Oxford Cambridge and RSA

Thursday 15 October 2020 – Morning

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Time allowed: 2 hours 15 minutes

You must have:
- a clean copy of the Advance Notice Article (inside this document)
- the Data, Formulae and Relationships Booklet

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

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) ______________________

Last name ______________________

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **28** pages.

ADVICE
- Read each question carefully before you start your answer.

SECTION A

Answer **all** the questions.

1 A student connects the circuit shown in **Fig. 1.1**.

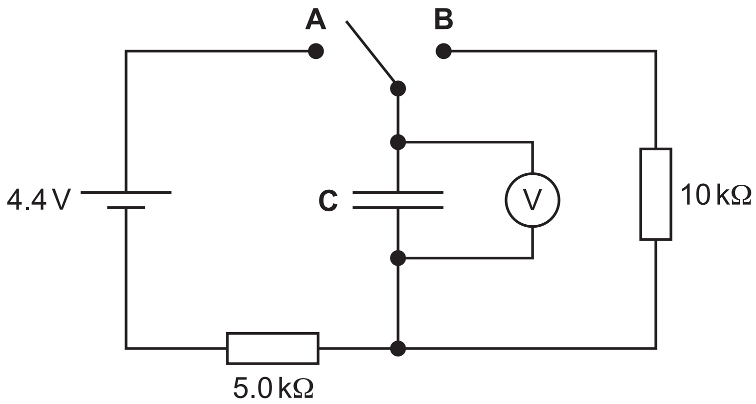

Fig. 1.1

The student uses a data logger to take readings of p.d. over time when the switch is put in position **A**. She obtains the results displayed in **Fig. 1.2**.

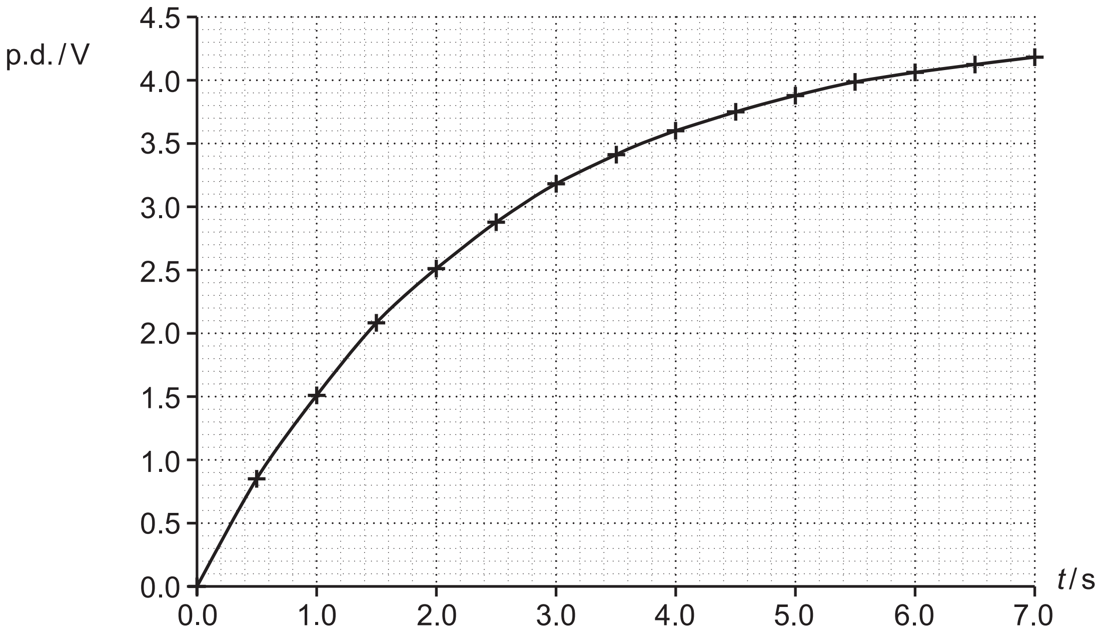

Fig. 1.2

(a) **(i)** Suggest why the student chooses to use a data logger rather than a digital meter.

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.... **[1]**

(ii) Use data from the graph to show that the capacitance of **C** is about 500 μF.

[3]

(iii) Calculate the energy stored in the capacitor when the p.d. across it is 4.2 V (at t = 7.0 s).

energy = ... J **[2]**

(b) (i) When the capacitor is charged to 4.2 V, the student resets the data logger to t = 0.0 s and moves the switch from position **A** to position **B**.

Draw a line on **Fig. 1.2** to show how the p.d. across the capacitor will change from t = 0.0 s to t = 7.0 s. Explain your reasoning.

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.... **[3]**

(ii) Calculate the time from the beginning of the discharge for the energy stored on the capacitor to fall to half its value.

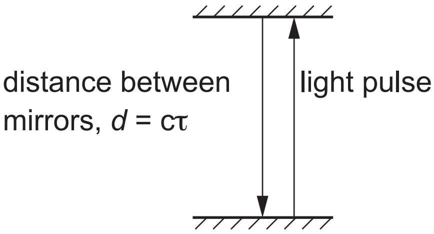
time = ... s **[3]**

2 Albert Einstein published his theory of Special Relativity in 1905. Central to the theory is the statement that the speed of light is constant for all observers.

A passenger on a train is holding a ‘light clock’. This is a pair of mirrors with a pulse of light bouncing between them as shown in **Fig. 2.1**. The distance between the mirrors can be measured in ‘light seconds’, the distance covered by light in one second.

