OCR
Oxford Cambridge and RSA

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Wednesday 21 June 2017 – Morning

Time allowed: 2 hours 15 minutes

You must have:
- the Insert (inserted)
- the Data, Formula and Relationships booklet (sent with general stationery)

You may use:
- a scientific or graphical calculator
- a ruler (cm/mm)

First name	
Last name	
Centre number	
Candidate number	

INSTRUCTIONS
- The Insert will be found inside this document.
- Use black ink. You may use an HB pencil for graphs and diagrams.
- Complete the boxes above with your name, centre number and candidate number.
- Answer **all** the questions.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the barcodes.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- This document consists of **24** pages.

SECTION A

Answer **all** the questions.

1 This question is about notes produced by a flute.

A flute is an instrument that produces standing waves with displacement antinodes (A) at both ends. The nodes (N) and antinodes for the lowest note possible for a flute of length L are shown in Fig. 1.1.

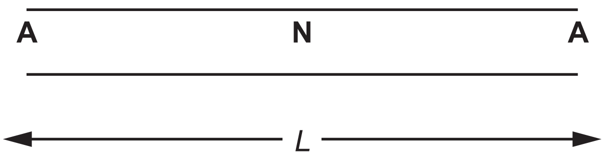

Fig. 1.1

(a) Explain how standing waves are formed in air.

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.... **[3]**

(b) Mark the antinodes and nodes on Fig. 1.2 for a note of **twice** the frequency of the note indicated in Fig. 1.1. Explain your answer.

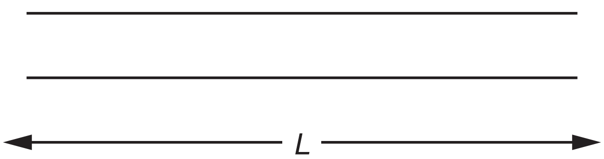

Fig. 1.2

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.... **[2]**

(c) The velocity of sound in air v is given by the equation $v = \sqrt{\frac{kp}{\rho}}$ where p is the pressure of the gas, ρ is the density of the gas and k is a constant.

Use the expression $pV = nRT$ and the expression for density, $\rho = \frac{m}{V}$, to show that $v = \sqrt{\frac{kRT}{M}}$ where $M = \frac{m}{n}$ is the mass of one mole of air.

[2]

(d) A flute of length L sounds a note of 262 Hz at a temperature of 293 K. Calculate the frequency of the note from the same length flute when the temperature of the air in the flute has increased to 303 K. The change in length of the flute caused by this temperature rise is negligible.

frequency at 303 K = ... Hz **[3]**

2 This question is about charging a capacitor in a circuit with two resistors in series.

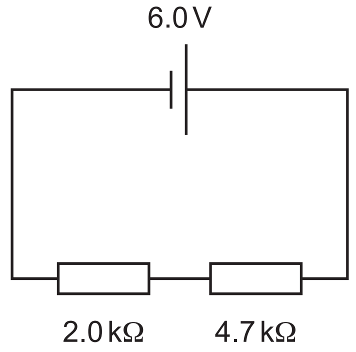

Fig. 2.1

(a) Show that the p.d. across the 4.7 kΩ resistor in the circuit in Fig. 2.1 is about 4 V, assuming that the cell has zero internal resistance.

[2]

(b) A student changes the circuit as shown in Fig. 2.2

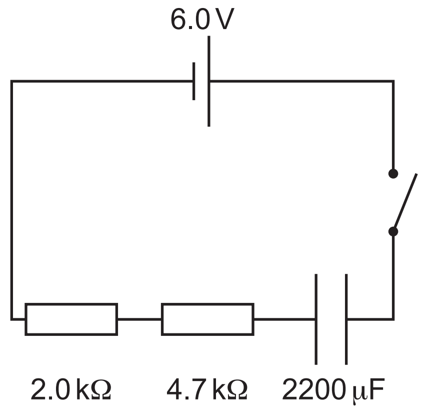

Fig. 2.2

Show that the time constant of the circuit is about 15 s.

[2]

(c) The graph in Fig. 2.3 shows how the p.d. across the capacitor varies with time up to 5*RC.* Add a line to the graph that shows how the p.d. across the **4.7 kΩ resistor** varies with time.

