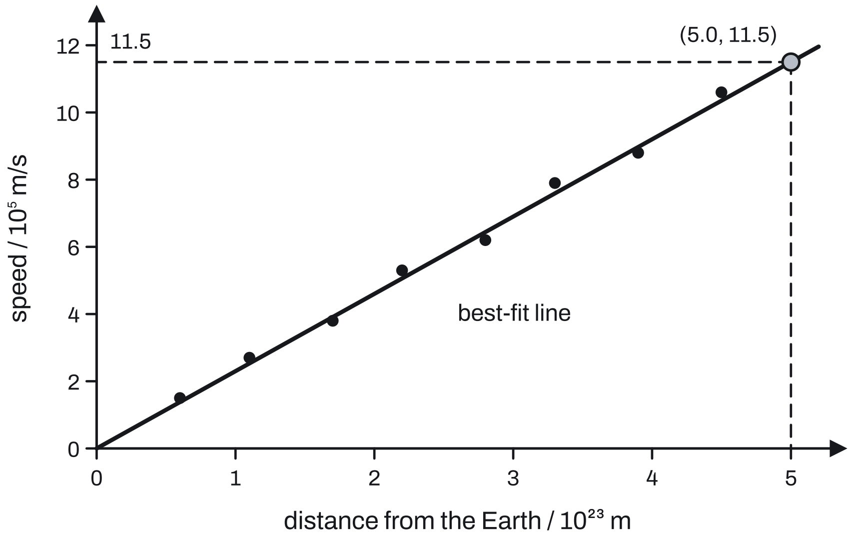
For far galaxies, astronomers measure two things separately:

- the **speed** v at which a galaxy is moving away, from the **change in wavelength** of its starlight (the amount of redshift);
- its **distance** d, from the **brightness of a supernova** in that galaxy: the dimmer it looks, the further away it is.

Plotting v against d for many galaxies gives a straight line through the origin: v **is directly proportional to** d. The gradient of the line is the **Hubble constant**, H_0, defined as the **ratio** of the speed at which a galaxy is moving away from the Earth to its distance from the Earth:

$$H_0 = \frac{v}{d}.$$

Its current estimate is $H_0 = 2.2 \times 10^{-18}$ **per second** (s^{-1}): speed in m/s divided by distance in m leaves 1/s.



The age of the Universe. If a galaxy has always moved away at speed v, then the time since it was at the same place as us is

$$t = \frac{d}{v} = \frac{1}{H_0} = \frac{1}{2.2 \times 10^{-18}} = 4.5 \times 10^{17}\ \text{s},$$

which is about 1.4×10^{10} years (14 billion years). Because $\frac{d}{v}$ comes out the **same** for **every** galaxy, every galaxy was at the same place at the same moment. This is evidence that **all the matter in the Universe was once at a single point**, and $\frac{1}{H_0}$ is an estimate of the age of the Universe.

Key facts and formulas

There is no formula sheet in the IGCSE Physics exam, so you must learn all of these.

Formula	Status
Speed of light in space $c = 3.0 \times 10^8$ m/s; distance $d = c \times t$, time $t = \dfrac{d}{c}$	Learn it
1 light-year $= 9.5 \times 10^{15}$ m $= 9.5 \times 10^{12}$ km (Extended)	Learn it
1 year $= 365 \times 24 \times 3600 = 3.15 \times 10^7$ s (about 3.2×10^7 s)	Learn it
Hubble constant $H_0 = \dfrac{v}{d}$, so $v = H_0 d$ and $d = \dfrac{v}{H_0}$ (Extended)	Learn it
$H_0 = 2.2 \times 10^{-18}$ per second (s^{-1}) (Extended)	Learn it

Formula	Status
Age of the Universe $\approx \dfrac{d}{v} = \dfrac{1}{H_0} = 4.5 \times 10^{17}$ s $\approx 1.4 \times 10^{10}$ years (Extended)	Learn it

Facts to learn: the Sun is a medium-sized star, mostly hydrogen and helium, radiating mostly infrared, visible and ultraviolet; the Milky Way is a galaxy about 100 000 light-years across; the Universe has many billions of galaxies, each with many billions of stars.