In **Fig. 2.1**, this distance $d = c\tau$ where c is the velocity of light and τ is the time taken for the pulse to travel from the bottom mirror to the top mirror, as measured by the passenger holding the light clock.

One ‘tick’ of the light clock is the time for the pulse to travel to the top mirror and back (2τ).



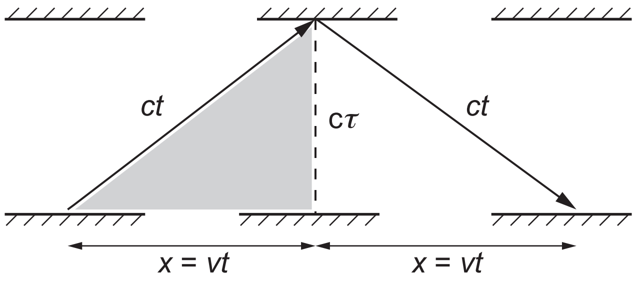
Light beam observed by the passenger on the train.

Fig. 2.1

(a) The mirrors are a distance of 0.80 m apart. Calculate this distance in light seconds.

distance = ... light seconds
[1]

(b) The train moves at constant velocity v relative to an observer on the platform. The observer sees the light pulse take the path shown in **Fig. 2.2**.



Light pulse seen by the observer on the platform.

Fig. 2.2

(i) Explain why the 'ticks' will be further apart for the observer on the platform than for the passenger on the train.

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.... **[2]**

(ii) Use Pythagoras's theorem to show that, for the shaded triangle in **Fig. 2.2**, $t = \dfrac{\tau}{\sqrt{1 - \dfrac{v^2}{c^2}}}$.

[2]

(c) Slow neutrons outside the nucleus have a half-life of 611 s. ‘Fast’ neutrons released in a fission reactor typically have speeds of up to $5.4 \times 10^7\,\mathrm{m\,s^{-1}}$. Calculate the half-life of a neutron travelling at $5.4 \times 10^7\,\mathrm{m\,s^{-1}}$ as measured by a stationary observer.

half-life = ... s **[2]**

(d) It has been said that, ‘from the point of view of a photon, it takes no time to cross the Universe’. Use the equation in **(b)(ii)** to explain this statement.

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.... **[2]**

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Question 3 starts on page 8

3 An electron in a hydrogen atom moves from the $n = 3$ to the $n = 2$ energy level as represented in **Fig. 3.1**.

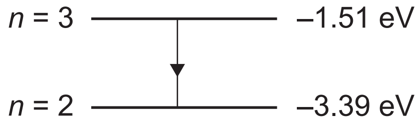

Fig. 3.1

(a) Calculate the wavelength of the light released by the electron.

wavelength = ... m **[2]**

(b) The 'striking potential' of a light emitting diode (LED) is the potential difference across the diode when it just begins to glow. The energy transferred to an electron crossing this potential difference is equal to the energy of the photon released.

In an experiment to determine a value for the Planck constant, a student increases the potential difference across an LED and records the value when the LED just begins to glow. She repeats this for LEDs emitting different wavelengths and plots a graph of striking potential against $\frac{1}{\lambda}$ as shown in **Fig. 3.2**. She included uncertainty in the potential difference readings. She used the manufacturer's data for the wavelength of light emitted.

