IGCSE PHYSICS 0625 · CHAPTER 12 NOTES · ~12 MIN READ

# Space physics

Day, night, seasons and the Moon, then the Solar System, the life of stars, galaxies, redshift and the Big Bang.

Earth, Sun & Moon | Seasons & phases | Solar System | Orbits | Stars & life cycle | Light-years | Redshift | Big Bang & Hubble constant

RS by Riyaz Sir
mentorriyaz.in

No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

### IN 30 SECONDS

- The Earth **spins** once a day (day and night) and **orbits** the Sun once a year. Its **tilted axis** causes the seasons.
- The Moon orbits the Earth about **monthly**; its phases show how much of the lit half we see.
- **Eight planets**: the inner four are small and rocky; the outer four are large and gaseous.
- A **light-year** is a distance. Our galaxy, the **Milky Way**, is about 100 000 light-years across.
- Distant galaxies are **redshifted**, so the Universe is **expanding** and began in a **Big Bang**.

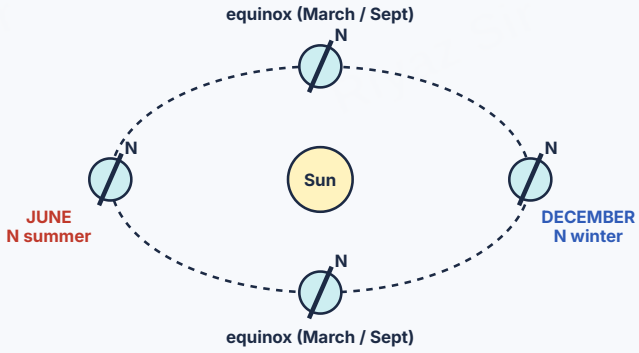
### BY THE END YOU CAN

- Explain day, night, seasons and Moon phases.
- Name the planets in order and explain why the inner and outer planets differ.
- Calculate light travel time and orbital speed ($v = 2\pi r \div T$). EXT
- Describe the Sun as a star and the life cycle of a star. EXT
- Explain redshift, the Big Bang, CMBR and the Hubble constant. EXT

## 1 The Earth, Sun and Moon

### Day, night and seasons

- The Earth **spins** on its axis once every **24 hours**. This gives **day and night**, and makes the Sun seem to rise in the east and set in the west.
- The Earth **orbits the Sun** once every **365 days**.
- The axis is tilted at **23.5°** and always points the same way in space.



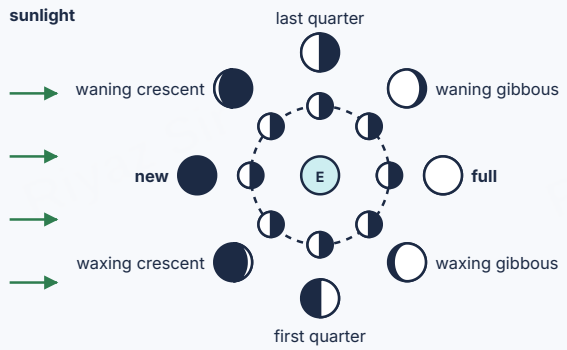

the tilt (23.5°) always points the same way in space, so the hemisphere leaning towards the Sun changes as the Earth orbits it

In June the northern hemisphere leans towards the Sun: more direct sunlight and longer days (summer). Six months later it leans away (winter).

**COMMON MISTAKE**

"It is summer when the Earth is closer to the Sun." No — the seasons come from the tilt of the axis, not the distance.

## The Moon




**the Moon is always half lit; phases = how much of the lit half we can see**

The Moon is always half lit. The phases are how much of the lit half we can see from the Earth.

- The Moon **orbits the Earth about once a month** (about 28 days). We see it by reflected sunlight.

**COMMON MISTAKE**

"The phases are caused by the Earth's shadow." No — they come from our changing view of the lit half. (The Earth's shadow causes a lunar eclipse.)