How to do it

We have tagged 102 questions on this topic (96 different; 2023–2025; Papers 1–4). 20 of them mix more than one type, so the counts add up to more than 102.

Question type	Questions
State what the Sun is made of and the radiation it gives out	25
Define, convert and use light-years	20
Describe galaxies, the Milky Way and the Universe	18
Describe redshift and what it shows	17
Use the Hubble constant $H_0 = v/d$	16
Describe the life cycle of a star	12
State how stars are powered (fusion of hydrogen)	12
Estimate the age of the Universe with $1/H_0$	6
Describe the cosmic microwave background radiation	5
State how a far galaxy's speed and distance are measured	5

1. State what the Sun is made of and the radiation it gives out (25 questions)

1. **Size:** a **medium-sized star** (a star, not a planet or a galaxy).
2. **Elements:** mostly **hydrogen** and **helium** (one mark each). Hydrogen makes up most of its mass.
3. **Radiation:** most of its energy is **infrared**, **visible light** and **ultraviolet**. If the question names one, give the other two.

Variations you will meet:

- **A table of four stars, "which is the Sun?"**: pick the row with hydrogen and helium **and** infrared, visible and ultraviolet.
- **Spot the wrong statement**: "one of the biggest stars", "the largest planet", "mostly carbon and nitrogen", "mostly gamma rays" or "mostly radio waves and microwaves" are all false.

- **The least energy**: from a list such as infrared, microwave, ultraviolet and visible, the Sun radiates the **least** as **microwaves**, the only one outside its three main regions.
- **A pie chart or a graph** of the Sun's energy in three regions, with one or two named: the missing one is the third of infrared, visible, ultraviolet. On an energy–wavelength graph the order from short to long wavelength is **ultraviolet, visible, infrared** (the first diagram).
- **Radiation received on the Earth**: the same three regions.

2. Define, convert and use light-years (20 questions)

1. **Define:** "the **distance** travelled by light in (the vacuum of) space in **one year**". Say "distance", never "time" or "speed".
2. **Convert light-years to metres:** multiply by 9.5×10^{15} (or by 9.5×10^{12} for km). **Metres to light-years:** divide by 9.5×10^{15}.
3. Give the answer in standard form, usually to 2 significant figures, with the unit asked for.

For example, a nebula 3.8×10^3 light-years away is $3.8 \times 10^3 \times 9.5 \times 10^{15} = 3.6 \times 10^{19}$ m away.

Variations you will meet:

- **"Show that 1 light-year** $= 9.5 \times 10^{15}$ **m"**: write $d = c \times t$, give $c = 3.0 \times 10^8$ m/s and one year in seconds ($365 \times 24 \times 3600 = 3.15 \times 10^7$ s), multiply, and give the answer to 3 significant figures (9.46×10^{15} m).
- **Pick the value** from options such as 5.9×10^{15} m or 9.5×10^{15} km: it is 9.5×10^{15} **m** (9.5×10^{12} **km**).
- **Very small distances** in light-years work the same way: 2.0×10^{-5} light-years $= 2.0 \times 10^{-5} \times 9.5 \times 10^{15} = 1.9 \times 10^{11}$ m.
- **Light travel distance or time** in metres and seconds: $d = c \times t$. Light that takes 190 s to travel from the Sun to Mercury has come $3.0 \times 10^8 \times 190 = 5.7 \times 10^{10}$ m. The reverse is $t = d \div c$.
- **Statements about a star x light-years away**: its light takes x years to reach us, so we see it as it was x years ago, and a radio message from there takes x years. A star a few light-years away is **inside** the Milky Way (it is $100\,000$ light-years across). Light from the Sun going **there and back** takes $2x$ years.
- **Travelling at a fraction of the speed of light**: at 2% of the speed of light, a probe needs $100 \div 2 = 50$ years for each light-year. To a star 9 light-years away that is $9 \times 50 = 450$ years one way; double it for a return trip.
- **Why don't we send spacecraft to planets outside the Solar System?** The distances are far too great: the journey would take many thousands of years.

