A level Physics B

H557/02 Scientific literacy in physics

Question Set 19 Section C

This question set is based on the **Advance Notice** article from **June 2017** (included in this document – see 'Resource Materials')

1 State the feature of the diagram in **Fig. 1** in the article which shows that the distance scale is logarithmic and suggest a possible **disadvantage** of representing data in this manner. **[2]**

2 The density of silver is 10 500 kg m^{-3}. The mass of one silver atom is 1.8 × 10^{-25} kg.

Use this data to calculate an estimate for the diameter of an atom of silver, explaining your reasoning and assumptions.

diameter of silver atom =.......................................m **[4]**

3 This question is about an experiment to estimate the resolution of the human eye.

Two vertical, parallel black lines are drawn on a piece of card. The separation between the lines is 2.0 ± 0.5 mm. The card is fixed to a wall at head height.

A group of students look at the card whilst each covering one eye. They walk back from the card until they can no longer separate the two lines. The distance L between the eye and the card is measured.

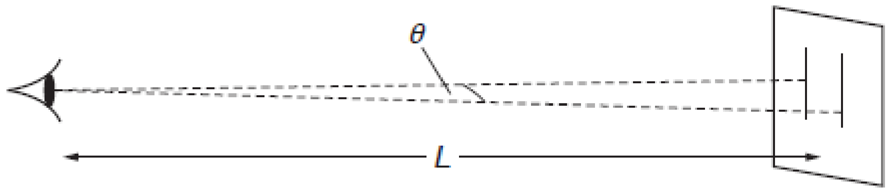

Fig. 3.1

Here are the results from five students:

student	A	B	C	D	E
maximum distance L/m	6.2	5.8	6.1	5.9	6.1

(a) **(i)** State the spread of the distance values.

spread = ± ....m **[1]**

(ii) A student suggests that the uncertainty in the distance values can be ignored when calculating the minimum angle that can be resolved because of the uncertainty in the separation of the lines on the card. Comment on this suggestion, explaining whether or not you agree. **[2]**

(iii) Calculate a value for the minimum angle that can be resolved. Include an estimate of the uncertainty in your value. Explain how you estimated the uncertainty.

minimum angle that can be resolved = ... ±...........................rad **[3]**

(b) An approximate value for the minimum resolvable angle θ_{min} can be obtained from the

equation $\theta_{min} = \frac{\text{wavelength of light}}{\text{diameter of pupil of the eye}}$.

The students estimated the diameter of the pupil to be 3 mm and the wavelength of light to be 5×10^{-7} m. Use the data to estimate the minimum resolvable angle and compare your answer with the value obtained in **(a)(iii)**.

minimum angle that can be resolved =……………………..…….rad

[2]

4 This question is about measuring stellar distances by parallax.

The parallax of the star Sirius is 0.38 arc seconds.

One light year is the distance light travels in one year.

Calculate the distance to Sirius in light years.

Earth-Sun distance = 1 AU = 1.5×10^{11} m
1 year = 3.2×10^{7} seconds

distance = ………………………………..…….. light year **[3]**

5 Explain why turbulence in the atmosphere limits the resolution of ground-based optical telescopes (lines 7–39). **[2]**

6* This question is about spectroscopic measurements of stellar distances.

Describe how absorption spectra are formed and how they are useful in establishing the spectral class of a star.

Explain how determining the value for the absolute brightness and apparent brightness of a star can lead to a measurement of the distance to a star.

The following example may help in your explanation:

Star **X** is known to have three times the absolute brightness of star **Y** but both appear to be equally bright in the sky. The distance to star **Y** has been measured as 12 parsecs. **[6]**

Total Marks for Question Set 19: 25

Resource Materials

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.

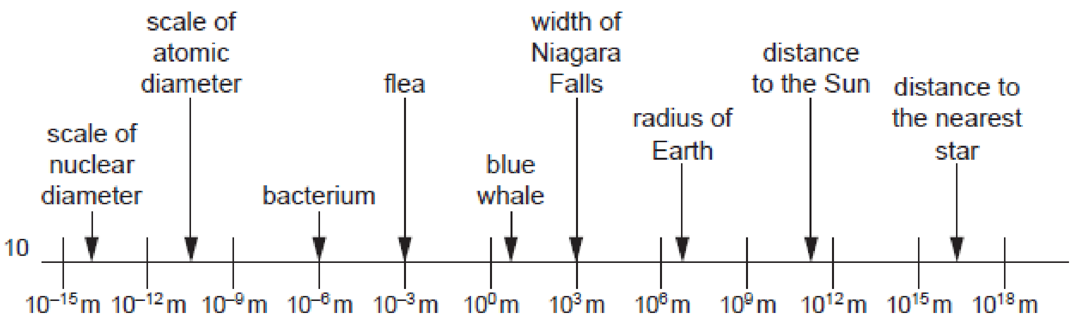

Fig. 1

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 ofatoms 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.

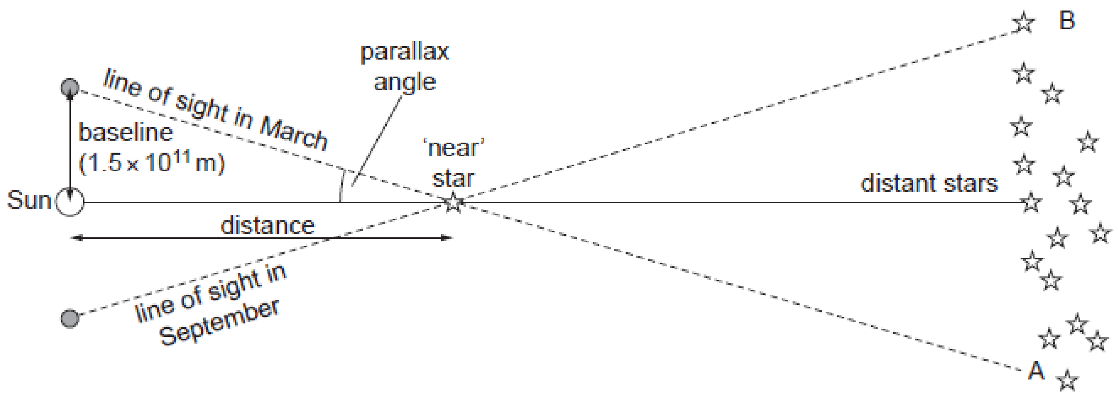

Fig. 2

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. Hemeasured 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.

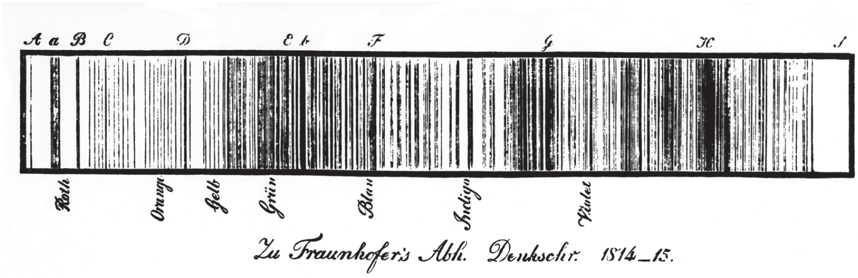

Fig. 3

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

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

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

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