Add another line to show how the p.d. across the **2.0 kΩ resistor** varies with time. Label the lines.

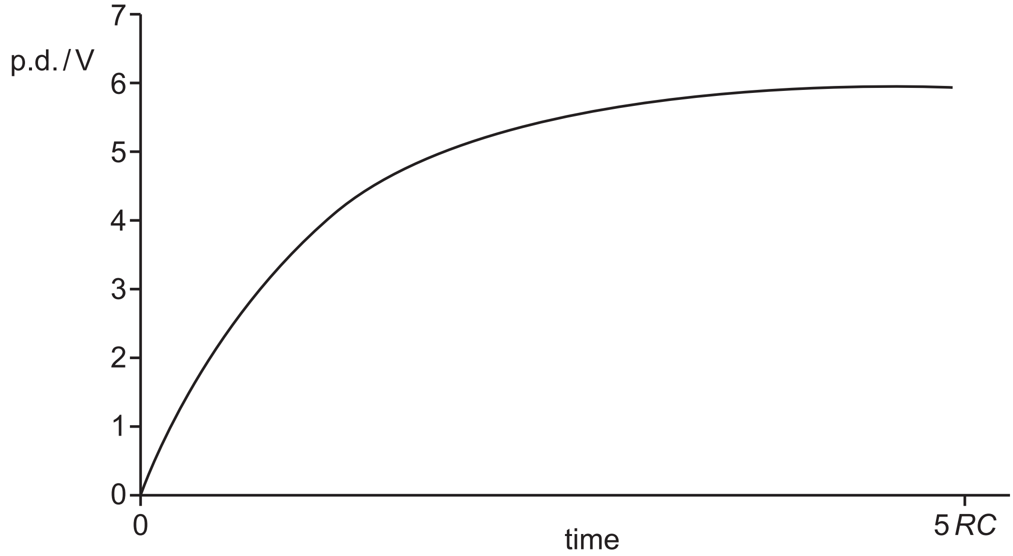

Fig. 2.3

[2]

(d) Calculate the time it takes from the start of the charging for the p.d across the capacitor to reach 5.0 V.

time = ... s **[4]**

3 This question is about the force on a sail of a land yacht, a small vehicle that is powered by the wind.

Fig. 3.1

(a) Explain how air particles exert a pressure on a sail and why, when no wind is blowing, the sail experiences the same pressure on both sides.

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.... **[3]**

(b) A sail has an area 8.0 m^2. A wind of velocity 18.0 $m\,s^{-1}$ strikes the sail at 90° to the surface of the sail. It is assumed that the velocity of the wind falls to zero when it strikes the sail.

Calculate the force on the sail and suggest why the assumption may not be accurate.

density of air = 1.2 $kg\,m^{-3}$

force on sail = ... N **[4]**

(c) A constant force of 300 N strikes the sail of a land yacht at an angle of 50° to the direction of motion of the vehicle as shown in Fig. 3.2. The mass of the yacht and rider is 135 kg.

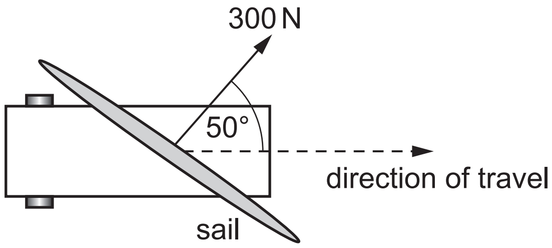

Fig. 3.2

Calculate the time for the land yacht to travel 50 m in the direction shown. The yacht starts from rest. Ignore resistive forces.

time = ... s **[4]**

SECTION B

Answer **all** the questions.

4 This question is about the New Horizons spacecraft mission to the dwarf planet Pluto.

In July 2015, the Long Range Reconnaissance Imager (LORRI) sent the image shown in Fig. 4.1a.

