Oxford Cambridge and RSA

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Insert

Wednesday 21 June 2017 – Morning

Time allowed: 2 hours 15 minutes

6830687715

INSTRUCTIONS
- Do not send this Insert for marking; it should be retained in the centre or recycled.
- Please contact OCR Copyright should you wish to re-use this document.

INFORMATION
- This Insert contains the Advance Notice.
- This document consists of **4** pages.

How far are the stars?

Over the past two hundred years, scientists have measured the Universe from the largest scale, that of the Universe itself, to the smallest particle. Fig. 1 illustrates some of the range of these measurements.

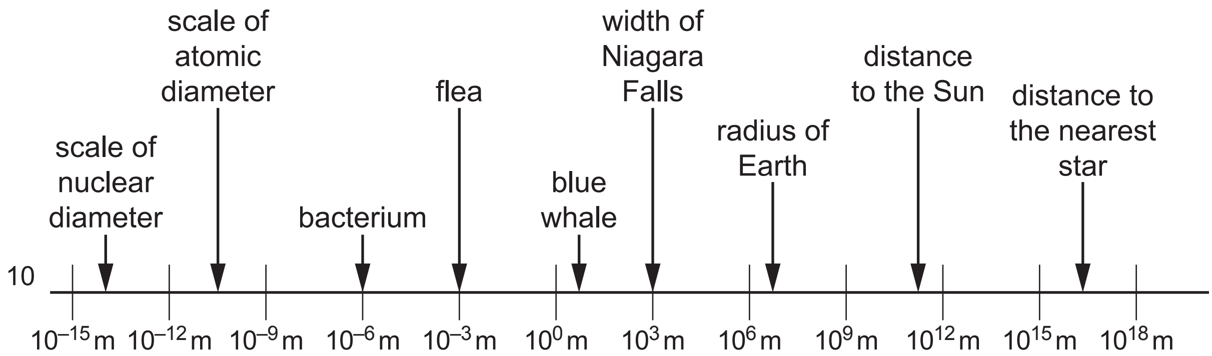

Fig. 1

The world of the very small – angular resolution of optical images

The limit of detail that can be identified is considered in terms of **angular resolution**: the minimum angle between objects that can be formed into separate images. Diffraction effects limit the angular resolution of all optical instruments, including the human eye which has an angular resolution of about 0.02°.

The story of scientific measurement is one of early approximations followed by successive improvements in techniques and instruments. For example, some early estimates of the sizes of atoms came from estimating the number of atoms in a known volume whereas estimates of the distances to stars used the (incorrect) assumption that all stars are equally bright.

The distance to the nearest stars

Fig. 2 shows the principle of stellar parallax. As the Earth moves around the Sun a nearby star will shift its position relative to more distant stars. If the Earth-Sun distance is known, the angular shift can lead to a value for the distance to the nearby star using simple trigonometry.

