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ADVANCED
General Certificate of Education
January 2009

Physics

Assessment Unit A2 1

assessing

Module 4: Energy, Oscillations and Fields

[A2Y11]

TUESDAY 13 JANUARY, AFTERNOON

Centre Number	
71	

Candidate Number

TIME

1 hour 30 minutes.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.
Answer **all six** questions.
Write your answers in the spaces provided in this question paper.

INFORMATION FOR CANDIDATES

The total mark for this paper is 90.
Quality of written communication will be assessed in question **1(b)**.
Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question.
Your attention is drawn to the Data and Formula Sheet which is inside this question paper.
You may use an electronic calculator.
Question **6** contributes to the synoptic assessment requirement of the Specification.
You are advised to spend about 55 minutes in answering questions **1–5**, and about 35 minutes in answering question **6**.

For Examiner's use only	
Question Number	**Marks**
1	
2	
3	
4	
5	
6	
Total Marks	

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If you need the values of physical constants to answer any questions in this paper, they may be found on the Data and Formulae Sheet.

Answer **all six** questions

1 Your answer to part (b) of this question should be in continuous prose. You will be assessed on the quality of your written communication.

Fig. 1.1 shows a cylindrical metal rod, clamped firmly at the left-hand end.

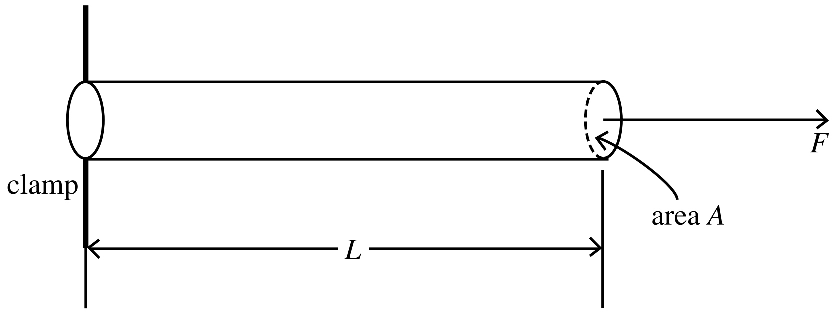

Fig. 1.1

The rod is of original length L and cross-sectional area A. The application of the longitudinal force F causes the rod to extend by x.

The Young modulus E of the material of the rod is defined by the equation

$$E = \frac{\text{stress}}{\text{strain}}$$

(a) Write down expressions for the stress σ and the strain ε in terms of the quantities defined above.

stress: σ = ____________________

strain: ε = ____________________ [2]

Examiner Only	
Marks	Remark

(b) Describe a school laboratory experiment to determine the Young modulus of a copper wire. Structure your answer under the following headings: labelled diagram of experimental arrangement, experimental procedure, processing of results.

Examiner Only	
Marks	Remark

Diagram

[2]

Procedure

____

____

____

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____

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____

____

____

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____

____

____ [5]

Processing of results

Examiner Only	
Marks	Remark

___ [3]

Quality of written communication [2]

2 The **internal energy** of a system is the sum of the random kinetic and potential energies of the constituents of the system.

Examiner Only	
Marks	Remark

(a) A metal crystal has a lattice of positive ions, through which electrons can move at random. The ions in the lattice vibrate.

Detail the contributions to the internal energy of the metal crystal.

Kinetic: ____

____

Potential: ____

____ [2]

(b) Helium can be assumed to behave as an ideal gas. A sample of helium at 27 °C contains 1.20 mol of atoms.

(i) Calculate the internal energy of the helium sample.

Internal energy = ______________ J [4]

Examiner Only	
Marks	Remark

(ii) A world-class sprinter of mass 80 kg can run 100 m in 9.8 s.
Calculate the ratio:

$$\frac{\text{Internal energy of helium sample in } \textbf{(b)(i)}}{\text{average kinetic energy of sprinter}}$$

Ratio = ______________________ [3]

3 **(a)** A particle rotates with uniform angular velocity ω in a circle of radius r. The particle has an instantaneous linear velocity v.

(i) Define **angular velocity**. ____________________

____________________ [1]

(ii) Write down the relation connecting v with ω.

____________________ [1]

(b) A boy swings a ball attached to one end of a string in a horizontal circle at a constant angular velocity. The other end of the string is held in the boy's hand.

(i) State the direction of the force on the ball to maintain this circular motion.