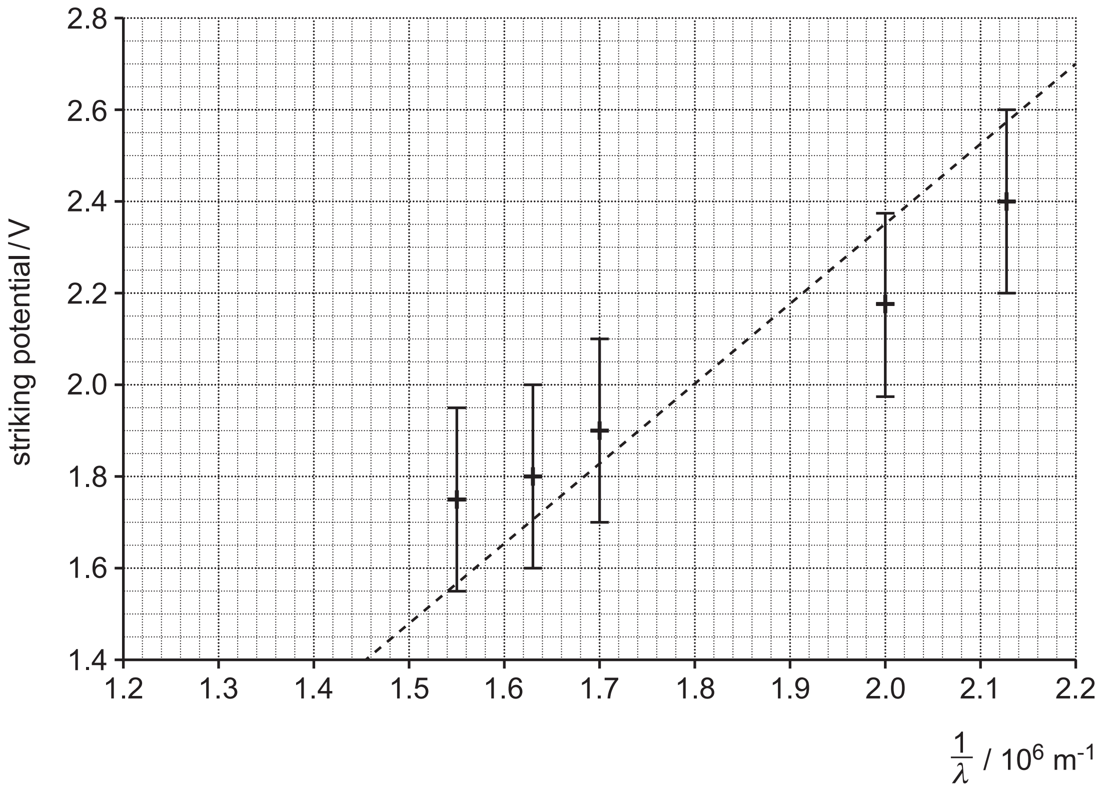

Fig. 3.2

(i) A 'steepest-possible' line has been drawn. Add a best-fit line to the graph.

[1]

(ii) Show that the Planck constant is related to the gradient of the graph by the equation $h = gradient \times \frac{e}{c}$ where e is the charge on an electron and c is the velocity of light.

[2]

(iii) Find a value of the Planck constant from your best-fit line on **Fig. 3.2**. Show all your working.

Planck constant = ... J s **[3]**

(iv) The gradient of the 'steepest-possible' line is 1.74×10^{-6} V m. Use this to calculate an estimate of the uncertainty of the value for the Planck constant in **(b)(iii)**. State your value of the Planck constant together with its uncertainty.

Planck constant = ... ± .... J s **[3]**

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Question 4 starts on page 11

SECTION B

Answer **all** the questions.

4 This question is about imaging using a simple mobile phone camera.

(a) The lens system of the camera acts like a single lens of focal length 3.85 mm. Calculate the curvature added to waves when they pass through the lens.

curvature added to waves = ... D **[1]**

(b) Use ideas about curvature of waves to explain why the lens cannot form an image of an object closer than or equal to 3.85 mm from the lens.

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.... **[2]**

(c) The light-sensitive surface in the camera is fixed 3.85 mm behind the lens. The image recorded on this surface will be clear if the true position of the image is within ± 0.1 mm of the surface.

Explain, with calculations, why the image on the light-sensitive surface will be clear if the object is 1.2 m from the lens, but the image of an object 0.05 m from the lens will not be clear.

[3]

(d) The camera is used to form an image of a resin chess piece **Fig. 4 a**. The chess piece is 0.090 m long. It is 0.35 m from the lens.

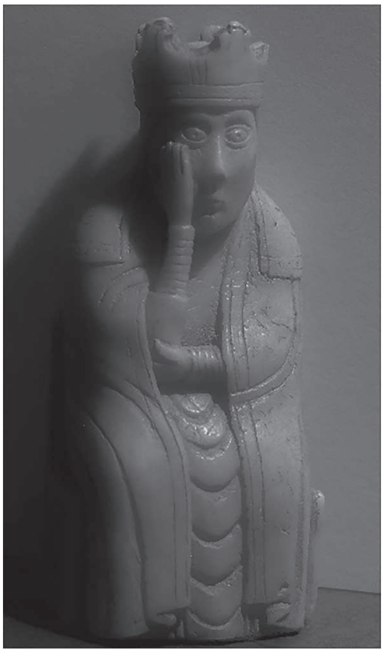

Image recorded by camera
Fig. 4 a

Processed image
Fig. 4 b

Calculate the length of the image of the chess piece on the light-sensitive surface.

length of image = ... m **[2]**

(e) There are 12×10^6 square pixels on the rectangular light-sensitive surface.
The dimensions of the surface are 4.89 mm × 3.65 mm.

Use these data and your answer from **(d)** to calculate the resolution of the image.

resolution of image = ... m **[4]**

(f) The image in **Fig. 4 b** has been processed. Identify a change that has been made in the image and explain how the data producing the image has been altered. Explain why quick and easy image processing using smartphones can be both a benefit and a problem for society.

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.... **[4]**

5 A student uses the apparatus shown in **Fig. 5.1** to investigate 'bungee jumping', a sport where players drop from a high point such as a bridge while attached to a long elastic cord which stretches just enough to stop them hitting the ground.

The student measures the maximum extension of the cord when the tennis ball is dropped from the position shown.

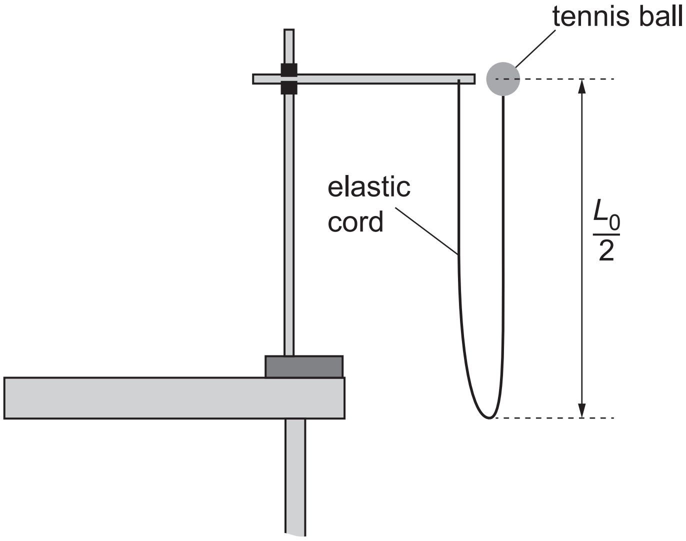

Fig. 5.1

Data:

Unstretched length of elastic cord L_0 = 1.15 m

Mass of tennis ball = 0.059 kg

The mass of the cord and the effects of air resistance are assumed to be negligible.

