Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

1420U30-1

S25-1420U30-1

MONDAY, 2 JUNE 2025 – AFTERNOON

PHYSICS – A2 unit 3
Oscillations and Nuclei

2 hours 15 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1.**	**13**	
	2.	**16**	
	3.	**14**	
	4.	**15**	
	5.	**11**	
	6.	**11**	
Section B	**7.**	**20**	
	Total	**100**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

This paper is in 2 sections, **A** and **B**.

Section **A**: 80 marks. Answer **all** questions. You are advised to spend about 1 hour 35 minutes on this section.

Section **B**: 20 marks. Comprehension. You are advised to spend about 40 minutes on this section.

The number of marks is given in brackets at the end of each question or part-question.

The assessment of the quality of extended response (QER) will take place in question **4**(c).

VP/JS*(S25-1420U30-1)

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SECTION A

Answer **all** questions.

1. (a) The first law of thermodynamics may be expressed as:

$$\Delta U = Q - W$$

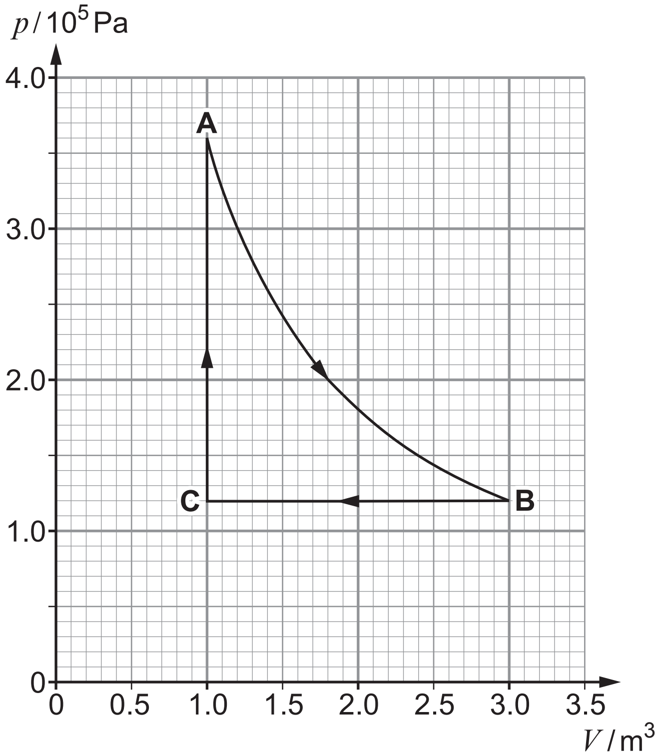
State what is represented by: [3]

ΔU ....

Q ....

W ....

(b) A cylinder fitted with a leak-proof piston containing 85 mol of a gas is taken through a closed cycle ABCA.



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(i) Sinead claims that the expansion **AB** takes place at a constant temperature of approximately 500 K. Evaluate this claim. [4]

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(ii) Determine the approximate amount of work done in the expansion **AB**. [2]

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(iii) Hence or otherwise, calculate the net heat flow over the whole cycle ABCA. [4]

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2. A weather balloon contains helium, which has a relative molecular mass of 4.0. At ground level, the volume of the balloon is $0.15\,m^3$ and the temperature of the helium is $20\,°C$. The helium is at atmospheric pressure, which is $1.01 \times 10^5\,Pa$.

(a) (i) Show that the balloon contains approximately 6 mol of helium. [3]

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(ii) Calculate the rms speed of the helium molecules in the balloon. [3]

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(iii) A sample of five helium molecules have speeds 950, 1200, 1325, 1500 and $1625\,m\,s^{-1}$. Explain whether the rms speed of this sample is consistent with your answer from (a)(ii). [3]

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(b) The balloon is released from the ground and reaches an altitude of 10 km. At this altitude, the temperature is far lower than at ground level.

(i) Explain what is meant by 'heat'. [1]

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(ii) Explain why the rate of flow of heat through the walls of the balloon eventually approaches zero. [2]

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(iii) At an altitude of 10 km, the pressure in the balloon reaches 28 kPa whilst the surrounding atmosphere is at a pressure of 25 kPa.

Natalie states, 'The rms speed of helium molecules in the balloon at this altitude is the same as that of the oxygen molecules in the atmosphere surrounding the balloon because they are at the same temperature'.