____________________ [1]

(ii) How is this force on the ball provided?

____________________ [1]

(iii) What is the direction of the force on the boy's hand?

____________________ [1]

Examiner Only	
Marks	Remark

Examiner Only	
Marks	Remark

(iv) The string attached to the ball breaks. Air resistance is negligible.

1. Describe exactly the motion of the ball **at the instant** the string breaks.

____

____

____ [1]

2. What is the only force that now acts on the ball?

____

Describe the effect of this force.

____

Describe also the subsequent path taken by the ball.

____

____ [3]

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Examiner Only	
Marks	Remark

4 **(a)** One of the equations which describes simple harmonic motion is

$$a = -\omega^2 x$$

State what the following symbols in the equation stand for:

x: ____

a: ____

ω: ____ [3]

(b) A loaded helical spring is often used as an example of a system which undergoes simple harmonic motion. The period T of this system is given by

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where m is the suspended mass and k is the spring constant (the constant of proportionality in Hooke's law equation as applied to the spring).

(i) State the SI base units of the spring constant.

____ [1]

(ii) Hence show that the SI base unit of the left-hand side of the equation for the period is consistent with the SI base units of the right-hand side.

____

____

____ [1]

(c) A **baby bouncer** is a light harness, into which a baby can be placed, suspended by a vertical spring **(Fig. 4.1)**.

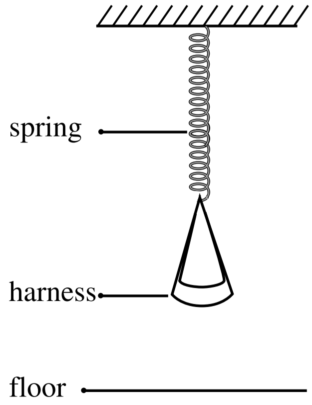

Fig. 4.1

The length of the vertical spring is adjusted so that, when the baby is in the harness and the spring is fully extended under his or her weight, the baby's feet are a few centimetres above the floor. An adult starts vertical oscillations by pulling the baby in the harness downwards and releasing the baby. The baby can amuse him or herself, and take exercise, by kicking the floor to continue the oscillations. The oscillations die away quickly, and to keep them going the baby has to keep kicking on the floor at just the right moment.

The arrangement can be modelled using the equation for the loaded helical spring. Here m is the mass of the baby and harness and k is the spring constant of the vertical spring.

(i) The spring constant is 130 SI units and the mass of the baby is 7.50 kg. Show that the period of vertical oscillations is about 1.5 s.

[2]

Examiner Only	
Marks	Remark

Examiner Only	
Marks	Remark

(ii) State the name that is given to oscillations that die away quickly.

____

Describe how a loaded helical spring system in a school laboratory could be made to show oscillations that die away quickly. State how your modification achieves the effect.

____

____

____ [3]

(iii) State the name that is given to oscillations such as those that are kept going by the baby kicking on the floor.

____ [1]

(iv) The baby finds that by kicking on the floor at a certain frequency the amplitude of the bounces can be made to increase to a maximum.

State the name that is given to this effect.

____

Using the data given in **(c)(i)**, find the frequency that is most effective in producing it.

Frequency = _________ Hz [2]

(v) The baby's cousin, of mass 6.00 kg, comes on a visit, and is placed in the bouncer.
Calculate the frequency at which this child must kick the floor to produce the largest amplitude of oscillation.

Frequency = _________ Hz [2]

5 The planets move round the Sun in approximately circular orbits.

(a) State the force that causes a planet to move in this way.

____ [1]

(b) For a planet in a circular orbit, it can be shown that

$$T^2 = \frac{4\pi^2 r^3}{GM_s} \qquad \textbf{Equation 5.1}$$

where T is the period of the orbital motion and r is the radius of the orbit. The quantity G is the gravitational constant and M_s is the mass of the Sun.

Table 5.1 gives data for T, r and $\frac{r^3}{T^2}$ for some of the planets.

Table 5.1

Planet	T/Earth years (yr)	$r/10^6$ km	$\left(\frac{r^3}{T^2}\right) \Big/ 10^{24}\ \mathrm{km^3\,yr^{-2}}$
Mercury	0.241	57.9	3.34
Venus	0.615	108	3.33
Earth	1.00	150	3.38
Mars	1.88	228	3.35
Jupiter	11.9	778	3.33

(i) Find the arithmetic mean of the figures in the right-hand column of **Table 5.1**.

