19.5 Spectra

Specification reference: 5.5.2

The discovery of helium

Helium was discovered not from a sample on Earth, but by careful analysis of the light from the Sun. During a total eclipse in 1868, Pierre Janssen, a French astronomer, observed a bright yellow light with a wavelength of 587.49 nm in the spectrum of the gases surrounding the Sun. No element known at the time produced photons of this specific wavelength. The new element was named after Helios, the ancient Greek Sun god, by the English astronomer Sir Norman Lockyer later the same year.

The technique of analysing the light from stars proved so useful that the science of **spectroscopy** was born. Because different atoms have different **spectral lines**, the spectra from starlight can be used to identify the elements within stars, even those billions of miles away, without a direct, physical sample from the star.

Continuous, emission, and absorption spectra

There are three kinds of spectra.

- **Emission line spectra** — each element produces a unique emission line spectrum because of its unique set of energy levels.
- **Continuous spectra** — all visible frequencies or wavelengths are present. The atoms of a heated solid metal (e.g., a lamp filament) will produce this type of spectrum.
- **Absorption line spectra** — this type of spectrum has series of dark spectral lines against the background of a continuous spectrum. The dark lines have exactly the same wavelengths as the bright emission spectral lines for the same gas atoms.

If the atoms in a gas are excited (e.g., within the hot environment of stars), then when the electrons drop back into lower energy levels they emit photons with a set of discrete frequencies specific to that element. This produces a characteristic **emission line spectrum**. Each spectral line corresponds to photons with a specific wavelength. These spectra can be observed in a laboratory from heated gases. Each coloured line in Figure 2 represents a unique wavelength (or frequency) of photon emitted when an electron moves between two specific energy levels.

Absorption line spectra

An absorption line spectrum is formed when light from a source that produces a continuous spectrum passes through a cooler gas. As the photons pass through the gas, some are absorbed by the gas atoms, raising electrons up into higher energy levels and so exciting the atoms. Only photons with energy exactly equal to the difference between the different energy levels are absorbed. This means that only specific wavelengths are absorbed, creating dark lines in the spectrum.

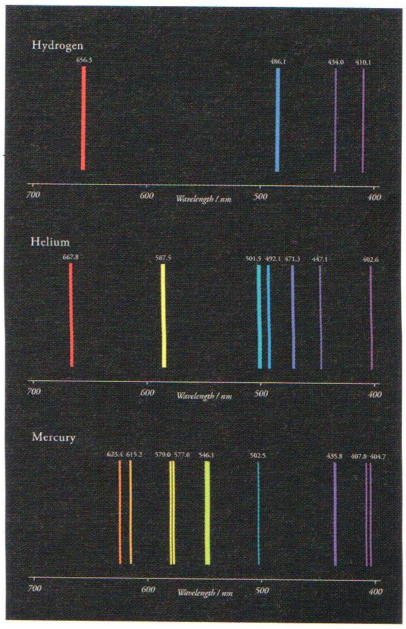
Learning outcomes

Demonstrate knowledge, understanding, and application of:

→ different atoms have different spectral lines, which can be used to identify elements within stars

→ continuous spectra, emission line spectra, and absorption line spectra.

▲ **Figure 1** *The Sun is around one quarter helium*



▲ **Figure 2** *Gas atoms of different elements produce different emission line spectra, which act like a unique fingerprint for each element*

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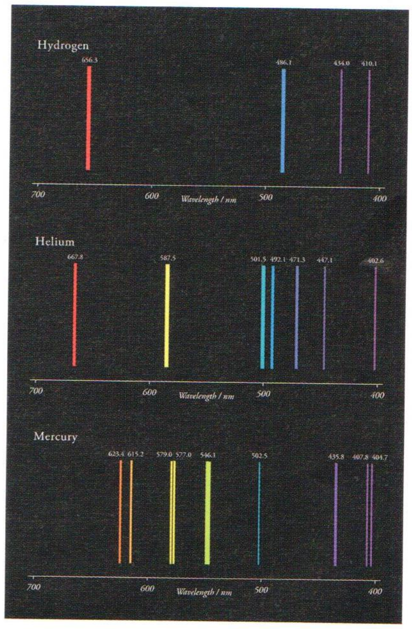