3. Describe galaxies, the Milky Way and the Universe (18 questions)

1. A **galaxy** is a collection of **many billions of stars**.
2. The Sun (with the Solar System) is in the galaxy called the **Milky Way**, about **100 000 light-years** across.
3. The **Universe** is made of **many billions of galaxies**.

Variations you will meet:

- **Name the galaxy containing the Sun**: the Milky Way (not Andromeda, not "the Universe").
- **Is the Sun a star or a galaxy? The Milky Way?** The Sun is a star; the Milky Way is a galaxy.
- **Fill the gaps**: "The Milky Way is a **galaxy** made up of about a hundred **billion** stars."
- **The diameter of the Milky Way**: $100\,000$ light-years, not $100\,000$ km and not 1000 light-years.
- **Wrong statements to reject**: the Milky Way is "a group of galaxies", "all the stars we can see", "about 1000 stars", "1 light-year across", or "has stars about as far from us as the Sun". The Universe is **not** "the Solar System only" and is not 100 000 galaxies.
- **Order of size**: star < galaxy < Universe.

4. Describe redshift and what it shows (17 questions)

1. **Describe:** an **increase** in the **observed wavelength** of **electromagnetic radiation (light)** from **receding** stars or galaxies (compared with the wavelength measured on the Earth).
2. **What it shows about the galaxies:** they are **moving away** from us (and from each other).
3. **What it shows about the Universe:** the more distant a galaxy, the bigger its redshift, so the faster it is moving away; the **Universe is expanding**. This supports the **Big Bang Theory**.

Variations you will meet:

- **Name the effect** when the observed wavelength is longer than the emitted one: **redshift**.
- **Data table** of wavelengths from a laboratory lamp and from galaxies at different distances: every galaxy's wavelength is longer, so all are moving away; the furthest galaxy has the biggest increase, so it is moving fastest; so the Universe is expanding.
- **"State one piece of evidence for the Big Bang Theory and explain it"**: redshift of light from distant galaxies (the evidence), showing the galaxies are moving apart and the Universe is expanding, so it all started from a single point (the explanation).
- **"Describe the evidence for an expanding Universe"** (3 marks): light from distant galaxies is redshifted; its observed wavelength is increased; more distant galaxies have a bigger redshift, so they are moving away faster.
- **"Why do the measurements suggest the Universe was once at a single point?"**: galaxies are moving apart now, so in the past they were closer together; further galaxies move faster, so going back in time they all meet.
- **Which property increases?** Wavelength. Frequency decreases; speed stays the same; it is not a change in amplitude.
- **Wrong statements**: redshift is not a decrease in wavelength; it does not show the Universe is contracting; galaxies are not moving towards us or "around each other"; stars in other galaxies are not "all red"; a galaxy moving towards us (such as Andromeda) is not evidence of expansion.

5. Extended only: Use the Hubble constant $H_0 = v/d$ (16 questions)

1. Write $H_0 = \dfrac{v}{d}$ and rearrange: $v = H_0 d$ or $d = \dfrac{v}{H_0}$.

2. **Match the units:** with H_0 in s^{-1}, speed in m/s goes with distance in m, and km/s goes with km. Convert light-years to m (or km) first.
3. Substitute $H_0 = 2.2 \times 10^{-18}$ s^{-1} unless the question gives another value, and give the unit.

For example, a galaxy 4.0×10^{24} m away moves away at $v = 2.2 \times 10^{-18} \times 4.0 \times 10^{24} = 8.8 \times 10^{6}$ m/s.

Variations you will meet:

- **Define** H_0: "the **ratio** of the speed at which a galaxy is moving away from the Earth to its distance from the Earth". Don't describe it as the rate of expansion in all directions, the change in wavelength, or the age of the Universe.
- **State the symbol's meaning, the equation, the value or the unit**: Hubble constant; $H_0 = v/d$; 2.2×10^{-18}; per second (s^{-1}).
- **The relationship**: v is **directly proportional** to d (not inversely). A galaxy three times as far away moves three times as fast.
- **Distance in light-years**: convert to m first. A galaxy 1.5×10^{8} light-years away is $1.5 \times 10^{8} \times 9.5 \times 10^{15} = 1.4 \times 10^{24}$ m away, so $v = 2.2 \times 10^{-18} \times 1.425 \times 10^{24} = 3.1 \times 10^{6}$ m/s.
- H_0 **from one galaxy's data**: $H_0 = v \div d$, in consistent units.
- H_0 **from one galaxy, then a second galaxy's speed**: work out H_0, then multiply by the new distance, or just scale (double the distance, double the speed).
- H_0 **from a graph** of speed against distance: H_0 is the **gradient** of the best-fit line. Read a point far along the **line** (not a data point), include the powers of ten on each axis, and divide speed by distance. If the axes are in km/s and km, km cancels and the answer is still in s^{-1} (the fourth diagram).