Mean value = ____________________ $\mathrm{km^3\,yr^{-2}}$ [1]

Examiner Only	
Marks	Remark

Examiner Only	
Marks	Remark

(ii) Calculate the conversion factor which should be used to multiply a value in $km^3\,yr^{-2}$ to turn it into a value in $m^3\,s^{-2}$.
($1\ yr = 3.16 \times 10^7\ s$.)

Multiplying factor = ____________________ [1]

(iii) Use your answers to **(b)(i)** and **(ii)** to express the arithmetic mean of the figures in the right-hand column of **Table 5.1** in $m^3\,s^{-2}$.

Mean value = ____________________ $m^3\,s^{-2}$ [1]

(iv) Use **Equation 5.1** and your mean value from **(b)(iii)** to calculate a value for the mass of the Sun. Give your answer to an appropriate number of significant figures.

Mass of Sun = ______________ kg [4]

6 Data analysis question

This question contributes to the synoptic assessment requirements of the Specification. In your answer, you will be expected to use the ideas and skills of physics in the particular situations described.

You are advised to spend about 35 minutes in answering this question.

Black-body radiation

A perfect black body is a body that absorbs all electromagnetic radiation, of any wavelength, that falls on it. Such a body is also a perfect emitter; that is, at any wavelength, it is a more efficient emitter of radiation than any other body. Radiation emitted from such a body is called **black-body radiation**. Theory gives the following relations for black-body radiation:

For a perfect black body of surface area A at kelvin temperature T, the total power P of radiation emitted is given by the Stefan law

$$P = \sigma A T^4 \qquad \textbf{Equation 6.1}$$

where σ is a constant called the Stefan–Boltzmann constant, which is equal to $5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$.

The spectrum of black-body radiation is a smooth curve with a maximum at a wavelength that depends on the temperature of the emitter. **Fig. 6.1** is a sketch graph of the way in which the power P_λ of radiation at a particular wavelength λ depends on that wavelength, for two emitter temperatures T (1400 K and 1600 K).

Examiner Only	
Marks	Remark

Note that the maximum in the spectrum shifts to shorter wavelengths as the temperature of the emitter increases.

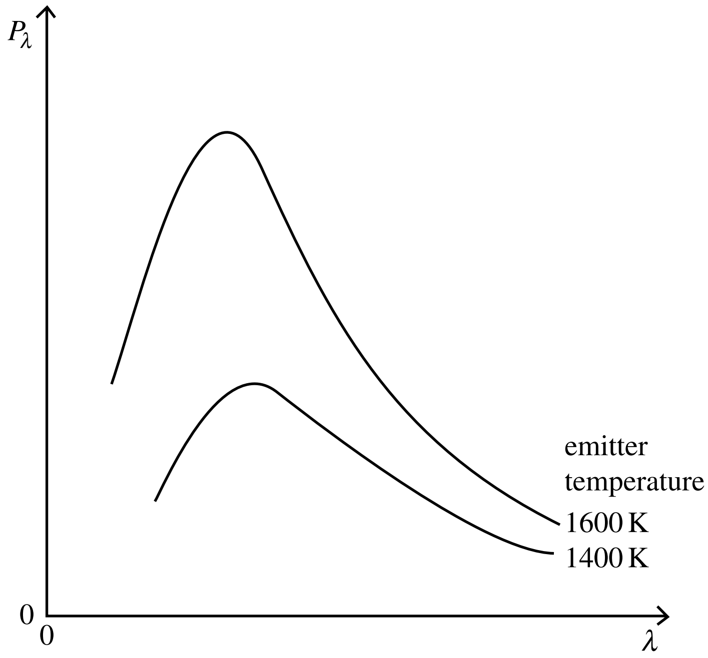

Fig. 6.1

The relation between the wavelength λ_m of the maximum in the spectrum and the emitter temperature T is given by the Wien law

$$\lambda_m T = B \qquad \textbf{Equation 6.2}$$

where B is a constant.

Examiner Only	
Marks	Remark

(a) Analysis of data on the Stefan law

Examiner Only

Marks	Remark

A practical approximation to a black body is a small, enclosed, electrically-heated furnace pierced with a small hole. The hole acts as the black body. The total power P radiated from a small hole in such a furnace is given by

$$P = \varepsilon\sigma A T^4 \qquad \textbf{Equation 6.3}$$

where σ, T and A are defined as in **Equation 6.1** and ε is a constant called the emissivity of the furnace. It is a measure of how efficiently the radiation from the hole in the furnace approaches that from a perfect black body.