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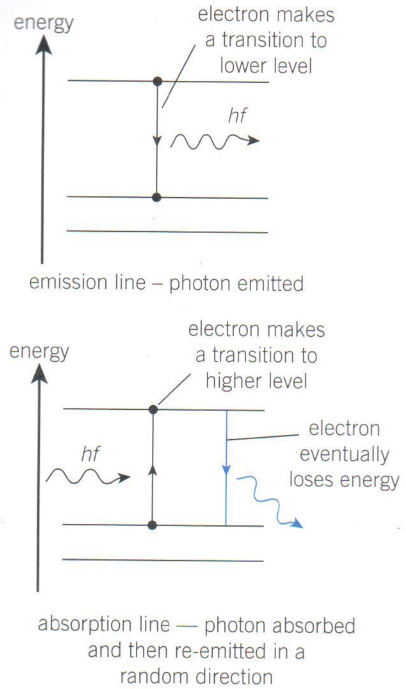
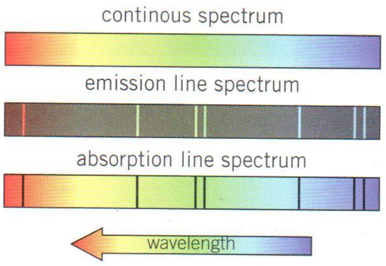


▲ **Figure 3** *A comparison of emission and absorption of photons*



▲ **Figure 4** *The three main types of visible spectra — can you see a link between the wavelengths of the emission and absorption spectral lines?*

These lines show which photons have been absorbed by the gas atoms. Although the photons are re-emitted when the electron drops back down to a lower energy level atom, they are emitted in all possible directions, so the intensity in the original direction is greatly reduced (see Figure 3).

The absorption line spectrum for any gas is very nearly a negative of its emission line spectrum (Figure 4). In fact, a few lines from the emission line spectrum may not be visible in the absorption line spectrum, simply because in excited atoms electrons may return to their ground state in stages, releasing a photon each time, whereas absorption lines are mostly caused by electrons starting from their ground state.

Detecting elements within stars

When the light from a star is analysed, it is found to be an absorption line spectrum. Some wavelengths of light are missing – the photons have been absorbed by atoms of cooler gas in the outer layers of the star.

If we know the line spectrum of a particular element, we can check whether the element is present in the star, even for extremely distant stars. If a particular element is present then its characteristic pattern of spectral lines will appear as dark lines in the absorption line spectrum.

Summary questions

1. Describe the differences between a continuous spectrum and an emission line spectrum. *(2 marks)*
2. Explain why the wavelengths of the emission lines for gas atoms of a particular element have the same wavelengths as the dark absorption lines for the same atoms. *(2 marks)*
3. An absorption line at a wavelength of 682 nm is observed in the spectrum from a star. Determine the difference between the energy levels for the atoms in the gas responsible for this absorption line. *(3 marks)*
4. An absorption line is observed in the spectrum of a particular gas when electrons absorb photons and move between energy levels at −10.4 eV and −4.6 eV. Calculate the wavelength of these photons and so identify the part of the electromagnetic spectrum to which this absorption line belongs. *(4 marks)*
5. The value of the energy level in eV for the hydrogen atom is given by the equation $E_n = -\frac{13.6}{n^2}$ where n is an integer 1, 2, 3 etc.
   a Draw an energy level diagram (to scale) for the hydrogen atom showing the five lowest energy levels. *(2 marks)*
   b Determine the wavelength of the emitted photon when an electron makes a transition between levels $n = 3$ and $n = 2$. *(3 marks)*