6. Extended only: Describe the life cycle of a star (12 questions)

Learn the chain in order, with the key word at each stage:

cloud of gas and dust (hydrogen) → **protostar** (collapses under gravity, heats up) → **stable star** (gravity balanced by outward force from high temperature; fusion of hydrogen) → hydrogen runs out → **red giant** (less massive) or **red supergiant** (more massive) → **planetary nebula + white dwarf**, or **supernova** → **nebula (hydrogen and heavier elements) + neutron star or black hole** → new stars with planets.

Variations you will meet:

- **Complete the sentences**: protostars form from **interstellar clouds of gas and dust**; a protostar becomes stable when the **inward gravitational force** is balanced by the **outward force due to the high temperature**; the initial fuel is **hydrogen**; a Sun-sized star's red giant forms a **planetary nebula** with a white dwarf at its centre.
- **"Describe and explain what happens as a cloud forms a protostar"**: the cloud **collapses**, because of its own **gravitational attraction**, and its **temperature increases**.
- **"Describe what happens as a protostar becomes a stable star"**: nuclear fusion starts; the **forces are balanced**: gravity inwards, the force due to the high temperature outwards.

- **"Describe what happens when most of the fuel in the centre has become helium"**: the star **expands** into a red giant (smaller star) or a red supergiant (more massive star).
- **"Describe how a black hole forms from a massive star"** (3 marks): most of its hydrogen becomes helium; it expands into a **red supergiant**; this **explodes as a supernova**; a **black hole** is left at the centre of the nebula.
- **Put stages in order**: cloud → protostar → stable star → red giant → white dwarf. A stable star never comes **before** a protostar.
- **What forms directly from a supernova?** A nebula and a neutron star (or black hole), not a white dwarf, red giant or protostar.
- **Which star will become a supernova?** From a table, the **red supergiant**, whatever its temperature. Red giants, white dwarfs and neutron stars will not.
- **Correct statements**: **all** stars eventually run out of hydrogen. Wrong ones: a red giant forms a nebula with a **supernova** at its centre; a white dwarf becomes a black hole; most stars expand into **protostars**.

7. Extended only: State how stars are powered (fusion of hydrogen) (12 questions)

1. The energy comes from **nuclear fusion**: **hydrogen nuclei join together to form helium nuclei**, releasing energy.
2. In a written answer name all three parts: **nuclear**, **fusion** (nuclei joining), **hydrogen** → **helium**.

Variations you will meet:

- **Multiple choice rows** of fission/fusion and fuel: fusion, hydrogen. Reject fission, helium into hydrogen, uranium, and "burning".
- **"Nuclei join together" vs "break up"**: hydrogen nuclei **join** to form helium nuclei.
- **A statement about the Sun**: "powered by fusion reactions, and electromagnetic radiation is produced" is correct.

8. Extended only: Estimate the age of the Universe with $1/H_0$ (6 questions)

1. Age of the Universe $\approx \dfrac{d}{v} = \dfrac{1}{H_0}$.
2. With $H_0 = 2.2 \times 10^{-18}$ s⁻¹: age $= 4.5 \times 10^{17}$ s.
3. **In years:** divide by the seconds in a year, $365 \times 24 \times 3600 = 3.15 \times 10^7$: 1.4×10^{10} years.