Mona states, 'The helium in the balloon and oxygen in the atmosphere must have different rms speeds as they are at different pressures'.

Evaluate these statements. (Relative molecular mass of oxygen = 32) [4]

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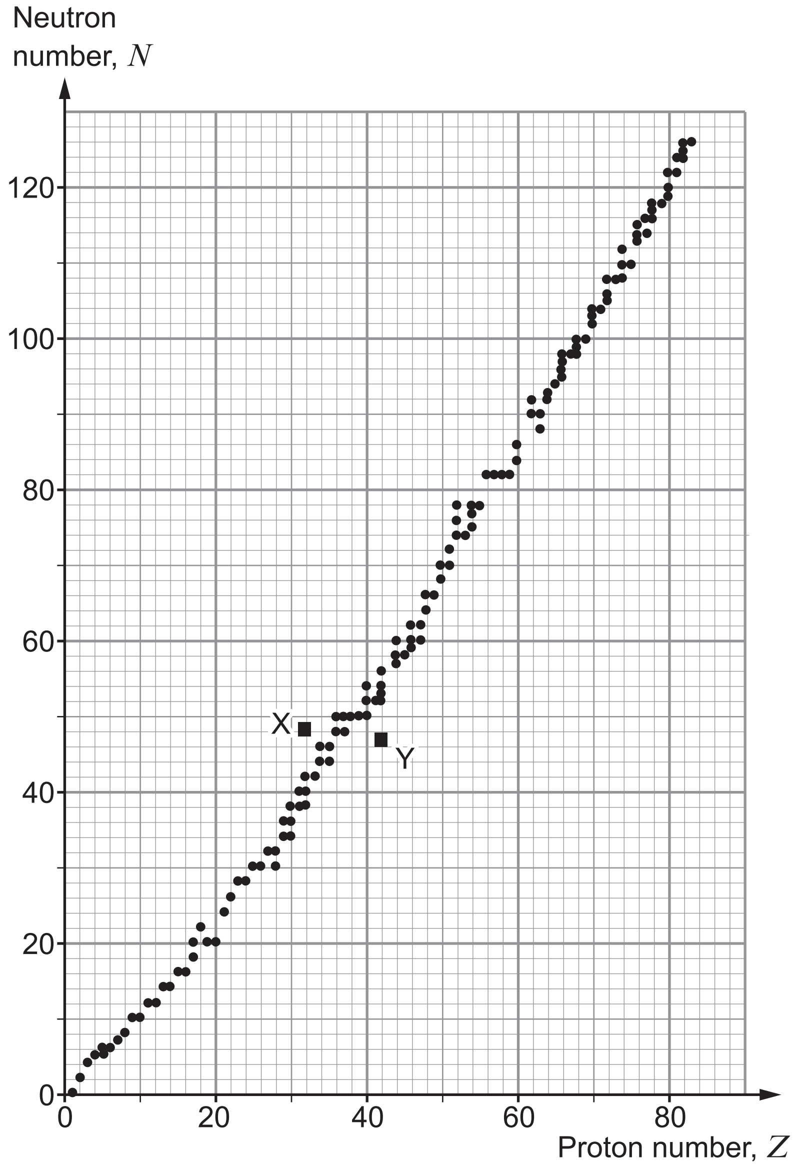
3. The graph is a plot of neutron number, N, against proton number, Z, for stable nuclei. Also plotted are the unstable nuclei X and Y.



(a) One of the unstable nuclei emits a β^- particle as it decays to become more stable.
Elliot states that the nucleus that emits a β^- as it decays is nucleus X.
Meg states that the nucleus that emits a β^- as it decays is nucleus Y.
Determine who is correct, explaining your reasoning. [3]

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(b) Define the half-life, $T_{\frac{1}{2}}$, of a radioactive substance. [1]

(c) Starting with the equation:

$$A = A_0 e^{-\lambda t}$$

Show, in clear steps, that:

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$ [3]

(d) The activity of a radioactive nuclide drops to 82% of its initial value in 730 years. Calculate its half-life. [4]

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(e) Ella carried out an experiment to model radioactive decay. She used a large number of identical **6**-sided dice. All dice had **2** sides painted black. She rolled the dice and removed those that landed with a black side facing upwards. The removed dice represented nuclei that had decayed.
Ella then repeated the experiment with a large number of **8**-sided dice. All dice had **3** sides painted black.
Each throw represented the same time interval.
Determine which of the dice (6-sided or 8-sided) represented the nuclei with the shorter half-life. Explain your reasoning. [3]