## Orbital speed

EXTENDED

$$v = \frac{2\pi r}{T}$$

average orbital speed (m/s) = circumference ÷ time for one orbit · r = orbital radius (m), T = orbital period (s)

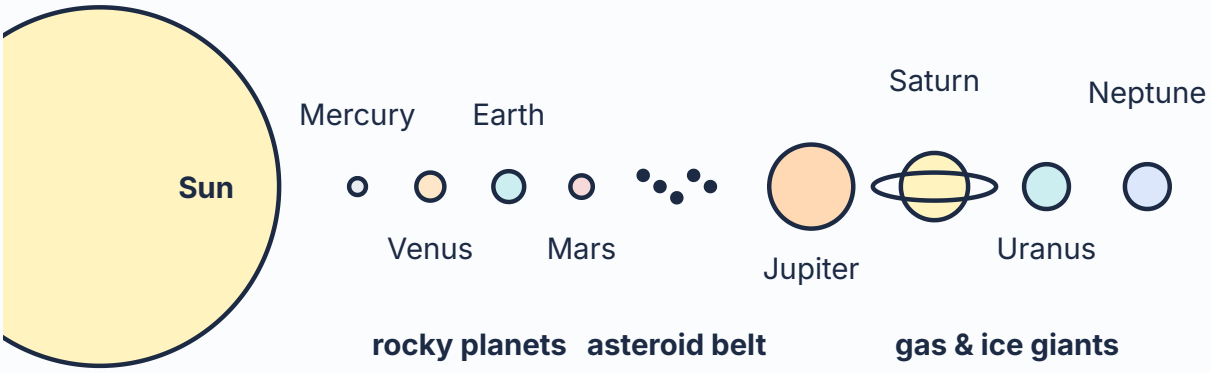
**WORKED EXAMPLE**

EXT **The Earth orbits the Sun at a radius of $1.5 \times 10^{11}$ m in 365 days. Find its average orbital speed.**

1. $T = 365 \times 24 \times 3600 = 3.15 \times 10^{7}$ s
2. $v = 2\pi r \div T = 2\pi \times 1.5 \times 10^{11} \div 3.15 \times 10^{7}$
3. **$= 3.0 \times 10^{4}$ m/s (30 km/s)**

## 2 The Solar System

### What is in it




not to scale · each planet orbits the Sun; moons orbit planets

The planets, in order from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune.

**MEMORY TRICK**

My Very Educated Mother Just Served Us Noodles — **M**ercury, **V**enus, **E**arth, **M**ars, **J**upiter, **S**aturn, **U**ranus, **N**eptune.

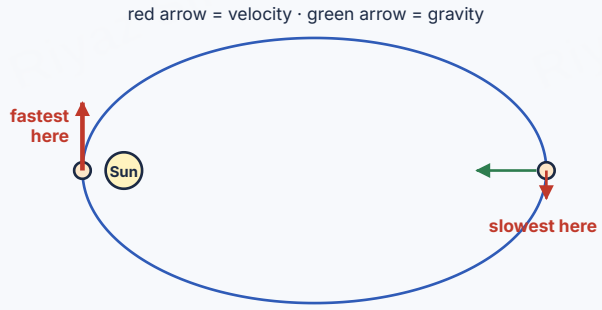
- The Solar System has **one star** (the Sun), **eight planets**, **dwarf planets** (such as Pluto), **asteroids** (mostly between Mars and Jupiter), **moons**, and smaller bodies such as **comets**.
- The Sun contains most of the mass, so its gravity keeps everything in orbit.
- The **inner four** planets are small and rocky. The **outer four** are large and gaseous.

## Why are the inner and outer planets different?

- This is the **accretion model**. A cloud of gas and dust spun into a **rotating disc** and **gravity** pulled the material together.
- Close to the young Sun it was too hot for gases to stay, so only heavier elements (rock and metals) gathered: **small, rocky planets**.
- Far from the Sun it was cold, so huge amounts of hydrogen and helium gathered: **large, gaseous planets**.

## Gravity and orbits

- Gravity at the surface of a planet depends on the planet's **mass**. It **decreases with distance** from the planet.
- EXT Planets and comets move in **ellipses**. The Sun is not at the centre unless the orbit is almost circular.




gravity pulls the comet towards the Sun; it speeds up as it falls closer

EXT A comet speeds up as it falls towards the Sun and slows as it moves away. Gravity (green) pulls it in; velocity is red.

- EXT Objects move **faster when they are closer to the Sun**, because gravitational potential energy is converted into kinetic energy. The Sun's gravity and the orbital speeds of the planets get **smaller** further from the Sun.