(a) **(i)** The cord stretches to a length L_1 = 1.31 m when the tennis ball hangs from it. Show that the force constant of the cord is about 3.7 N m^{-1}.

[1]

(ii) Calculate the energy stored in the cord at this length.

energy stored = ... J **[2]**

(iii)* The student releases the ball from the position shown in **Fig. 5.1**. It first stops when the length of the cord is stretched to $L_2 = 1.78\,\text{m}$.

Using ideas about the forces acting on the ball, describe **and** explain the changes in velocity and acceleration of the ball as it falls from the moment it is released to the moment the cord is at length L_2. State the length of the cord when the ball reaches maximum velocity and calculate a value for the maximum upwards acceleration. **[6]**

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Additional answer space if required

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(iv) Suggest and explain how the student could reliably measure, to the nearest centimetre, the maximum extension of the cord at the instant the tennis ball stops descending.

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.... **[2]**

(b) In the sport of bungee jumping, the jumper is tied to a long bungee rope and leaps from a high point. The bungee rope stretches until the jumper stops falling and is pulled upwards. Bungee ropes are made of polymers which can extend elastically to far higher strains than metal cables. Use the microscopic structure of polymers and metals to explain this difference in behaviour and why such polymer-based ropes are suitable for bungee-jumping cords. You may include diagrams in your explanation.

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.... **[4]**

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Question 6 starts on page 18

6 The satellite NOAA-20 was launched in November 2017. The satellite has an approximately circular orbit at an altitude of 825 km above the Earth's surface. The radius of the Earth = 6.4×10^6 m.

Fig. 6.1 shows how the gravitational field strength *g* of the Earth varies with distance *r* from the centre of the Earth.

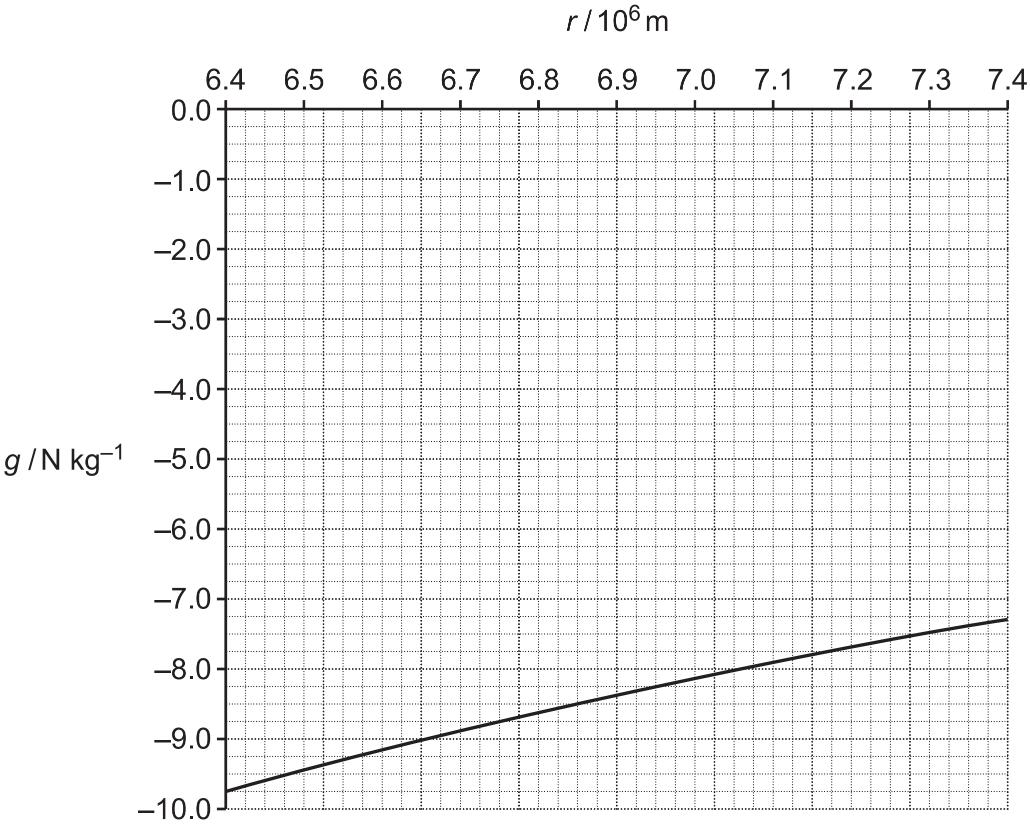

Fig. 6.1

(a) (i) The mass of the satellite is 2300 kg. Use the graph to show that the change in gravitational potential energy of the satellite between its launch and its position in orbit is about 1.6×10^{10} J. Explain your method.

[3]

(ii) Use the value for the change in potential energy from **(a)(i)** to show that the mass of the Earth is about 6×10^{24} kg.

[3]

(b) **(i)** Calculate the force on the satellite when orbiting at a height of 825 km above the Earth's surface.

force = ... N **[2]**

(ii) Calculate the time taken for one orbit of the satellite.

time = ... s **[3]**

(c) The satellite takes a polar orbit, revolving around the Earth from pole to pole, as shown in **Fig. 6.2**.
Geostationary satellites orbit at a greater distance from the Earth and remain above the same point on the surface at all times.

