General Certificate of Education
January 2006
Advanced Subsidiary Examination

PHYSICS (SPECIFICATION A) PHA3/W
Unit 3 Current Electricity and Elastic Properties of Solids

Thursday 12 January 2006  9.00 am to 10.00 am

For this paper you must have:
- a calculator
- a pencil and a ruler

Time allowed: 1 hour

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer all questions.
- Answer the questions in the spaces provided.
- Show all your working.
- Make and state any necessary assumptions.
- Do all rough work in this book. Cross through any work you do not want marked.

Information
- The maximum mark for this paper is 50. This includes up to 2 marks for the Quality of Written Communication.
- The marks for questions are shown in brackets.
- A Data Sheet is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are reminded of the need for good English and clear presentation in your answers. Questions indicated on the paper should be answered in continuous prose. Quality of Written Communication will be assessed in these answers.
Data Sheet

- A perforated *Data Sheet* is provided as pages 3 and 4 of this question paper.

- This sheet may be useful for answering some of the questions in the examination.

- You may wish to detach this sheet before you begin work.
### Fundamental constants and values

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed of light in vacuum</td>
<td>$c$</td>
<td>$3.00 \times 10^8$</td>
<td>m s$^{-1}$</td>
</tr>
<tr>
<td>permeability of free space</td>
<td>$\mu_0$</td>
<td>$4\pi \times 10^{-7}$</td>
<td>H m$^{-1}$</td>
</tr>
<tr>
<td>permittivity of free space</td>
<td>$\varepsilon_0$</td>
<td>$8.85 \times 10^{-12}$</td>
<td>F m$^{-1}$</td>
</tr>
<tr>
<td>charge of electron</td>
<td>$e$</td>
<td>$1.60 \times 10^{-19}$</td>
<td>C</td>
</tr>
<tr>
<td>the Planck constant</td>
<td>$h$</td>
<td>$6.63 \times 10^{-34}$</td>
<td>J s</td>
</tr>
<tr>
<td>gravitational constant</td>
<td>$G$</td>
<td>$6.67 \times 10^{-11}$</td>
<td>N m$^2$ kg$^{-1}$</td>
</tr>
<tr>
<td>the Avogadro constant</td>
<td>$N_A$</td>
<td>$6.02 \times 10^{23}$</td>
<td>mol$^{-1}$</td>
</tr>
<tr>
<td>molar gas constant</td>
<td>$R$</td>
<td>8.31</td>
<td>J K$^{-1}$ mol$^{-1}$</td>
</tr>
<tr>
<td>the Boltzmann constant</td>
<td>$k$</td>
<td>$1.38 \times 10^{-23}$</td>
<td>J K$^{-1}$</td>
</tr>
<tr>
<td>the Stefan constant</td>
<td>$\sigma$</td>
<td>$5.67 \times 10^{-8}$</td>
<td>W m$^{-2}$ K$^{-4}$</td>
</tr>
<tr>
<td>the Wien constant</td>
<td>$\alpha$</td>
<td>$2.90 \times 10^{-3}$</td>
<td>m K</td>
</tr>
<tr>
<td>electron rest mass (equivalent to 5.5 x 10$^{-4}$u)</td>
<td>$m_e$</td>
<td>$9.11 \times 10^{-31}$</td>
<td>kg</td>
</tr>
<tr>
<td>electron charge/mass ratio</td>
<td>$e/m_e$</td>
<td>$1.76 \times 10^{11}$</td>
<td>C kg$^{-1}$</td>
</tr>
<tr>
<td>proton rest mass (equivalent to 1.00728u)</td>
<td>$m_p$</td>
<td>$1.67 \times 10^{-27}$</td>
<td>kg</td>
</tr>
<tr>
<td>proton charge/mass ratio</td>
<td>$e/m_p$</td>
<td>$9.58 \times 10^{7}$</td>
<td>C kg$^{-1}$</td>
</tr>
<tr>
<td>neutron rest mass (equivalent to 1.00867u)</td>
<td>$m_n$</td>
<td>$1.67 \times 10^{-27}$</td>
<td>kg</td>
</tr>
<tr>
<td>gravitational field strength</td>
<td>$g$</td>
<td>9.81</td>
<td>N kg$^{-1}$ s$^{-2}$</td>
</tr>
<tr>
<td>acceleration due to gravity atomic mass unit</td>
<td>$u$</td>
<td>$1.661 \times 10^{-23}$</td>
<td>kg</td>
</tr>
</tbody>
</table>

