CAMBRIDGE
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For issue on or after: 13 March 2026

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Advance Notice Article

To prepare candidates for the examination taken on Monday 1 June 2026 – Morning

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INSTRUCTIONS
- Before the exam, read this article carefully and study the content of the learning outcomes for A Level Physics B (Advancing Physics).
- You can ask your teacher for advice and discuss this article with others in your class.
- You can investigate the topic of this article yourself using any resources available to you.
- Do **not** take this copy of the article or any notes into the exam.

INFORMATION
- In the exam you will answer questions on this article. The questions are worth 20–25 marks.
- A clean copy of this article will be given to you with the question paper.
- This document has **4** pages.

ADVICE
- In the exam you won't have time to read this article in full but you should refer to it in your answers.

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A Brief History of Helium

Helium is the element that most nearly approximates to an ideal gas. This is indicated by its boiling point of 4.2 K, the lowest of all elements. Although it makes up about 25% of the observed mass of the Universe it is rare on Earth, only accounting for 0.0005% of the atmosphere.

Helium is used in many applications including industry, medicine and scientific research. MRI scanners use liquid helium to cool the superconducting electromagnets used to produce uniform fields of around 3 T which require a current of about 1000 A. Once the current is produced the power supply can be removed and the current will remain almost constant for a number of years as the superconducting wires have zero resistance.

Gaseous helium is used in weather balloons. A given volume of helium has less mass than the equivalent volume of air at the same temperature and pressure so the upthrust due to the weight of the air displaced will be greater than the weight of the helium and balloon fabric allowing the balloon to rise through the atmosphere.

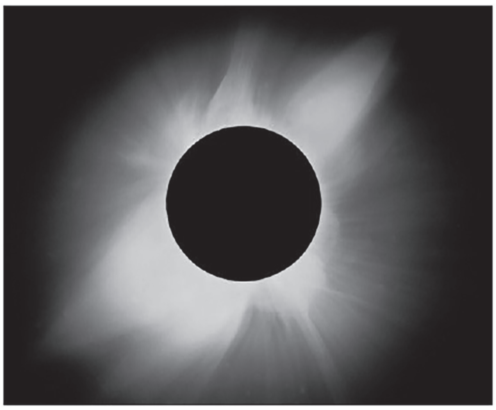
Figure 1

Airships such as the helium-filled Airlander shown in **Figure 1** on a test flight in Bedfordshire are now being considered once again as a form of air travel that has a lower carbon impact than conventional aircraft.

Discovery

Helium was first identified in 1868. The French astronomer Pierre Jules Jansen discovered bright spectral lines (emission lines) when the corona – a very hot region of gas in the outer layers of the Sun, was visible during a solar eclipse, see **Figure 2**.

Figure 2 the solar corona during a solar eclipse



Later that year, the English astronomer Norman Lockyear observed lines in the solar spectrum that did not match with those of known elements. He suggested that these were due to an element unknown on Earth which he named helium after the Ancient Greek god of the sun, Helios. Faint absorption lines due to helium are also visible, produced when photons from the core of the Sun pass through the cooler photosphere.

The spectral lines associated with helium were first observed in heated terrestrial rocks in 1881 but it was not until 1895 that the element was isolated by the Scottish chemist Sir William Ramsay.

Abundance of Helium

At the time of the discovery of helium, scientists assumed the principle of ‘uniformity of nature’. That is, that the Sun and stars were composed of the same elements as Earth, with the same abundances. It was clear that helium and hydrogen were present in very small amounts on Earth, so these elements were expected to be rare in the Sun as well. This idea was questioned in 1924 by the work of a twenty-four-year-old graduate from England, working at Harvard University. Celia Payne (later known by her married name of Celia Payne-Goposhkin) used her training in physics as she meticulously worked through a quarter of a million photographs of spectra, slowly unravelling the information within the images, see **Figure 3**. The ‘intensity’ of a spectral line is related to the abundance of the isotope responsible for the line. A bright emission line shows that many photons are released in unit time, showing that there are many electrons changing energy levels, which requires many atoms, although there are also many other factors that must be considered.

Figure 3 Celia Payne at work

Payne’s careful study of the intensities of the spectral lines suggested that helium was a thousand times more abundant in the Sun than on Earth and that hydrogen was a million times more abundant. This discovery is one of the great steps forward in our understanding of the Universe. However, the scientific establishment was not ready to overturn its long-held uniformity principle and it was not until 1929 that Payne’s conclusions became widely accepted.

Hydrogen absorption lines are also visible, produced when photons from the core of the Sun pass through the cooler photosphere.

Where does the helium come from?

The idea that hydrogen fusion powers the stars has been around since the 1930s but this cannot explain the amount of helium found in stars and in interstellar gas. This helium was formed in the first few minutes after the Big Bang.

The first particles to appear after the Big Bang are quarks and leptons, followed by composite particles such as protons and neutrons. When the Universe is about 20 seconds old the ‘Big Bang nucleosynthesis’ of helium begins. Deuterium ($^{2}_{1}H$) is the first isotope to be produced but this is ripped apart at temperatures higher than 10^{9} K. Once the temperature falls so that deuterium nuclei remain intact for sufficient time, helium is formed through two reactions:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$$

$$^{3}_{2}He + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{1}p$$

After about twenty minutes the Universe has expanded and cooled to a point where the energy and number density of the nuclei are too low for further fusions to occur. To put this in a human scale, virtually all the helium in the Universe is created in less time than an average candidate spends on Section C of their *Scientific Literacy in Physics* examination!

What about the Earth?

Helium does not remain in the Earth's atmosphere. A miniscule fraction may leave through *Jeans escape* in which the helium atoms gain sufficient kinetic energy through random collisions to reach the required escape velocity. This happens in the *exosphere*, the level of the atmosphere that begins around 1000 km above the surface of the Earth. The density of gases is extremely low at this height – the International Space Station orbits at a height of 400 km above the surface of the Earth and the definition of the edge of space is the *Karman line*, a mere 100 km above sea level.

Almost all helium escapes from the atmosphere through a mechanism known as the *polar wind*. A weak electric field accelerates He^+ ions upwards through the atmosphere in the region of the poles. Although this field is weak the acceleration over a large distance is sufficient to give the ions enough energy to surpass the negative potential of the gravitational field.

Over time this process would remove all the helium from the atmosphere, but this has not happened because helium constantly enters the atmosphere from the Earth's crust where it is produced in the alpha decay of thorium-232 and uranium-238. The alpha particles pick up two electrons to become helium-4 atoms which gradually diffuse through the crust and enter the atmosphere. It is estimated that about two million helium atoms are released into the atmosphere each second for every square centimetre of the Earth's surface. Next time you see a party balloon floating up to the ceiling, remember that to a very good approximation, every atom of helium in the balloon was once an alpha particle.

Helium can be collected from natural gas reserves which can contain up to 7% helium through *fractional distillation*. As helium has such a low boiling point, when the natural gas is cooled, other gases liquefy before the helium, allowing the helium gas to be separated. Although helium is produced continually through alpha decay, it is effectively a finite resource as it can only be economically collected from gases produced over millions of years. As it has vital uses in medicine and research many scientists feel that it needs to be conserved for more important uses than novelty party decorations.