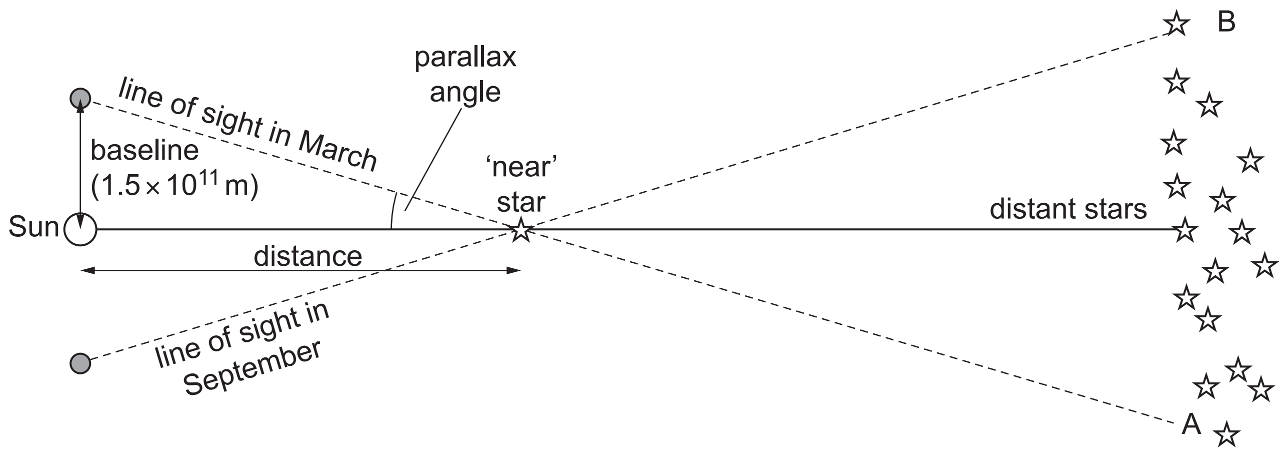

Fig. 2

It was not until well into the 19th Century that the resolution of telescopes reached a standard where observations of parallax could be made where the uncertainties in the measurements did not swamp any possible measurement of parallax angle. In 1868, Friedrich Bessel used a refined version of the process described above to establish the distance to the star 61 Cygni. He measured the parallax angle as 0.000 079 8°, suggesting a distance of between 11 and 12 light years.

The astronomical unit and the parsec

The Earth-Sun distance is known as the 'astronomical unit' (AU).

The arcsecond is 1/3600 of a degree. If a star gives a parallax angle of one arcsecond, the distance from Earth is defined as one parsec (parallax-second). The parsec is a measure of distance rather than time, whatever some science fiction films suggest.

For small angles the distance in parsecs is given by the equation:

$$\text{distance in parsecs} = \frac{1}{\text{parallax angle in arcseconds}}.$$

Gaia

The turbulent movements of the Earth's atmosphere produce density changes in the air through which the light from stars travels and limits the resolution of ground-based telescopes to about one-hundredth of an arcsecond. This means that the greatest distance that can be measured using parallax is about one hundred parsecs. Achieving better resolution requires satellite observations; beyond the atmosphere the Gaia satellite (launched in 2013) can produce images with an angular resolution of as little as 0.000 02 arc seconds.

Spectroscopic measurement of stellar distances

Professional astronomers measure brightness with a logarithmic scale called stellar magnitudes, but this is not appropriate here. We shall deal only with absolute brightness and apparent brightness.

Absolute brightness is the power emitted by a star in the visible range of the spectrum. Stars do not have the same absolute brightness as one another. However, different 'spectral classes' of stars have different ranges of brightness. Some classes of stars are always brighter than others. This can be useful in estimating distances from the apparent brightness of stars. If we know that a certain star belongs to a class that are very bright but the particular star appears to be quite dim we can conclude that it must be far from the Earth. The spectral class of a star can be determined by analysing the spectral lines in its spectrum.

When light passes through the relatively cool, gaseous upper layers of a star the atoms of the gas absorb frequencies specific to each isotope present in the layer. This produces the dark lines of an 'absorption spectrum'.

Fig. 3 shows an early diagram of the solar spectrum, drawn by the German spectroscopist Josef von Fraunhofer in 1814 although the explanation of the lines had to wait until the development of the quantum picture of light.

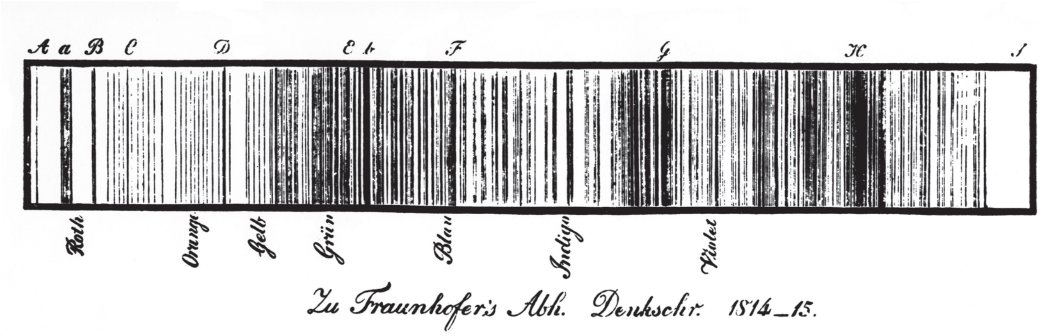

Fig. 3

The position and thickness of the spectral lines allow astronomers to identify the **spectral classification of the star**. Once this is known, the absolute brightness of the star can be found. The distance to the star can be calculated by comparing its absolute brightness with its apparent brightness and using the inverse-square law:

apparent brightness $\propto \dfrac{1}{r^2}$ where r is the distance to the star.

Apparent brightness = absolute brightness only for a star at a distance $r = 10\,\text{pc}$, so

Apparent brightness $= K \times \dfrac{\text{absolute brightness}}{r^2}$

where the constant $K = 100\,\text{pc}^2$ when the distance r is measured in pc.

END OF ADVANCE NOTICE ARTICLE