### Mechanics and Applied Physics

- **Equation for velocity:** $v = u + at$
- **Equation for displacement:** $s = \frac{(u + v)t}{2}$
- **Equation for velocity:** $v^2 = u^2 + 2as$
- **Force equation:** $F = \frac{\Delta(mv)}{\Delta t}$
- **Power output:** $P = Fv$
- **Efficiency:** $\eta = \frac{\text{power output}}{\text{power input}}$

### Fields, Waves, Quantum Phenomena

- **Equation for electric field:** $E = \frac{F}{Q}$
- **Equation for magnetic field:** $B = \frac{F}{Q}$
- **Equation for angular momentum:** $I = \frac{L}{\omega}$

### Fundamental particles

<table>
<thead>
<tr>
<th>Class</th>
<th>Name</th>
<th>Symbol</th>
<th>Rest energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>photon</td>
<td>photon</td>
<td>$\gamma$</td>
<td>0</td>
</tr>
<tr>
<td>lepton</td>
<td>neutrino</td>
<td>$\nu_e$</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>electron</td>
<td>$e^-$</td>
<td>0.510999</td>
</tr>
<tr>
<td></td>
<td>muon</td>
<td>$\mu^-$</td>
<td>105.659</td>
</tr>
<tr>
<td>mesons</td>
<td>pion</td>
<td>$\pi^+$</td>
<td>139.576</td>
</tr>
<tr>
<td></td>
<td>$\pi^0$</td>
<td>134.972</td>
<td></td>
</tr>
<tr>
<td></td>
<td>kaon</td>
<td>$K^+$</td>
<td>493.821</td>
</tr>
<tr>
<td></td>
<td>$K^0$</td>
<td>497.762</td>
<td></td>
</tr>
<tr>
<td>baryons</td>
<td>proton</td>
<td>$p$</td>
<td>938.257</td>
</tr>
<tr>
<td></td>
<td>neutron</td>
<td>$n$</td>
<td>939.551</td>
</tr>
</tbody>
</table>

### Properties of quarks

<table>
<thead>
<tr>
<th>Type</th>
<th>Charge</th>
<th>Baryon number</th>
<th>Strangeness</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>$+\frac{1}{3}$</td>
<td>$+\frac{1}{2}$</td>
<td>0</td>
</tr>
<tr>
<td>d</td>
<td>$-\frac{1}{3}$</td>
<td>$+\frac{1}{2}$</td>
<td>0</td>
</tr>
<tr>
<td>s</td>
<td>$-\frac{1}{3}$</td>
<td>$+\frac{1}{2}$</td>
<td>-1</td>
</tr>
</tbody>
</table>

### Geometrical equations

- **Arc length:** $r \theta$
- **Circumference of a circle:** $2\pi r$
- **Area of a circle:** $\pi r^2$
- **Area of a cylinder:** $2\pi rh$
- **Volume of a cylinder:** $\pi r^2 h$
- **Area of a sphere:** $4\pi r^2$
- **Volume of a sphere:** $\frac{4}{3}\pi r^3$
magnitude of induced e.m.f. = \( N \frac{\Delta \Phi}{\Delta t} \)

\[ I_{rms} = \frac{I_0}{\sqrt{2}} \]

\[ V_{rms} = \frac{V_0}{\sqrt{2}} \]

**Mechanical and Thermal Properties**

the Young modulus = tensile stress = \( \frac{F}{A} \frac{L}{\varepsilon} \)

energy stored = \( \frac{1}{2} Fe \)

\[ \Delta Q = mc \Delta \theta \]

\[ \Delta Q = ml \]

\[ pV = \frac{1}{2} Nmc^2 \]

\[ \frac{1}{2} mc^2 = \frac{1}{2} kT + \frac{3RT}{2N_A} \]