A researcher decides to use data from an experiment with such a furnace to test whether the power of 4 in **Equation 6.3** is correct for his furnace and to determine the emissivity ε of the furnace. He first re-writes **Equation 6.3** in the logarithmic form

$$\lg P = \lg(\varepsilon\sigma A) + 4\lg T \qquad \textbf{Equation 6.4}$$

(the notation "lg P" means "the logarithm to the base 10 of the numerical value of P") and then compares **Equation 6.4** with the standard linear equation

$$y = mx + c,$$

with the idea of obtaining a linear graph from which the value of m can be deduced. He plots the values of $\lg T$ from his experiment on the horizontal axis and those of $\lg P$ on the vertical axis. The plotted points are shown on **Fig. 6.2**.

(i) The researcher writes down the temperature T corresponding to the extreme right-hand point on **Fig. 6.2** as 2501 K.

1. To how many **significant figures** is this value recorded?

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

2. To how many **decimal places** is this value recorded?

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐

In each case, state your answer by inserting a tick (✓) in the appropriate box. [2]

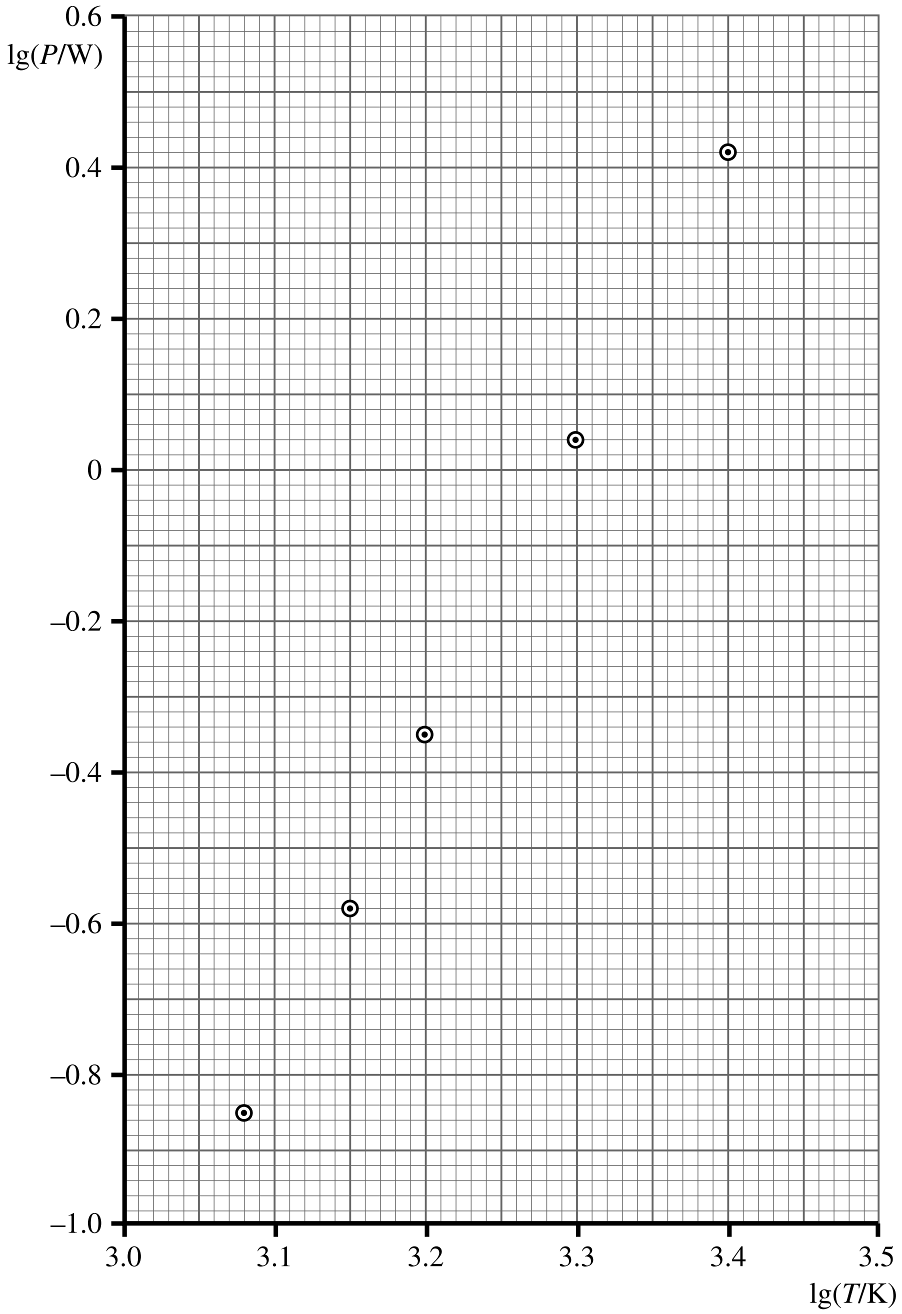

Fig. 6.2

(ii) By recording this temperature as 2501 K, the researcher is indicating that he is confident that the value of *T* lies between certain limits. State these limits.

Lower limit = _________ K   Upper limit = _________ K [2]

Examiner Only	
Marks	Remark

Examiner Only	
Marks	Remark

(iii) The symbol T represents a quantity that has both magnitude and unit.

The researcher has correctly labelled the horizontal axis as $\lg(T/\mathrm{K})$. Explain why it would be wrong to label it as $\lg T$.

____

____

____ [2]

(iv) State how the power 4 to which T is raised in **Equation 6.3** can be checked from **Fig. 6.2**.

____

____

____ [2]

(v) On **Fig. 6.2**, draw the best straight line through the plotted points. [1]

(vi) Use the line you have drawn in **(a)**(**v**) to carry out the procedure you have described in **(a)**(**iv**). State your value of the power to which T is raised.

Power = ________________ [3]

(vii) You will have found in drawing your best straight line in **(a)**(**v**) that the researcher's points do not lie on a perfect straight line. By drawing a line on **Fig. 6.2** which you think represents the **steepest** example of a good straight line through the points, obtain an estimate of the uncertainty in the value of the power you obtained in **(a)**(**vi**).