## Planetary data

EXTENDED

| Planet | Distance from Sun (million km) | Orbit time | Surface temp. (°C) | Surface gravity (N/kg) |
|---|---|---|---|---|
| Mercury | 58 | 88 days | 167 | 3.7 |
| Venus | 108 | 225 days | 464 | 8.9 |
| Earth | 150 | 365 days | 15 | 9.8 |
| Mars | 228 | 687 days | −65 | 3.7 |
| Jupiter | 778 | 11.9 years | −110 | 24.8 |
| Neptune | 4500 | 165 years | −200 | 11.2 |

- Further from the Sun means a **longer year** and (usually) a **colder** planet. Venus is hottest because its thick atmosphere traps heat.
- Surface gravity depends on the planet's mass, not on its distance from the Sun.

## Light travel time

**WORKED EXAMPLE**

**How long does light take to travel from the Sun to Neptune ($4.5 \times 10^{12}$ m)? Use $3.0 \times 10^{8}$ m/s.**

1. t = distance ÷ speed = $4.5 \times 10^{12} \div 3.0 \times 10^{8}$
2. = 15 000 s
3. **= 4.2 hours**

# 3 Stars and galaxies

## The Sun as a star

- The Sun is a **medium-sized star**, made mostly of hydrogen and helium. It gives out mostly **infrared, visible and ultraviolet** radiation.
- EXT Stars are powered by **nuclear fusion** of hydrogen into helium (see Nuclear physics).

## Light-years and galaxies

**Light-year** — the distance light travels in one year. It is a unit of distance, not time. EXT 1 light-year = $9.5 \times 10^{15}$ m.

- Other stars are **much further away** than the Sun. The nearest, Proxima Centauri, is about 4.2 light-years away.
- A **galaxy** is a group of billions of stars held together by gravity. The Sun is in the **Milky Way**, which is about **100 000 light-years** across. The Universe has billions of galaxies.




billions of galaxies make up the Universe

The Milky Way is a spiral galaxy about 100 000 light-years across, with over 100 billion stars. Our Sun is out in one of the spiral arms.

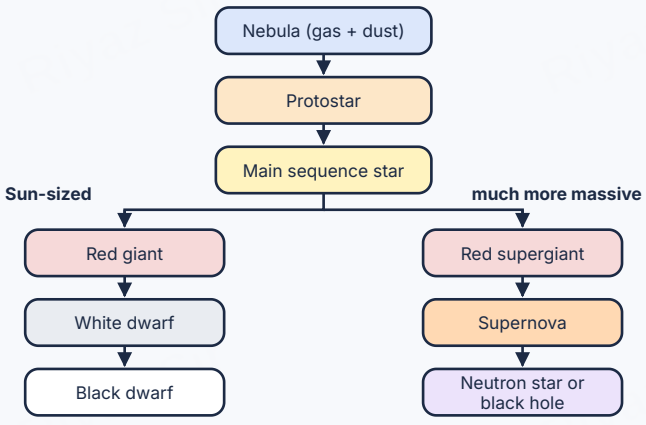
**WORKED EXAMPLE**

EXT **Proxima Centauri is 4.2 light-years away. Find the distance in metres.**

1. distance = $4.2 \times 9.5 \times 10^{15}$
2. **= $4.0 \times 10^{16}$ m**

## Life cycle of a star

EXTENDED

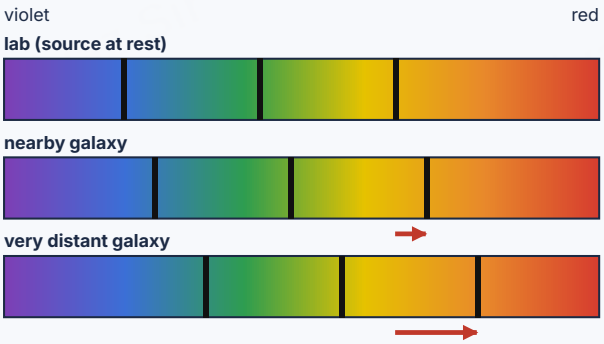



A star's path depends on its mass. A Sun-sized star ends as a white dwarf; a much more massive star ends in a supernova.

- A star begins as a **nebula** (a cloud of gas and dust). **Gravity** pulls it together to make a **protostar**, which heats up until hydrogen fusion starts.
- It then stays **stable** for billions of years, while the inward pull of gravity balances the outward push of the energy from fusion.
- A **Sun-sized** star then expands into a **red giant**, sheds its outer layers, and shrinks into a **white dwarf**.
- A **much more massive** star becomes a **red supergiant** and explodes as a **supernova**, leaving a **neutron star** or a **black hole**.
- The supernova scatters heavy elements into space. Later **new stars and planets** form from this gas and dust.

