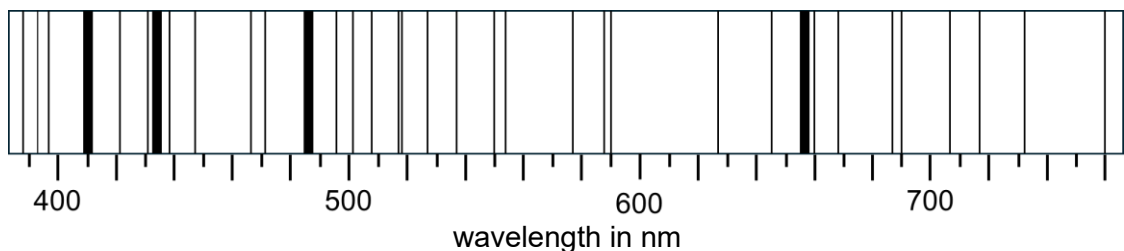


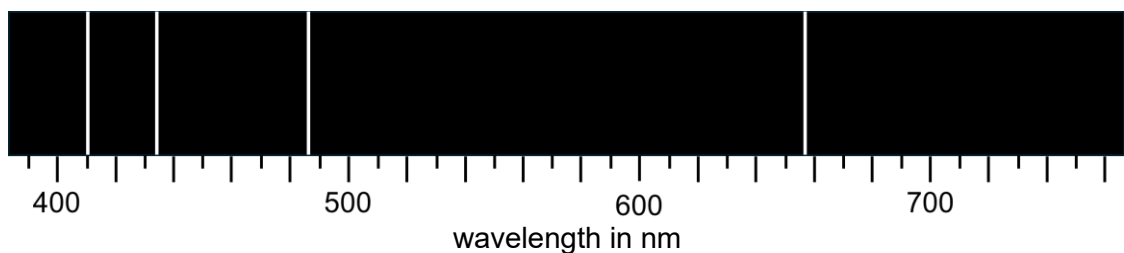
- 8 In 1814, Joseph von Fraunhofer studied the light from the Sun. He made a crucial discovery when he observed dark lines on a continuous spectrum of white light, known as the solar absorption spectrum, shown in Fig. 8.1. These lines, now known as Fraunhofer lines, were later found to be absorption lines caused by elements in the Sun's outer gas layers.

The thickness of the lines shows the amount of absorption that happens for a particular wavelength. Thicker lines indicate a higher amount of absorption by the gases in the outer gas layers.

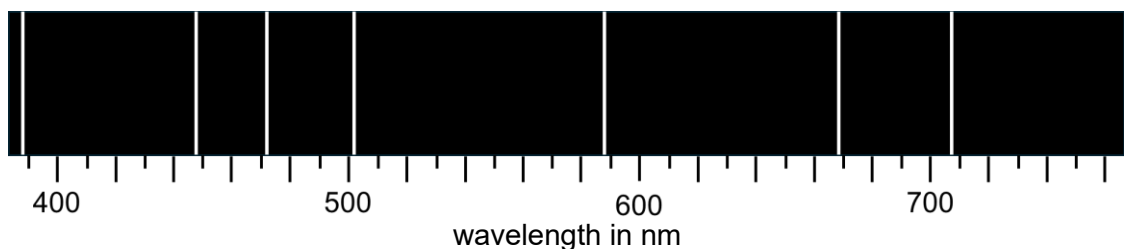


**Fig 8.1:** Solar absorption spectrum

By the early 20<sup>th</sup> century, scientists had established that each element produces a unique line spectrum when excited. This occurs because electrons in atoms can only occupy specific energy levels, and when they transit between these levels, they emit or absorb light of precise wavelengths, known as an emission or absorption spectrum. This principle has enabled astronomers to determine the chemical composition of distant celestial objects, such as the Sun, simply by analysing the light they emit. The emission spectrum for hydrogen and helium are shown in Fig. 8.2 and Fig 8.3 respectively.

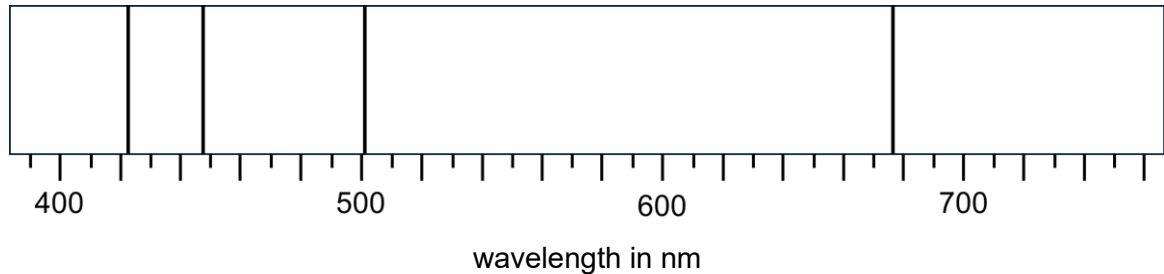


**Fig 8.2:** Hydrogen emission spectrum



**Fig 8.3:** Helium emission spectrum

In 1929, Edwin Hubble made a groundbreaking observation while studying the line spectra of distant galaxies at Mount Wilson Observatory. He noticed that the spectral lines from these galaxies were systematically shifted towards longer wavelengths compared to the same spectral lines measured from a stationary source such as a hydrogen lamp in the laboratory. For instance, the hydrogen absorption spectrum from a distant galaxy J1030 is shown in Fig. 8.4.