Variations you will meet:

- **"Which quantity is an estimate of the age?"**: $\dfrac{1}{H_0}$, not H_0, $d \times H_0$ or $v \times H_0$.
- **"State the equation"**: age $= \dfrac{1}{H_0}$ (or $\dfrac{d}{v}$).
- **An expression from one galaxy's data in years**: for a galaxy d light-years away moving at v km/s, change d to km ($\times 9.5 \times 10^{12}$), divide by v to get seconds, then divide by the seconds in a year:

$$\text{age in years} = \frac{d \times 9.5 \times 10^{12}}{v \times 3.2 \times 10^7}.$$

For a galaxy at 2.0×10^8 light-years moving at 4200 km/s this gives $\dfrac{2.0 \times 10^8 \times 9.5 \times 10^{12}}{4200 \times 3.2 \times 10^7} = 1.4 \times 10^{10}$ years.

- **Why is this evidence for a single starting point?** $\frac{d}{v}$ is the same for every galaxy, so they were all at one point at the same time.

9. Extended only: Describe the cosmic microwave background radiation (5 questions)

1. **What it is**: microwave radiation of a particular frequency, detected at **all points in space** (from every direction).
2. **When it was produced**: **shortly after the Universe was formed** (shortly after the Big Bang).
3. **Why it is now microwaves**: the **Universe has expanded**, stretching (redshifting) the radiation, so its **wavelength has increased** into the microwave region.

Variations you will meet:

- **Early radiation shifted from gamma to microwave**: wavelength **increased**, speed **stayed the same**.
- **Correct statements**: the CMBR had a **shorter wavelength in the past**. Wrong ones: its frequency is now higher than infrared's (microwaves have lower frequency than infrared); it has always had the same frequency; it was produced long after the Universe formed.

10. Extended only: State how a far galaxy's speed and distance are measured (5 questions)

1. **Speed** v: from the **change in wavelength** of the galaxy's starlight, that is, the amount of **redshift**.
2. **Distance** d: from the **brightness of a supernova** in that galaxy.

Variations you will meet:

- **A table of methods**: distance ↔ brightness of a supernova; speed ↔ change in wavelength of starlight. Not "brightness of the galaxy".
- **"Which quantity can be found from a supernova's brightness?"** The distance, not the speed.
- **Answers that don't score**: measuring distance and time directly, or $v = d \div t$. We can't time a galaxy over a distance.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) The Sun is described as a medium-sized star. Name the **two** elements that make up most of the Sun. **[2]**

(b) State the **three** regions of the electromagnetic spectrum in which the Sun radiates most of its energy. **[2]**

(c) **(Extended)** In several billion years most of the hydrogen in the Sun's centre will have been converted to helium. Describe what will then happen to the Sun. **[3]**

(d) **(Extended)** A star with a mass twenty times the Sun's also runs out of hydrogen in its centre. State **two** ways in which its end is different from the Sun's. **[2]**

(a) Hydrogen **B1** and helium **B1**.

(b) Infrared, visible light and ultraviolet. **B2** (all three for 2 marks; two of them for 1 mark).

(c) The Sun will expand **B1** to form a red giant. **B1** The red giant will then form a planetary nebula with a white dwarf at its centre. **B1**

(d) Any two of: it expands into a red **supergiant**, not a red giant **B1**; it explodes as a **supernova B1**; it leaves a **neutron star or black hole**, not a white dwarf, in a nebula containing heavier elements **B1**.

Example 2

A star cluster is 2.4×10^4 light-years from the Earth.

(a) State what is meant by a light-year. **[1]**

(b) **(Extended)** Calculate the distance of the cluster from the Earth in km. **[2]**

(c) A student says that the cluster must be outside the Milky Way because it is so far away. Explain why the student is wrong. **[1]**

(d) State how long ago the light we now receive from the cluster left it. **[1]**

(a) The distance travelled by light in (the vacuum of) space in one year. **B1**

(b) 1 light-year $= 9.5 \times 10^{12}$ km. **C1**

$d = 2.4 \times 10^4 \times 9.5 \times 10^{12} = 2.3 \times 10^{17}$ km **A1**

(c) The Milky Way is about $100\,000$ light-years across, so a distance of $24\,000$ light-years can still be inside it. **B1**

(d) $24\,000$ years ago (light takes one year to travel each light-year). **B1**

Example 3 (Extended)

Hydrogen in a laboratory gives out light with a wavelength of 486 nm. Light from the same hydrogen line in a distant galaxy is observed on the Earth with a wavelength of 495 nm.