Fig. 4.1a

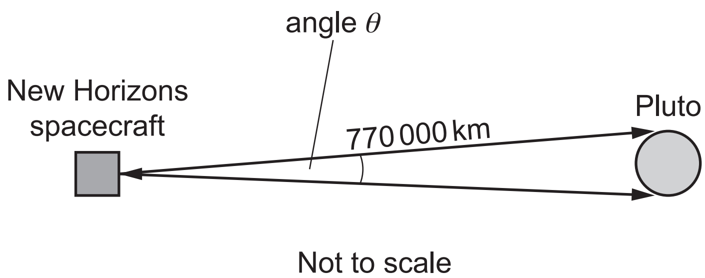

Fig. 4.1b

(a) It takes 4.5 hours for the radio signal from the spacecraft at Pluto to reach the Earth. Calculate the distance of the spacecraft from Earth when the signal was transmitted.

distance = ... m **[2]**

(b) The square image is 1024 pixels wide. The diameter of Pluto is 2700 km.

(i) Calculate the resolution of the image in km pixel $^{-1}$.

resolution = ... km pixel^{-1} **[3]**

(ii) The image in Fig. 4.1a was taken at a distance of 770 000 km. The **angular** resolution of LORRI is 5×10^{-6} radian per pixel. This means that each pixel covers an angle of 5×10^{-6} radian. By calculating how many radians Pluto subtends (angle θ in Fig. 4.1b), test whether the value for angular resolution agrees with your value for the resolution in **(b)(i).** Comment on your answer.

[4]

(c)* New Horizons is powered by a radioisotope thermal generator. This produces electrical power from the thermal energy of decaying plutonium-238.

Explain why solar power is not used for this spacecraft. Use the data below to calculate the energy released per second at launch and the reduction in energy released per second when New Horizons reached Pluto. Comment on your results.

Data:

Mean Sun-Pluto distance = 40 × mean Sun-Earth distance

Amount of plutonium-238 carried by spacecraft: 36 mol

Number of plutonium-238 nuclei in one mole: $6.0 \times 10^{23}\ \text{mol}^{-1}$

Half-life of plutonium-238: 87.7 years (2.8×10^{9} s)

Energy released in the decay of one plutonium nucleus: 5.6 MeV

Journey time to Pluto: 9 years

[6]

5 This question is about the Boltzmann factor, $f = e^{-E/kT}$.

Fig. 5.1 shows how the Boltzmann factor varies with temperature for three processes: **A**, **B** and **C**.

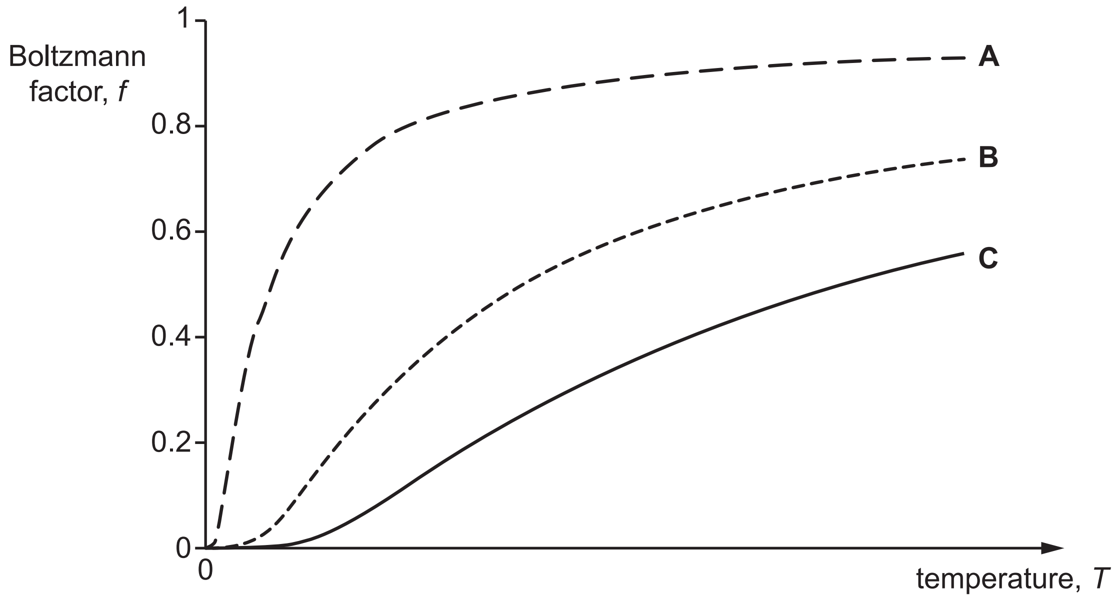

Fig. 5.1

(a) Explain how the graphs in Fig. 5.1 show that line **C** represents the process with the greatest activation energy *E*.