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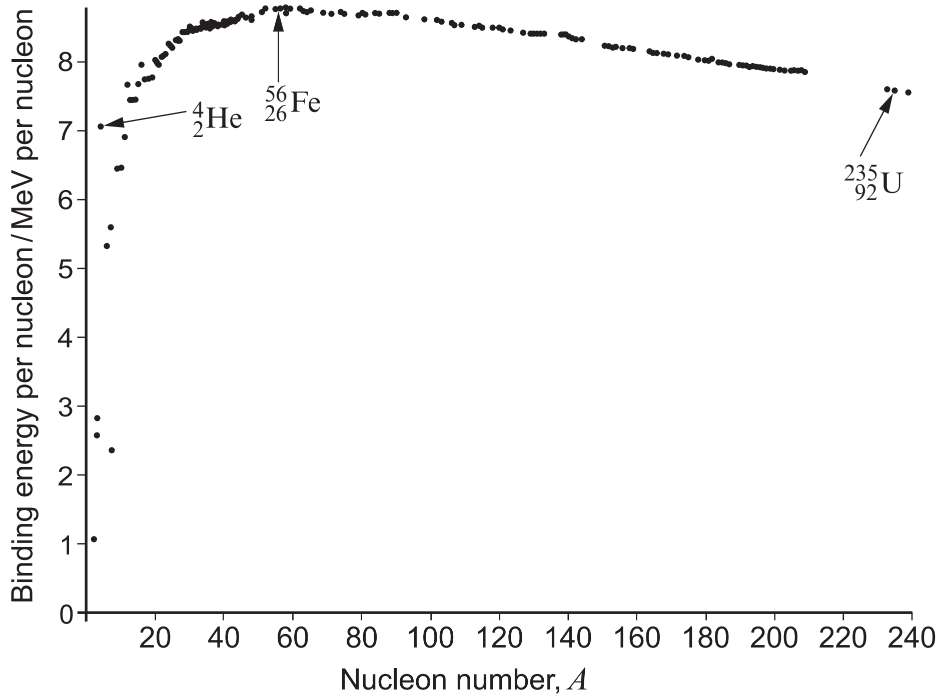
4. The graph below shows the binding energy per nucleon plotted against the nucleon number.



(a) **Circle** the region of the most stable nuclide. [1]

(b) State why $^{1}_{1}H$ has a binding energy per nucleon of zero. [1]

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(c) Use the graph to explain why energy is released during nuclear fusion and nuclear fission. [6 QER]

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(d) The nuclear fusion of deuterium (^2_1H) and tritium (^3_1H) may be used in future nuclear fusion power stations.

$$^2_1H + {}^3_1H \longrightarrow {}^4_2He + {}^1_0n$$

Calculate the energy released in this nuclear fusion reaction. Give your answer **in J**. [4]

mass of ^2_1H = 2.0136 u

mass of ^3_1H = 3.0155 u

mass of ^4_2He = 4.0015 u

mass of ^1_0n = 1.0087 u

1 u = 931 MeV

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(e) The UK government is investing £220 million to fund the first phase of the UK's first prototype nuclear fusion energy power station. Discuss whether this is a good use of public money. [3]

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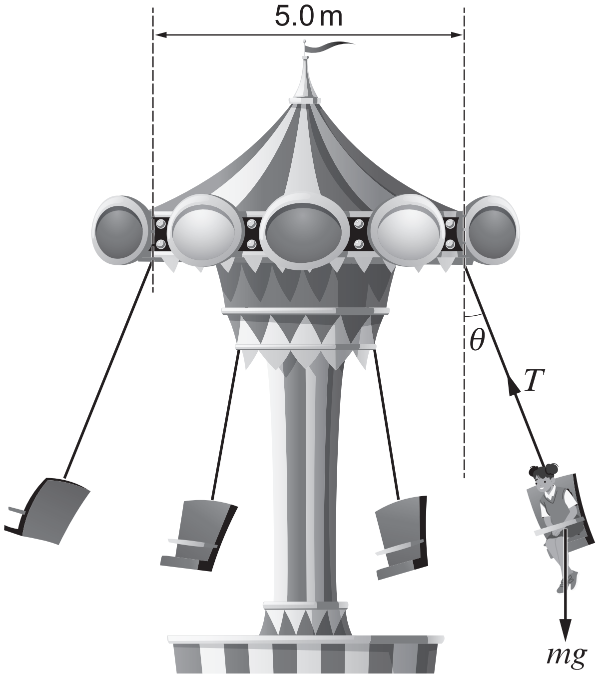
5. Rhiannon is sitting on a rotating ride in a fun fair. Her speed and the angle, θ, are constant.