(a) State the name of this effect and what it shows about the galaxy. **[2]**

(b) Astronomers use the change in wavelength to find that the galaxy is moving away at 5.5×10^6 m/s. Using $H_0 = 2.2 \times 10^{-18}$ per second, calculate the distance of the galaxy from the Earth in light-years. **[3]**

(c) State another method that could be used to find the distance to this galaxy. **[1]**

(a) Redshift **B1**. The galaxy is moving away from the Earth (receding). **B1**

(b) $d = \dfrac{v}{H_0} = \dfrac{5.5 \times 10^6}{2.2 \times 10^{-18}} = 2.5 \times 10^{24}$ m **C1**

In light-years: $\dfrac{2.5 \times 10^{24}}{9.5 \times 10^{15}}$ **C1**

$= 2.6 \times 10^8$ light-years **A1**

(c) Measure the brightness of a supernova in the galaxy. **B1**

Example 4 (Extended)

The fourth diagram in "Understand it" shows measurements of the speed of eight galaxies moving away from the Earth against their distance from the Earth.

(a) State the relationship between the speed and the distance shown by the graph. **[1]**

(b) Use the best-fit line to determine a value for the Hubble constant. **[3]**

(c) Use your value to estimate the age of the Universe, in seconds and in years. **[3]**

(d) Explain why these measurements suggest that all the matter in the Universe was once at a single point. **[2]**

(a) The speed is directly proportional to the distance (a straight line through the origin). **B1**

(b) $H_0 = \text{gradient} = \dfrac{v}{d}$ **C1**. A point on the line: $d = 5.0 \times 10^{23}$ m, $v = 11.5 \times 10^5$ m/s **C1**.

$H_0 = \dfrac{1.15 \times 10^6}{5.0 \times 10^{23}} = 2.3 \times 10^{-18}$ per second **A1**

(c) Age $= \dfrac{1}{H_0} = \dfrac{1}{2.3 \times 10^{-18}}$ **C1** $= 4.3 \times 10^{17}$ s **A1**

In years: $\dfrac{4.35 \times 10^{17}}{365 \times 24 \times 3600} = 1.4 \times 10^{10}$ years **A1**

(d) All the galaxies are moving away from each other, so in the past they were closer together. **B1** Further galaxies move faster in proportion, so $\frac{d}{v}$ is the same for all of them: going back $\frac{1}{H_0}$ in time, they were all at the same point. **B1**

Common mistakes

- **Calling a light-year a time or a speed.** It is a **distance**: the distance light travels in space in one year. Examiners see "a year with more sunlight" and "the time light takes" every year.
- **Redshift as a decrease in wavelength.** Redshift is an **increase** in the **observed** wavelength. Many candidates know the galaxy is moving away but still pick "decrease".
- **Vague redshift answers.** Say whose radiation is redshifted: **light (electromagnetic radiation) from distant galaxies**. "The wavelength of the galaxy", "redshift of planets" or just "things moving away" don't score.
- **Mixing up red giant and red supergiant.** Only a red **supergiant** explodes as a supernova and leaves a neutron star or black hole. Don't write "white dwarf" or "black dwarf" for what a supernova leaves.
- **Forgetting what the supernova nebula contains**: hydrogen **and new, heavier elements**.
- **Putting a stable star before the protostar** in the life cycle. It is cloud → protostar → stable star.
- **Confusing fission and fusion.** Stars fuse **hydrogen into helium**; fission splits large nuclei like uranium. Say that **nuclei** join; "hydrogen fuses" alone is too vague, and "atoms join" is wrong.
- **Getting the Hubble relationship upside down.** v is **directly** proportional to d, and $H_0 = v/d$, not d/v. Use the units to check: s^{-1} = (m/s) ÷ m.
- **Saying speed is found from $v = d \div t$.** The speed of a galaxy comes from the **change in wavelength** (redshift); the distance from the **brightness of a supernova**. Answers of "distance" or "light-years" to "state a measurement" are too vague.
- **Mixing km and m** in $v = H_0 d$. Keep both in m, or both in km. Convert light-years first, with the right factor (9.5×10^{15} m or 9.5×10^{12} km).
- **Giving the age in seconds when years are asked.** Divide by 3.15×10^{7}.
- **Answering redshift for the CMBR "when" question.** It was produced **shortly after the Universe formed**, and it is found **everywhere** in space.