**Nuclear Physics and Turning Points in Physics**

force = \( eV \frac{\varepsilon}{d} \)

force = \( Bev \)

radius of curvature = \( \frac{mv}{Be} \)

\[ eV \frac{d}{v} = mg \]

work done = \( eV \)

\[ F = 6\pi mnv \]

\[ I = k \frac{l_0}{x^2} \]

\[ \Delta N = -\lambda \Delta t \]

\[ \lambda = \frac{h}{\sqrt{2mecV}} \]

\[ N = N_0 e^{-\lambda t} \]

\[ T_i = \frac{\ln 2}{\lambda} \]

\[ R = r_0 A^{\frac{3}{2}} \]

\[ E = mc^2 = \frac{mc^2}{\left(1 - \frac{\nu^2}{c^2}\right)^{\frac{1}{2}}} \]

\[ l = l_0 \left(1 - \frac{\nu^2}{c^2}\right)^{\frac{1}{2}} \]

\[ t = \frac{l_0}{\left(1 - \frac{\nu^2}{c^2}\right)^{\frac{3}{2}}} \]

**Astrophysics and Medical Physics**

**Body** | **Mass/kg** | **Mean radius/m**
---|---|---
Sun | \( 2.00 \times 10^{30} \) | \( 7.00 \times 10^8 \)
Earth | \( 6.00 \times 10^{24} \) | \( 6.40 \times 10^6 \)

1 astronomical unit = \( 1.50 \times 10^{11} \) m

1 parsec = \( 206265 \) AU = \( 3.08 \times 10^{16} \) m = 3.26 ly

Hubble constant \( (H) = 65 \text{ km s}^{-1} \) \( \text{Mpc}^{-1} \)

\[ M = \frac{f}{\nu} \]

angle subtended by image at eye

\[ M = \frac{f_o}{f_e} \]

angle subtended by object at unaided eye

\[ m - M = 5 \log \frac{d}{10} \]

\[ \lambda_{max} T = \text{constant} = 0.0029 \text{ m K} \]

\[ v = H d \]

\[ P = \alpha A T^4 \]

\[ \frac{\Delta f}{f} = \frac{\nu}{c} \]

\[ \Delta \lambda = \frac{\nu}{\lambda} \]

\[ \frac{\lambda}{c} = \frac{2GM}{c^2} \]

**Medical Physics**

\[ \text{power} = \frac{1}{f} \]

\[ \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \]

\[ m = \frac{v}{u} \]

\[ \text{intensity level} = 10 \log \frac{I}{I_0} \]

\[ I = I_0 e^{-\alpha d} \]

\[ \mu_m = \frac{\mu}{\rho} \]

**Electronics**

**Resistors**

Preferred values for resistors (E24)

Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms and multiples that are ten times greater

\[ Z = \frac{V_{rms}}{I_{rms}} \]

\[ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots \]

\[ C_T = C_1 + C_2 + C_3 + \cdots \]

\[ X_C = \frac{1}{2\pi fC} \]

**Alternating Currents**

\[ f = \frac{1}{T} \]

**Operational amplifier**

\[ G = \frac{V_{out}}{V_{in}} \]

voltage gain

\[ G = -\frac{R_1}{R_1} \]

inverting

\[ G = 1 + \frac{R_1}{R_1} \]

non-inverting

\[ V_{out} = -R_1 \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \]

summing
Answer all questions in the spaces provided.

1 (a) A steady current of 0.25 A passes through a torch bulb for 6 minutes. Calculate the charge which flows through the bulb in this time.

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(2 marks)

(b) The torch bulb is now connected to a battery of negligible internal resistance. The battery supplies a steady current of 0.25 A for 20 hours. In this time the energy transferred in the bulb is $9.0 \times 10^4$ J. Calculate

(i) the potential difference across the bulb,
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(ii) the power of the bulb.
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(3 marks)

Turn over for the next question
2 In the circuit shown in Figure 1, the battery, of negligible internal resistance, is connected to two resistors which form a potential divider.

**Figure 1**

(a) (i) Calculate the current through the ammeter.

(ii) A 20 $\Omega$ resistor is now connected between X and Y. State and explain, without further calculation, whether the current through the ammeter will increase or decrease. You may be awarded marks for the quality of written communication in your answer.