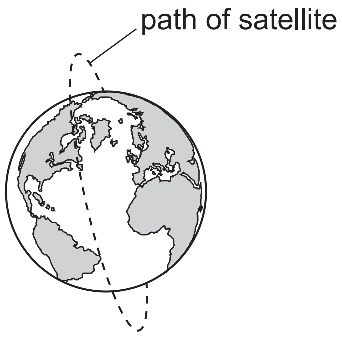

Fig. 6.2

Explain why a low, polar orbit is useful for satellites used for weather forecasting and suggest why geostationary satellites are used for telecommunications.

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.... **[3]**

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Question 7 starts on page 22

SECTION C

Answer **all** the questions.

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

7 This question is about some of the physics of the flute (lines 8–42).

Fig. 7.1 represents the waveform of a note played on a flute-like instrument which acts as an open pipe. The waveform is a superposition of the first harmonic (fundamental) and the second harmonic.

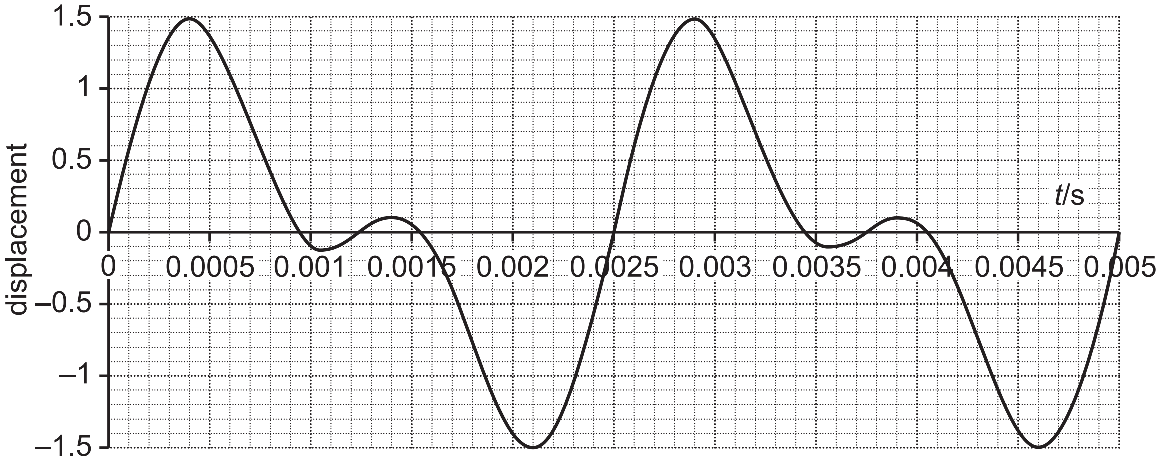

Fig. 7.1

(a) Use the graph to find the frequency of the first harmonic.

frequency = ... Hz **[1]**

(b) State the minimum sampling frequency required to accurately digitise the waveform. Explain your answer.

minimum sampling frequency = ... Hz

Explanation:

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.... **[3]**

(c) The velocity of sound in air is proportional to the square root of the kelvin (absolute) temperature.

(i) State why the note produced by a flute will increase in frequency when the temperature of the air in the flute rises.

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.... **[1]**

(ii) A flute sounds a note frequency 440 Hz when the temperature of the air in the tube is 285 K. Calculate the temperature rise needed for the same length tube to produce a note of frequency 445 Hz.

temperature rise = ... K **[2]**

8 This question is about radiocarbon dating (lines 44–61).

(a) Carbon-14 decays by beta emission. Identify the particle **X** in the equation below and state how it ensures that lepton number and mass-energy is conserved in the decay.

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{......}_{......}X$$

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.... **[3]**

(b) Radiocarbon dating uses a value for the half-life of $^{14}C = 5.70 \times 10^{3}$ years.

The $^{14}C/^{12}C$ ratio in living material is about 1.4×10^{-12}.

Calculate the $^{14}C/^{12}C$ ratio from a sample of carbon taken from a 9000-year-old specimen, such as the ancient Chinese flute.

ratio = ... **[2]**

(c)* Explain why living plants growing near active volcanoes may have radiocarbon ages that suggest they have been dead for hundreds of years. Include a calculation to illustrate your reasoning, for example by calculating the effect of including 10% 'ancient carbon' with a vanishingly small $^{14}C/^{12}C$ ratio in a sample of living material. Explain how such effect of ancient carbon on dating samples can be taken into account if living trees are found in the same area as the sample to be dated. **[6]**

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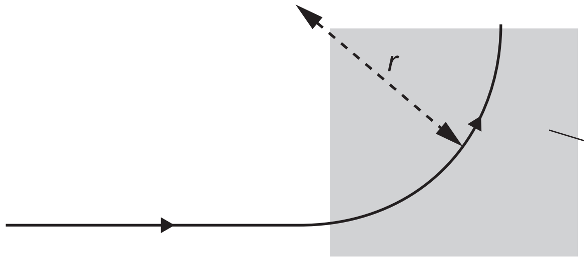
9 This question is about accelerator mass spectrometry (lines 83–107).

(a) A doubly-charged carbon-14 atom is accelerated through a potential difference of 4.2 MV and enters a uniform magnetic field of strength 0.72 T. Use the equation given in line 102 to find *r*, the radius of the circular arc it follows.



beam of $^{14}C^{2+}$ ions

Data: mass of $^{14}C^{2+}$ ion = 2.33×10^{-26} kg

radius of arc = ... m **[3]**

(b) Explain why it is important to ensure that no $^{12}CH_2^{2+}$ and $^{13}CH^{+}$ ions reach the second deflecting magnet (See **Fig. 6** in the Advance Notice Article).