How to get the marks

- **"State"** needs the exact term: "redshift", "Milky Way", "hydrogen and helium", "planetary nebula", "brightness of a supernova". Give only as many answers as asked; a wrong extra answer can cancel a right one.
- **"Define"** a light-year or H_0 needs every key word: **distance**, **light**, **one year** (in space); **ratio** of the **speed** a galaxy moves **away** to its **distance** from the Earth.
- **"Describe"** redshift: **increase** in **observed wavelength** of **light** from **receding** galaxies.
- **"Explain"** (such as why the CMBR is now microwaves, or how redshift supports the Big Bang) needs the cause: the **Universe has expanded**, so the radiation is stretched and its wavelength has increased; galaxies moving apart means they were once together.
- **"Calculate"** is usually 2–3 marks: the equation, the numbers substituted (including the light-year conversion), the answer with its unit. Show them, because the working marks count even if the final answer slips.

- **Units**: H_0 is in "per second" (s^{-1}). Give distances in the unit on the answer line (m or km), and years if asked.
- **Significant figures**: 2 significant figures matches the data usually given (2.2×10^{-18}, 9.5×10^{15}). For "show that", give one more figure than the printed value.
- **Graph questions**: use a large triangle on the best-fit line and show on the graph where your values came from.

Quick check

1. **(Extended)** Put these in the order they happen in the life of a very massive star: neutron star, protostar, red supergiant, supernova, interstellar cloud, stable star.
2. **(Extended)** A galaxy is 3.8×10^{21} m from the Earth. Calculate this distance in light-years.
3. **(Extended)** A galaxy is moving away from the Earth at 1.8×10^4 km/s. Using $H_0 = 2.2 \times 10^{-18}$ per second, calculate its distance from the Earth in m.
4. **(Extended)** Galaxy X is 1.5×10^{24} m from the Earth and is moving away at 3.3×10^6 m/s. (a) Calculate the Hubble constant from X's data. (b) Galaxy Y is moving away at 1.1×10^7 m/s. Use your answer to (a) to estimate the distance of Y from the Earth.
5. **(Extended)** State when the cosmic microwave background radiation was produced, and explain why it is now in the microwave region.

Answers

1. Interstellar cloud → protostar → stable star → red supergiant → supernova → neutron star.
2. $\dfrac{3.8 \times 10^{21}}{9.5 \times 10^{15}} = 4.0 \times 10^5$ light-years.
3. $v = 1.8 \times 10^4$ km/s $= 1.8 \times 10^7$ m/s. $d = \dfrac{v}{H_0} = \dfrac{1.8 \times 10^7}{2.2 \times 10^{-18}} = 8.2 \times 10^{24}$ m.
4. (a) $H_0 = \dfrac{3.3 \times 10^6}{1.5 \times 10^{24}} = 2.2 \times 10^{-18}$ per second. (b) $d = \dfrac{v}{H_0} = \dfrac{1.1 \times 10^7}{2.2 \times 10^{-18}} = 5.0 \times 10^{24}$ m.
5. Shortly after the Universe was formed (shortly after the Big Bang). Since then the Universe has expanded, stretching the radiation so that its wavelength has increased (it has been redshifted) into the microwave region.

Past questions to try

- **0625/41/M/J/24 Q9**: the Sun's radiation, the Sun–Earth distance and how a protostar becomes a stable star.
- **0625/43/O/N/24 Q9**: redshift from a table of wavelengths, and what it shows about the Universe.
- **0625/41/O/N/23 Q10**: fusion in a star, redshift, a galaxy's distance from H_0 and the age of the Universe in years.
- **0625/42/M/J/24 Q11**: the Milky Way, the Big Bang Theory and the CMBR.