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....

.... **[3]**

(b) This part of the question is about the evaporation of liquids; the process in which molecules of the liquid gain sufficient energy to enter into the vapour.

(i) The Boltzmann factor for water molecules escaping the liquid and entering the vapour state is 4.9×10^{-8} at 310 K.

Calculate the activation energy required for a water molecule to escape into the vapour state at this temperature.

activation energy = ... J **[3]**

(ii) Explain how particles with an average energy lower than the activation energy gain enough energy to escape into the vapour.

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[2]

(iii)* The activation energy for a molecule of ethyl alcohol to escape into the vapour state is 6.6×10^{-20} J.

Calculate the Boltzmann factor at 310 K for this process and use ideas from the question to explain why a drop of ethyl alcohol feels colder on the skin than a drop of water.

[6]

6 This question is about muon decay. Muons are charged leptons. They are formed by cosmic rays interacting with the upper atmosphere.

The decay equation of a negative muon, μ^- is:

$$\mu^- \rightarrow e^- + \bar{\nu} + \nu$$

where $\bar{\nu} + \nu$ represent an antineutrino and a neutrino respectively.

(a) Explain how the decay equation shows that charge and lepton number are both conserved and name one other property that is conserved in the decay.

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....

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.... **[3]**

(b) The maximum total energy of the particles formed from the muon is about 106 MeV.

Show that this suggests that the mass of the muon is about 200 times that of an electron.

[3]

(c) Muons travel through the atmosphere at 98% of the speed of light.
The half-life of a muon at rest is about 1.5×10^{-6} s. Show that about 0.0005% of the original muons will remain after travelling 8 km through the atmosphere, ignoring relativistic effects.

[3]

(d) (i) In a measurement it is found that about 9% of the muons remain after travelling through 8 km of atmosphere.
Explain why a greater number of muons remain than suggested by the non-relativistic calculation in **(b)**.

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.... **[3]**

(ii) Use your answer to **(c)** and the measured value of 9% of muons remaining after passing through 8 km of atmosphere to calculate the relativistic factor γ for the muons.

relativistic factor $\gamma =$ .... **[3]**

SECTION C

Answer **all** the questions.

This section is based on the Advance Notice article, which is an insert.

7 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.

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.... **[2]**

8 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]**

9 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.

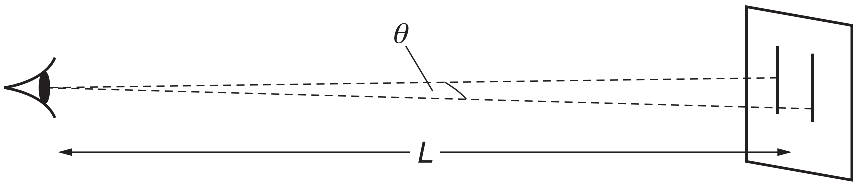

Fig. 9.1

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.

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.... **[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 $\theta_{min} = \dfrac{\text{wavelength of light}}{\text{diameter of pupil of the eye}}$.

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]**

10 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]**

11 Explain why turbulence in the atmosphere limits the resolution of ground-based optical telescopes (lines 7–39).

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.... **[2]**

12* 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]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

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A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Insert

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Time allowed: 2 hours 15 minutes

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.