(a) Explaining your reasoning, show that the tension, T, in the cable is given by:

$$T\cos\theta = mg$$ [2]

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(b) The distance between the top of the cable and Rhiannon's centre of mass is 3.0 m. Explain why the radius of Rhiannon's circular path is given by:

$$r = 2.5 + 3.0\sin\theta$$ [1]

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(c) The combined mass of Rhiannon and the seat is 52.0 kg and the tension in the cable is 550 N. Calculate:

(i) the angle θ; [2]

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(ii) the radius of Rhiannon's circular path; [1]

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(iii) Rhiannon's speed; [3]

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(iv) the period of motion. [2]

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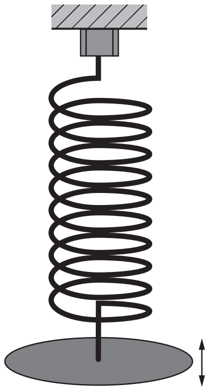
6. Ephraim investigates the damped oscillations of a mass on a spring. The mass is in the form of a disc with a large area as shown in the diagram.



(a) Explain what causes the motion of the disc to be damped. [2]

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(b) Ephraim starts the disc oscillating with an amplitude of 15.0 cm and measures the amplitude after every 5 complete oscillations. The data are shown in the table.

Number of oscillations	Amplitude (A)/cm $\pm$ 0.3	$\ln(A/\text{cm})$
0	15.0	2.71 $\pm$ 0.02
5	11.8	2.47 $\pm$ 0.03
10	8.9	2.19 $\pm$ 0.03
15	7.1	1.96 $\pm$ 0.04
20	5.3	1.67 $\pm$ 0.06
25	4.3	.... $\pm$ ....
30	3.5	1.25 $\pm$ 0.09

(i) **Complete the table.**
Hint: Consider the maximum and/or minimum possible values of $\ln(A)$.
Space for calculation. [2]