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.... **[2]**

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).

Oxford Cambridge and RSA

Thursday 15 October 2020 – Morning

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Advance Notice Article

Time allowed: 2 hours 15 minutes

INSTRUCTIONS
- Do **not** send this Advance Notice Article for marking. Keep it in the centre or recycle it.

INFORMATION
- This is a clean copy of the Advance Notice Article you have already seen.
- This document has **8** pages.

A date with the past

A number of flutes uncovered in an archaeological dig in China have been dated at around 9000 years old. The flutes, made from wing bones of large birds, are amongst the oldest playable musical instruments found. Although these ancient instruments look different from modern flutes or recorders, the physics that explains how the sounds are produced is the same for both new and very old instruments.

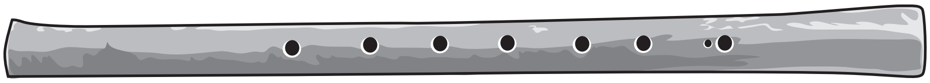
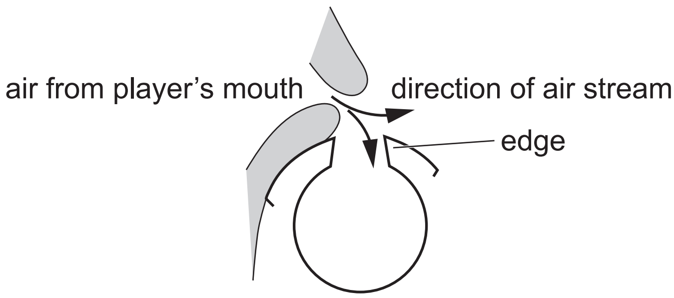


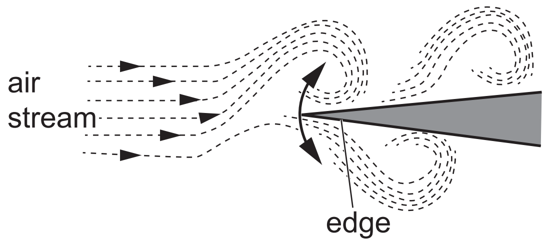
Fig. 1 ancient Chinese flute

Some physics of the flute

All flute-like instruments work on the same basic principles. The player directs a stream of air across an edge. This makes the edge oscillate as the air stream goes above and below the edge as shown in Fig. 2 and Fig. 3.



player forcing a stream of air across an edge
Fig. 2



oscillation of air stream over an edge
Fig. 3

The oscillation of the edge sends pressure waves down the tube which are reflected back up to the edge. The time taken for the wave to travel up and down the tube depends on the speed of the wave and the length of the tube. The edge will initially vibrate over a range of frequencies but after a very short time will vibrate with a frequency matching the frequency of the pressure wave in the tube. This happens because the vibration of the air in the tube will drive the same frequency vibration of the edge. This feedback mechanism produces a standing wave in the tube; this is the wave that determines the frequency of the note you hear. The speed of sound in air increases with temperature so the frequency of the note sounded by a flute will rise when the player’s breath warms the air in the tube.

Flutes are **open pipes**. Waves in open pipes have an antinode near each end of the pipe (where one end is the bottom of the tube and the other is near the oscillating edge) as shown in Fig. 4a. If the flute player makes the edge oscillate at twice the frequency, a standing wave of half the wavelength is produced, as shown in Fig. 4b. Further higher frequency, shorter wavelength standing waves can also be produced. In fact, a number of such higher frequency waves are produced at the same time so the note we hear from the flute is produced by superposition of waves of different frequencies simultaneously. The air in open pipes oscillates at the ‘first harmonic’, f_1, and at integer multiples of f_1. The second harmonic has frequency $f_2 = 2\,f_1$ and so on.

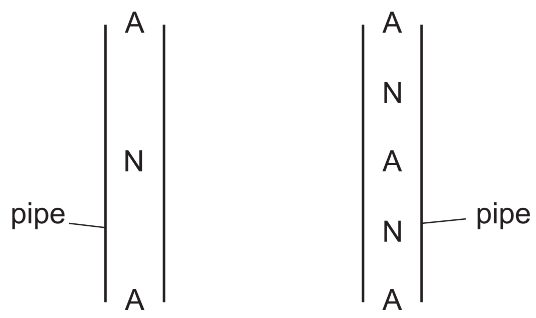


Fig. 4a
first harmonic

Fig. 4b
second harmonic

When a flute plays its lowest note, the frequency of the note you hear matches that of the first harmonic. The relative amplitude of the other harmonics in the note changes the shape of the waveform and gives the instrument its tone or *timbre*. This is why a flute producing a note of a given frequency sounds different from the same note produced on a different instrument; the first harmonic is the same frequency but the recipe of the higher harmonics on different instruments changes the superposition pattern of the waves. This is shown in Fig. 5a and b in which the second harmonic has a smaller amplitude than the first, producing the superposition shown.