**Fig. 8.4:** Hydrogen absorption spectrum from galaxy J1030

This can be explained by the Doppler effect. The effect, first described by Christian Doppler in 1842, explains how light waves change wavelength when their source moves relative to an observer. When a light source moves away from an observer, the wavelength increases. Conversely, when the source moves towards the observer, the wavelength decreases. This effect is quantified in the equation

$$z = \frac{\lambda_{\text{moving}} - \lambda_o}{\lambda_o} = \frac{v}{c}$$

where  $z$  is a quantity known as “red-shift”,

$\lambda_{\text{moving}}$  represents the wavelength from the moving light source,

$\lambda_o$  represents the wavelength from a stationary source,

$v$  is the speed of the moving source, and

$c$  is the speed of light.

This discovery led to one of the most important methods in cosmology: using the wavelength of emitted light from a galaxy to determine if it is stationary or moving relative to Earth.

- (a) The Sun is modelled to have a hot dense core, surrounded by an outer layer of cooler gases. Explain how Fig. 8.1 supports this model.

.....  
 .....  
 .....  
 ..... [2]

- (b) Using Fig. 8.1, Fig. 8.2 and Fig. 8.3, compare whether there is more hydrogen or helium in the gas layer. Explain your answer.

.....  
 .....  
 ..... [2]

- (c) Using Fig. 8.1, Fig. 8.2 and Fig. 8.3, state and explain whether only hydrogen and helium are present in the outer gas layer of the Sun.

.....  
 .....  
 ..... [2]

- (d) (i) Show that the highest frequency of light in the hydrogen emission spectrum is  $7.3 \times 10^{14}$  Hz.

[1]

- (ii) Calculate the energy of the photon in d(i).

energy = ..... J [2]

- (e) A distant galaxy GN-Z11 is found to be moving away from Earth and is a moving light source.

Fig. 8.5 compares certain wavelengths of the line spectra of hydrogen obtained from a stationary source on Earth and GN-Z11. Some values of  $z$  and  $v$  are also included.

Hydrogen spectral wavelengths from GN-Z11 / nm	Hydrogen spectral wavelengths from stationary source on Earth / nm	$z$	$v / \text{m s}^{-1}$
676	656	0.0305	$9.15 \times 10^6$
500	485		

**Fig 8.5**

- (i) Complete the table in Fig. 8.5. [2]

- (ii) Suggest why the shift in wavelengths is called “red shift”.

.....  
 ..... [1]

- (iii) The hydrogen spectral wavelengths from another galaxy, the Andromeda Galaxy, were instead discovered to be shorter than the wavelengths from a stationary source on Earth.

State what this implies about the motion of the Andromeda Galaxy relative to Earth.

.....  
 ..... [1]

- (f) Fig. 8.6 below shows the  $z$  values of four galaxies, and their distance from Earth  $d$ .

Galaxy	$z$	$d$ / million light-years
Perseus	0.018	250
NGC 4889	0.022	308
Coma	0.023	321
Hercules Cluster	0.037	500

Fig. 8.6

- (i) One *light-year* is defined as the distance travelled by light in one year. Express one light-year in metres.

one light-year = ..... m [1]

- (ii) Using the data in Fig 8.6, describe qualitatively the relationship between the distance of a galaxy and the speed with which it is moving away from Earth.

.....  
 ..... [1]

- (iii) Fig. 8.7 shows the variation of  $z$  with distance  $d$ .

Plot the data for the Hercules Cluster on Fig 8.7.

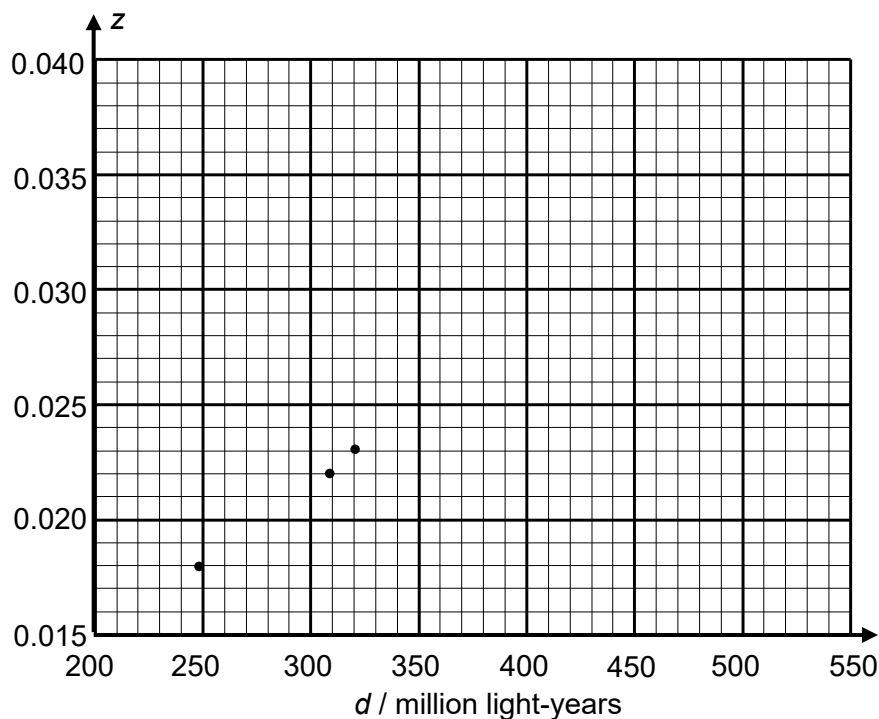


Fig. 8.7

[1]

- (iv) Add a line of best fit in Fig. 8.7.

[1]

- (v)  $z$  is related to  $d$  by the equation

$$z = \frac{H_0 d}{c}$$

where  $H_0$  is the Hubble constant and  $c$  is the speed of light.

Using the line of best fit in (iv), determine  $H_0$ .

$$H_0 = \dots\dots\dots \text{s}^{-1} \quad [3]$$

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