# 4 The Universe

## Redshift and the Big Bang




**spectral lines shifted towards red = the galaxy is moving AWAY**
the bigger the shift, the faster it is receding

Light from a galaxy moving away is stretched to a longer wavelength — shifted towards the red end of the spectrum. The faster it moves away, the bigger the shift.

**Redshift** — an increase in the observed wavelength of light from a source that is moving away from us.

- Light from distant galaxies is redshifted, so they are **moving away**. The **more distant** the galaxy, the **bigger** the redshift.
- So the Universe is **expanding**. Running time backwards, everything was once much closer together: this is the **Big Bang Theory**, about 13.8 billion years ago.




**space itself stretches: every galaxy moves away from every other**
farther galaxies recede faster ($v = H_o \times d$)
the Big Bang: everything began ~13.8 billion years ago

Space itself is stretching. Every galaxy moves away from every other galaxy, and the more distant ones move away faster.

## CMBR and the Hubble constant

EXTENDED

- **Cosmic microwave background radiation (CMBR)** is radiation coming from all directions in space. It was produced soon after the Big Bang. As the Universe expanded, its wavelength was stretched into the **microwave** region. It is strong evidence for the Big Bang.
- The **speed** of a receding galaxy can be found from its redshift. The **distance** of a far galaxy can be found from the brightness of a supernova in it.

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

Hubble constant = recession speed ÷ distance · $H_o \approx 2.2 \times 10^{-18}$ per second

EXT age of the Universe $\approx \frac{1}{H_0}$

this is an estimate of the time since the Big Bang

**WORKED EXAMPLE**

EXT **A galaxy is $1.0 \times 10^{23}$ m away. Find its recession speed. ($H_o = 2.2 \times 10^{-18}$ /s)**

1. $v = H_o \times d = 2.2 \times 10^{-18} \times 1.0 \times 10^{23}$
2. **$= 2.2 \times 10^5$ m/s (220 km/s)**

**WORKED EXAMPLE**

EXT **Estimate the age of the Universe from $H_o = 2.2 \times 10^{-18}$ /s. Give your answer in years.**

1. age $= 1 \div H_o = 1 \div (2.2 \times 10^{-18}) = 4.5 \times 10^{17}$ s
2. 1 year $= 3.15 \times 10^7$ s
3. **age $= 4.5 \times 10^{17} \div 3.15 \times 10^7 = 1.4 \times 10^{10}$ years (14 billion)**

## 5 Test yourself

### Test yourself — cover the answers first

**QUICK CHECK**

1. How long does the Earth take to spin once on its axis?
2. What causes the seasons?
3. Name the eight planets in order from the Sun.
4. Why are the outer planets large and gaseous?
5. What is a light-year?
6. What does redshift of a galaxy tell us?

**EXAM-STYLE**

7. EXT Mars orbits at a radius of $2.3 \times 10^{11}$ m with an orbit time of 687 days. Find its average orbital speed.
8. EXT Explain why a comet moves faster as it gets closer to the Sun. [2]
9. Light takes 760 s to travel from the Sun to Mars. Find the distance. ($c = 3.0 \times 10^8$ m/s)
10. EXT Describe the life cycle of a star much more massive than the Sun. [4]
11. EXT Explain how the cosmic microwave background radiation supports the Big Bang Theory. [3]

**Show answers**

1. 24 hours
2. The tilt of the Earth's axis as the Earth orbits the Sun.
3. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune
4. It was cold enough far from the Sun for lots of hydrogen and helium to be gathered by gravity.
5. The distance light travels in one year.
6. The galaxy is moving away from us, and the Universe is expanding.
7. $T = 687 \times 24 \times 3600 = 5.94 \times 10^7$ s
   $v = 2\pi r \div T = 2\pi \times 2.3 \times 10^{11} \div 5.94 \times 10^7 = 2.4 \times 10^4$ m/s
8. The Sun's gravitational pull does work on the comet
   so gravitational potential energy is changed into kinetic energy
9. $3.0 \times 10^8 \times 760 = 2.3 \times 10^{11}$ m
10. A nebula is pulled together by gravity to form a protostar
    fusion starts and it is stable for millions of years
    it becomes a red supergiant
    it explodes as a supernova, leaving a neutron star or black hole
11. It was produced soon after the Big Bang
    as the Universe expanded the wavelength stretched into the microwave region
    it comes from all directions in space, as predicted

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