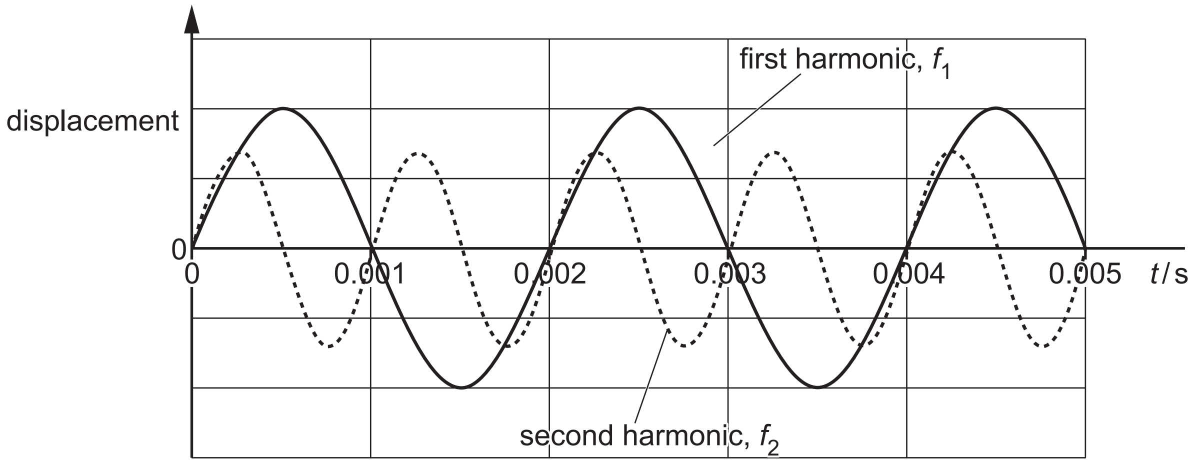


Fig. 5a

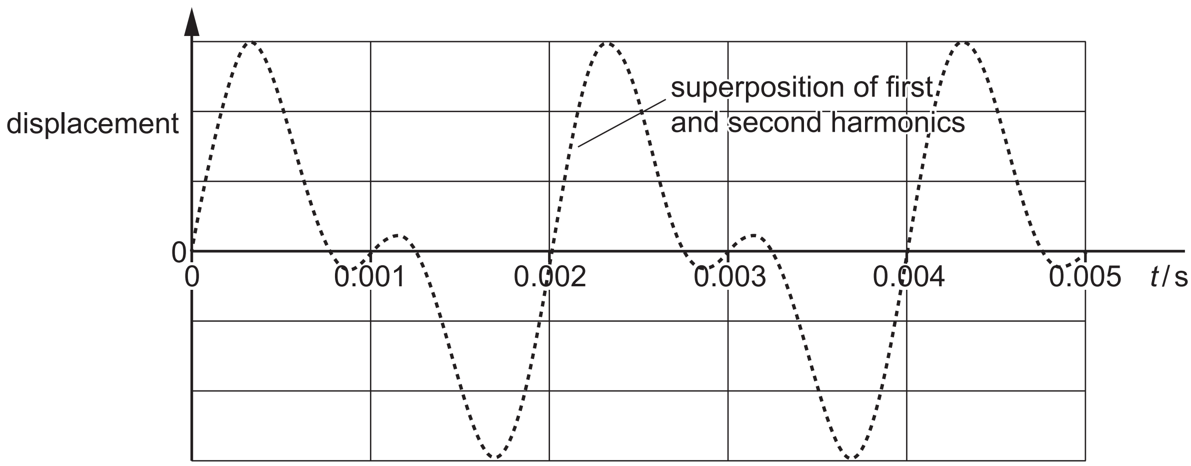


Fig. 5b

Dating the instruments

The age of the Chinese flutes was determined using ‘radiocarbon dating’. Nearly all carbon on Earth is ^{12}C but about 1.1% is ^{13}C and about 1×10^{-10} % is ^{14}C. Carbon-14 nuclei are produced in the upper atmosphere when neutrons derived from cosmic rays interact with nitrogen nuclei as shown in the equation:

$$^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + {}^{1}_{1}p .$$

The ^{14}C nucleus undergoes beta decay into a ^{14}N nucleus. The half-life of the carbon-14 nuclide is around 5.70×10^3 years. For any sample of biological material, R is the ratio of the number of ^{14}C nuclei to the number of ^{12}C nuclei, usually referred to as ‘the $^{14}C/^{12}C$ ratio’. In all living matter, this ratio $R = R_0$, which is constant, approximately the same as the ratio in air and has a value of about 1.4×10^{-12}. R_0 remains roughly constant because the decayed ^{14}C is continuously replaced with ‘new’ nuclei formed in the upper atmosphere.

Atmospheric ^{14}C reacts with oxygen to form carbon dioxide which is taken up by plants through photosynthesis and then enters the food chain. When an organism dies it will no longer absorb ^{14}C so its $^{14}C/^{12}C$ ratio will fall over time. This means that by determining the ratio of $^{14}C/^{12}C$ (or $^{14}C/^{13}C$), the age of the organism or artefact made from once-living material (such as a flute made from a bird bone) can be found. The age of the material (the time since death, t) is given by the equation $t = -\frac{1}{\lambda}\ln\left(\frac{R_t}{R_0}\right)$ where R_t is the ratio of $^{14}C/^{12}C$ in the specimen to be dated and λ is the decay constant of the carbon-14 nuclide.