Range of values of power = value from **(a)**(**vi**) ± ___________ [4]

Examiner Only	
Marks	Remark

(viii) By reference to **Equations 6.1** and **6.3**, deduce the maximum possible value of the emissivity ε.
Explain why this is the maximum possible value.

Maximum value = ______________

Explanation:

____

____ [2]

(ix) Choose a value of $\lg T$ in the range of values on **Fig. 6.2** and read off the corresponding value of $\lg P$ from your best straight line. Substitute these values in **Equation 6.4** and obtain a value of ε for the researcher's oven. The area A of the hole in the furnace from which the radiation is emitted is 1.5 mm^2.
(Reminders: **Equation 6.4** is

$$\lg P = \lg(\varepsilon\sigma A) + 4\lg T.$$

The value of σ is $5.67 \times 10^{-8}\,\text{W m}^{-2}\,\text{K}^{-4}$.)

Chosen value of $\lg T$ = ____________________

Corresponding value of $\lg P$ = ____________________

Emissivity ε = ____________________ [4]

(b) Analysis of data on the Wien law

Examiner Only	
Marks	Remark

The researcher analyses the spectrum of radiation from the emitter at various temperatures to determine the constant B in the Wien law $\lambda_m T = B$.

The researcher measures the wavelength λ_m at which the maximum in the spectrum occurs for a number of emitter temperatures T and tabulates the results in **Table 6.2**.

Table 6.2

T/K	λ_m/µm	
1200	2.42	
1400	2.07	
1600	1.81	
2000	1.45	
2300	1.24	

You are to plot a straight-line graph on **Fig. 6.5**, using values obtained from these data, to determine the value of B. In this part of the question, do **not** use a logarithmic graph.

(i) State the quantities you will plot on the graph.

Horizontal axis: ____________________

Vertical axis: ____________________ [1]

(ii) State how the constant B will be determined from your graph.

____

____ [1]

(iii) Head the blank column of **Table 6.2** appropriately, calculate the values required, and enter them in the table. [2]

(iv) Label the axes of the graph grid of **Fig. 6.5** and choose suitable scales. Plot the points and draw the best fit straight line through them. [5]

Fig. 6.5

(v) Use the graph to find the value of B and enter its value below.
State an appropriate unit.

Numerical value of B = ____________________

Unit: ____________________ [4]

Examiner Only	
Marks	Remark