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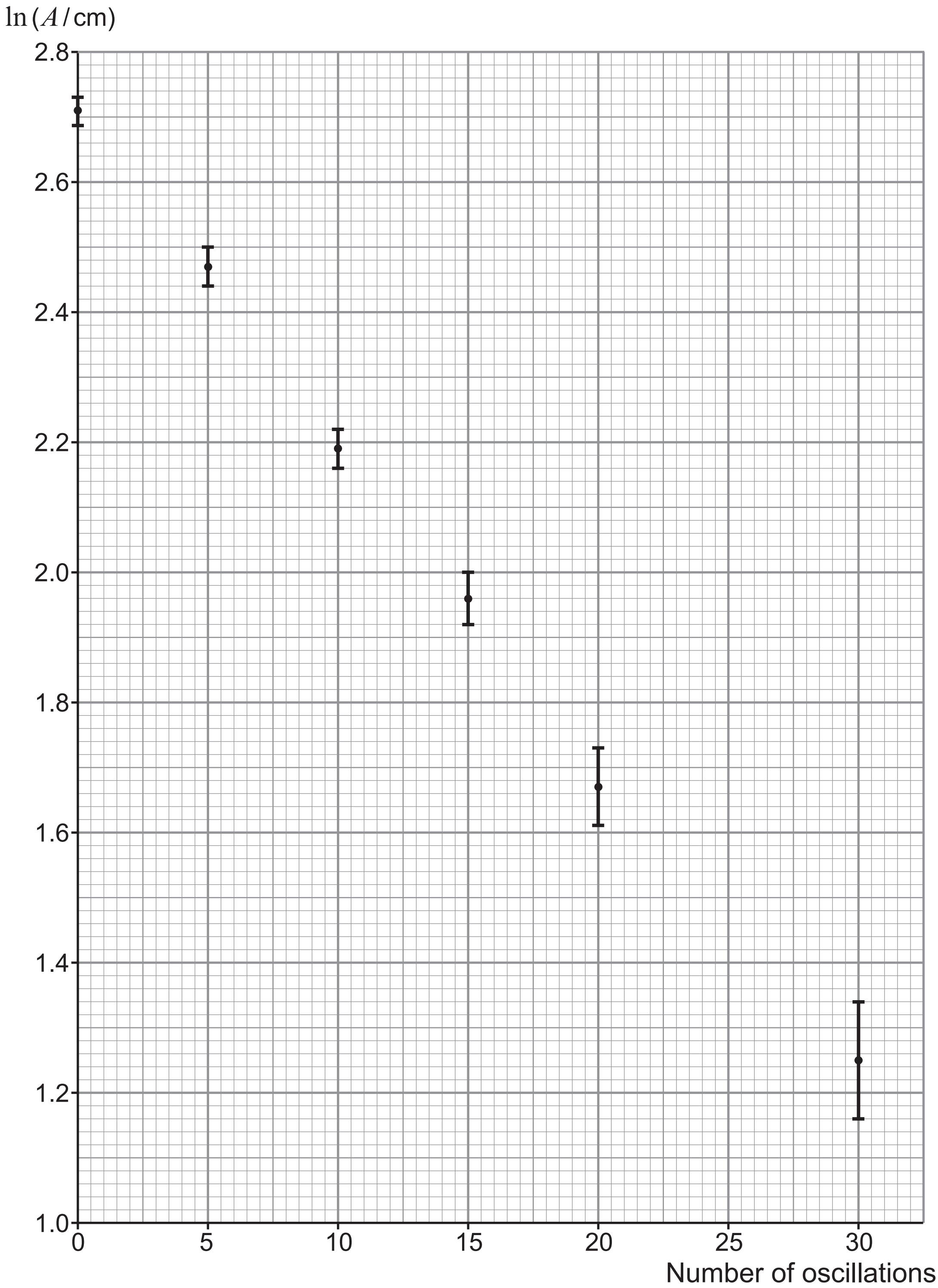
(ii) Ephraim plots a graph of the results. **Plot** the missing point and its error bar. [2]



Turn over.

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(iii) Ephraim expects the amplitude, A, of oscillation to decrease exponentially according to the equation:

$$A = A_0 e^{-kt}$$

where A_0 is the initial amplitude, t is the time and k is a constant. Discuss to what extent Ephraim's data confirm this relationship. [5]

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SECTION B

Answer **all** questions.

7. Read through the following article carefully. Paragraph

Are Cepheid variables giant stars or giant musical instruments?

Stars called Cepheid variables vary in brightness because they pulsate. Not a lot of people know this, but you can compare a Cepheid variable star with a tube having one end open and the other closed. The length of the tube will be a $\frac{1}{4}$ wavelength (for the fundamental frequency), whereas, in the star, the radius will be a $\frac{1}{4}$ wavelength. 1

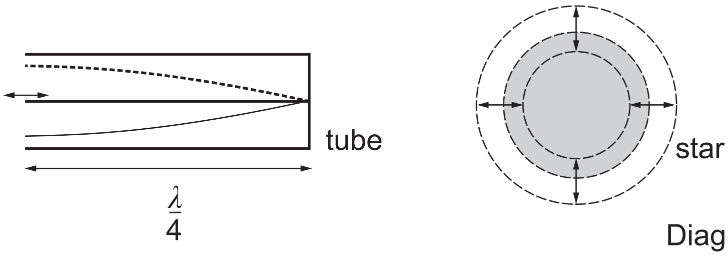

Diagram not drawn to scale

Hence, you can write the period, τ, of a Cepheid variable star as:

$$\tau = \frac{4R}{v} \qquad \textbf{Equation 1}$$ 2

where R is the radius of the star and v is the speed of sound in the star.

There is a well-known equation for the speed of sound in a gas and it is:

$$v = \sqrt{\frac{\gamma p}{\rho}} \qquad \textbf{Equation 2}$$ 3

where p is the pressure of the gas, ρ is the density of the gas and $\gamma = \frac{5}{3}$ for a monatomic gas (like the high energy hydrogen and helium found in stars).