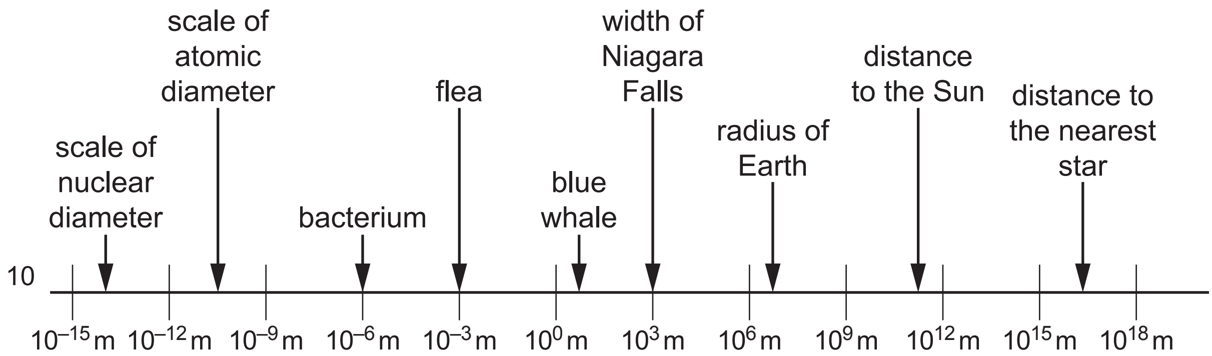

Fig. 1

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.

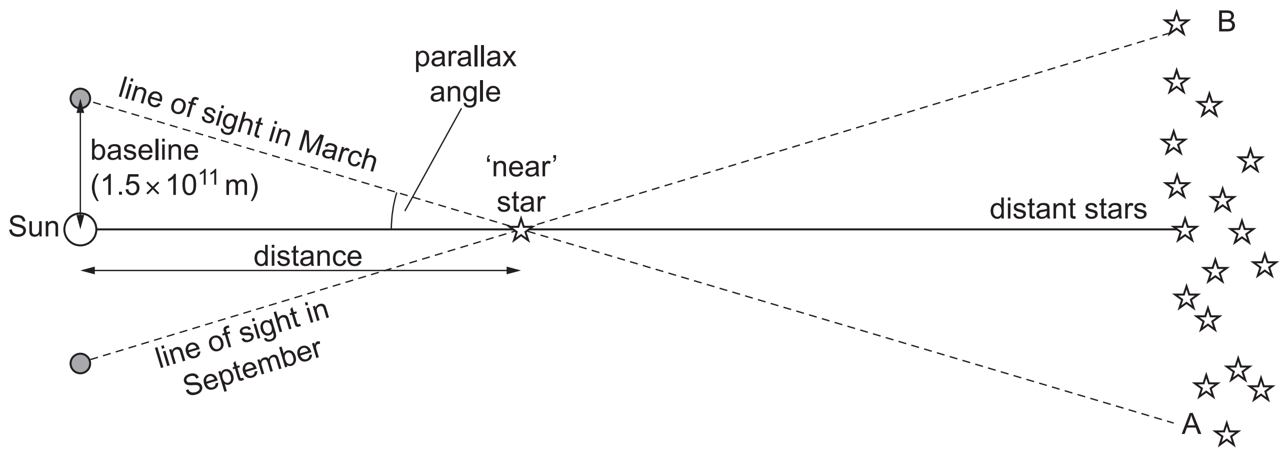

Fig. 2

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.

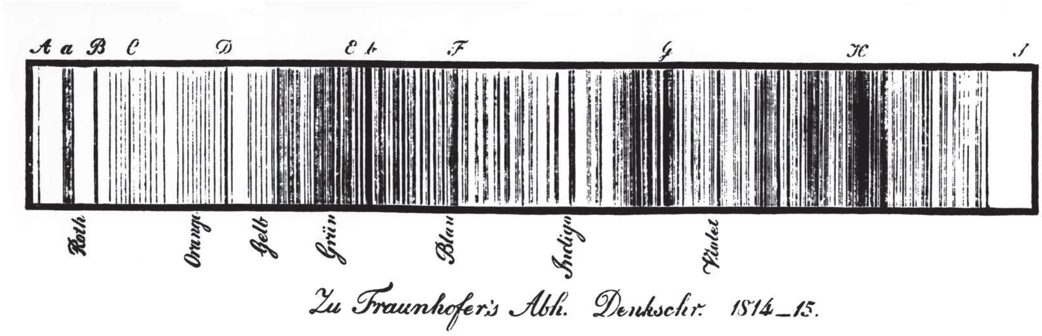

Fig. 3

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 $\propto \frac{1}{r^2}$ 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.

END OF ADVANCE NOTICE ARTICLE

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