Changes in the ratio

The carbon-14 originally present in the organic matter that makes up fossil fuels is now present in vanishingly small amounts. This means that the proportion of carbon-14 in the atmosphere since the growth of burning of fossil fuels has reduced. A similar effect is found near volcanoes where plants photosynthesise carbon dioxide produced from ancient carbon, reducing the $^{14}C/^{12}C$ ratio in the still-living plants. Material from the sea also has a different $^{14}C/^{12}C$ ratio from organic material from the land because deep sea water, which has a lower $^{14}C/^{12}C$ ratio than the atmosphere, gradually mixes with surface water. Although ^{14}C is more likely to dissolve in the ocean than ^{12}C, the effect of the water mixing means that a living fish, which should have a radiocarbon age of 0, can appear to have a radiocarbon age of 400 years as the oceanic and atmospheric $^{14}C/^{12}C$ ratios are different.

Finally, the atmospheric testing of nuclear bombs in the 1960s increased the number of neutrons in the atmosphere which again changed the proportion of $^{14}C/^{12}C$. All these effects have to be taken into account when estimating ages using radiocarbon dating.

One way to calibrate the ages found through radiocarbon dating is by comparing radiocarbon ages with ages found by counting tree rings. Each year a tree will add a new ring to its trunk as it grows. The carbon in the new ring will have the atmospheric $^{14}C/^{12}C$ ratio at the time of growing, but as soon as it stops growing the ratio will decrease. The rings near the centre of the tree trunk will have lower ratios than the outer rings. The age of the tree can be found by simply counting the rings and compared to the age determined by radiocarbon dating.

Counting carbon-14

Radiocarbon dating depends on establishing the ratio of $^{14}C/^{12}C$ in the specimen. Early measurements used the 'direct counting' method in which the activity of a known mass of carbon is measured to determine the $^{14}C/^{12}C$ ratio. This method can't be used for samples older than a few half-lives because the count rate becomes so low. Most radiocarbon dating now uses the process of accelerator mass spectrometry, first developed in the 1970s.

The carbon sample to be tested is turned into graphite. Negative carbon ions from the graphite and ionised molecules of similar mass (such as $^{12}CH_2^{2-}$ and $^{13}CH^-$) are selected by the first deflecting magnet. These pass through a 'tandem accelerator'. The ions accelerate through a p.d. of a few MV before passing through a 'stripper' that removes electrons from the ions, making them positive (C^+, C^{2+}, C^{3+} or C^{4+}). This process also breaks up any accelerated polyatomic ions such as $^{13}CH^-$. Positive ions of ^{12}C, ^{13}C and ^{14}C are accelerated through a second potential difference of the same magnitude as the first. The second deflection magnet can be tuned to select for each isotope of carbon, allowing the $^{14}C/^{12}C$ ratio of the sample to be found by determining the numbers of each isotope that pass through the accelerator.

Fig. 6 shows a simplified schematic diagram of the process.

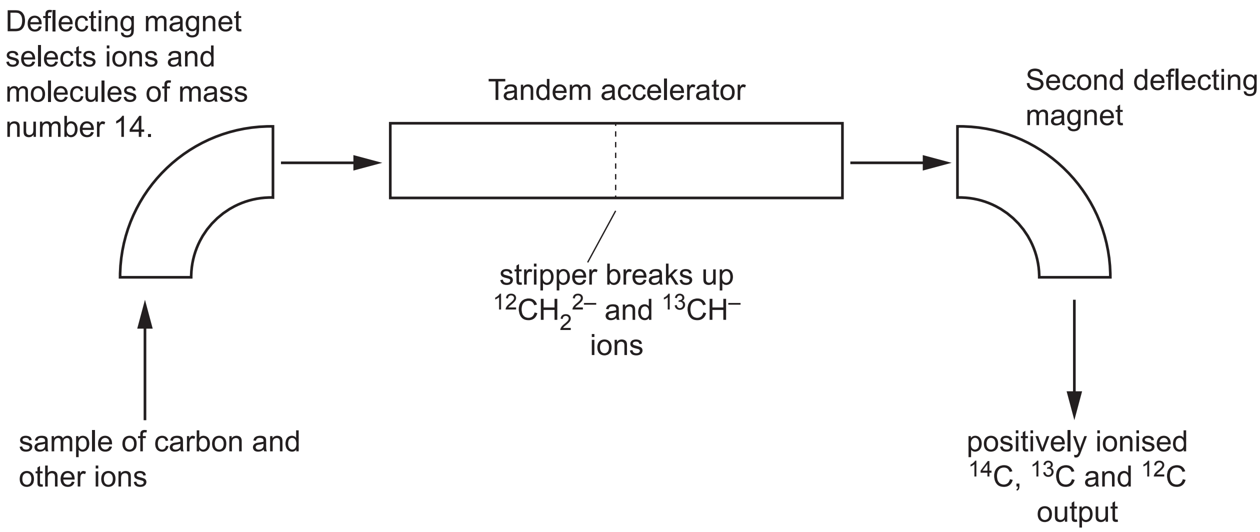


Fig. 6

The deflecting magnets produce a uniform magnetic field at right angles to the path of the ions. The interaction of the moving ions and the field results in a centripetal force on the ions which are deflected in a circular arc of radius *r* given by the equation $r = \frac{p}{Bq}$ where *p* is the momentum of the ion, *B* is the magnetic flux density and *q* is the charge on the ion.

Accelerator mass spectrometry helps archaeologists find the age of objects from a few milligrams of material, allowing the age of artefacts to be measured without damaging them. The ancient Chinese flutes are still playable after they have been dated, their eerie but recognisable sound giving a direct link to a long-vanished culture.

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