According to a very important theorem in physics: 4

2 × the kinetic energy of the particles of the system = − the potential energy of the particles of the system **Equation 3**

For a star, we can write Equation 3 as:

$$2 \times \frac{3}{2}kT \times \frac{M}{m_{\mathrm{H}}} \approx \frac{GM^2}{R} \qquad \textbf{Equation 4}$$

where T is the temperature of the star, k is the Boltzmann constant, M is the mass of the star and m_{H} is the mass of a hydrogen nucleus.

When equations 1, 2 and 4 are combined with $p = \frac{1}{3}\rho\overline{c^2}$, the period of oscillation of a star is given by:

$$\tau \approx 4 \times \sqrt{\frac{3R^3}{\gamma GM}}$$ **Equation 5** 5

Even though the Sun is not a Cepheid variable, when one substitutes the Sun's mass and
radius (2×10^{30} kg and 7×10^{8} m respectively) into Equation 5, one obtains an expected 6
period of oscillation of just over 2 hours.

Fine, so we can calculate the period of oscillation of a star but why does the star oscillate
in the first place? It's not as if there's an organist there pressing a key to start the 7
oscillation.

To explain the origin of the oscillation we have to consider what happens to the star if it gets slightly hotter. If the conditions in the star are right, this increase in temperature will lead to ionisation. When the hydrogen (and helium) in a star become ionised they interact more with the light trying to escape from the core of the star. This ionised gas absorbs more of the light and gets hotter and hotter. This means that the pressure increases and
the star has to expand which moves the oscillation outward. As the star expands it cools 8
and eventually cools enough so that the hydrogen and helium are no longer ionised. This means that light can escape easily again and the cool gas at the outer regions of the star can fall back towards the centre. Eventually, the gas falls back so far that the work done in the compression is great enough to cause a sufficient increase in temperature leading, once more, to ionisation. This process will repeat over and over at the frequency which can be calculated by Equation 5.

We can detect these oscillations because the brightness of the star varies as the radius, temperature and ionisation change. And these oscillations are large – the radius can vary by around 25% and the brightness can vary by a factor of up to 100. However, with A Level Physics theory, it is difficult to predict which part of the cycle gives the maximum
brightness. One person might argue that the Cepheid variable would be brightest when 9
it is hottest and conclude that the star is hottest and brightest at its smallest radius. However, another student might argue that the star is brightest when at its largest radius because of the increased surface area. Unfortunately, the truth is more complicated – the star is brightest as it is expanding at its quickest rate, around the centre of the oscillation.

Historically, it is the relationship between the period of a Cepheid variable and its mean luminosity (or absolute magnitude) that is crucial. The first person to notice that the period of a Cepheid variable increased with its brightness was Henrietta Swan Leavitt at Harvard
University over 100 years ago. This relationship is now known as "Leavitt's Law" and led 10
to one of the most amazing discoveries of all time – the expanding Universe.

The intensity of light arriving from a distant star depends on two factors – the distance of the star and its luminosity. After Henrietta Leavitt, the mean luminosity of a Cepheid variable could be obtained from its period. This meant that the distance to the Cepheid
variable could be measured. Before Leavitt's Law, only the distances to nearby stars 11
in the Milky Way could be measured. After Leavitt's Law, Edwin Hubble was able to measure the distances to Cepheid variables in nearby galaxies.

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Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

(a) Show that the period of a Cepheid variable can be written as:

$$\tau = \frac{4R}{v}$$

See paragraphs 1 and 2. [3]

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(b) Explain why the left-hand side of Equation 4 is a good approximation to 2 × the kinetic energy of the particles of the star. [3]

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(c) Show that the right-hand side $\left(\frac{GM^2}{R}\right)$ of Equation 4 has the units of J (you may want to look at the front page of the Data Booklet to obtain the unit of G). [2]

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(d) (i) Use Equation 5 and the data in paragraphs 3 and 6 to determine whether the expected period of the Sun's oscillations is just over 2 hours. [2]

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(ii) Michele states that the expected period of oscillation of Jupiter is exactly the same as that of the Sun because its radius is 10× smaller and its mass is 1000× smaller. Determine whether Michele is correct. [2]

(e) In your own words, explain why Cepheid variables oscillate (see paragraph 8). [4]

(f) Explain how a Cepheid variable can be distinguished from a normal star by observation (see paragraph 9). [1]

(g) In your own words, explain how the distance to a Cepheid variable can be determined (see paragraphs 10 and 11). [3]

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END OF PAPER

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