(4 marks)
(b) The 20\(\Omega\) resistor is now removed and replaced with a voltmeter. Stating the assumption made, show that the reading on the voltmeter is 4.9 V.

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(2 marks)

(c) The voltmeter is now removed and the terminals X and Y joined together with a wire. Calculate the reading on the ammeter.

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(2 marks)

Turn over for the next question
A student wishes to measure the resistivity of the material of a uniform resistance wire. The available apparatus includes a battery, a switch, a variable resistor, an ammeter and a voltmeter.

(i) Draw a circuit diagram which incorporates some or all of this apparatus and which enables the student to determine the resistivity of the material.

(ii) State the measurements which must be made to ensure that a reliable value of the resistivity is obtained.

(iii) Explain how a value of the resistivity would be obtained from the measurements.

(10 marks)
(b) A wire made from tin with cross-sectional area $7.8 \times 10^{-9} \text{ m}^2$, has a pd of 2.0 V across it. Calculate the minimum length of wire needed so that the current through it does not exceed 4.0 A.

resistivity of tin $= 1.1 \times 10^{-7} \Omega \text{ m}$

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(2 marks)

Turn over for the next question
There are no questions printed on this page
4 A battery of emf \( \varepsilon \) and internal resistance \( r \) is connected in series to a variable resistor \( R \) and an ammeter of negligible resistance. A voltmeter is connected across \( R \), as shown in **Figure 2**.

**Figure 2**

(a) (i) State what is meant by the emf of the battery.

....................................................................................................................................
....................................................................................................................................
....................................................................................................................................

(ii) The reading on the voltmeter is less than the emf. Explain why this is so.

....................................................................................................................................
....................................................................................................................................

....................................................................................................................................

(2 marks)

**Question 4 continues on page 13**
A student wishes to measure $\varepsilon$ and $r$. Using the circuit shown in Figure 2 the value of $R$ is decreased in steps and at each step the readings $V$ and $I$ on the voltmeter and ammeter respectively are recorded. These are shown in the table.

<table>
<thead>
<tr>
<th>reading on voltmeter/V</th>
<th>reading on ammeter/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.3</td>
<td>0.07</td>
</tr>
<tr>
<td>6.8</td>
<td>0.17</td>
</tr>
<tr>
<td>4.6</td>
<td>0.33</td>
</tr>
<tr>
<td>2.9</td>
<td>0.44</td>
</tr>
<tr>
<td>0.3</td>
<td>0.63</td>
</tr>
</tbody>
</table>

(i) Give an expression relating $V$, $I$, $\varepsilon$ and $r$.

(ii) Using the grid on page 12 of this booklet, draw a graph of $V$ (on the $y$-axis) against $I$ (on the $x$-axis).

(iii) Determine the values of $\varepsilon$ and $r$ from the graph, explaining your method.

$\varepsilon$: ........................................................................................................................................................................

$r$: ......................................................................................................................................................................................

(8 marks)
5  (a) When a tensile stress is applied to a wire, a tensile strain is produced in the wire. State the meaning of

tensile stress, ...................................................................................................................................................

...................................................................................................................................................

tensile strain. ...................................................................................................................................................

...................................................................................................................................................

(2 marks)

(b) A long, thin metal wire is suspended from a fixed support and hangs vertically. Masses are suspended from its lower end.

As the load on the lower end is increased from zero to a certain value, and then decreased again to zero, the variation of the resulting tensile strain with the applied tensile stress is shown in the graph.

(i) Describe the behaviour of the wire during this process. Refer to the points A, B, C and D in your answer.
You may be awarded marks for the quality of written communication in your answer.

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................

............................................................................................................................................................
(ii) State, with a reason, whether the material of the wire is ductile or brittle.

....................................................................................................................................
....................................................................................................................................

(iii) What does AD represent?

....................................................................................................................................
....................................................................................................................................

(iv) State how the Young modulus for the material may be obtained from the graph.

....................................................................................................................................
....................................................................................................................................

(v) State how the energy per unit volume stored in the wire during the loading process may be estimated from the graph.

....................................................................................................................................
....................................................................................................................................

(9 marks)

(c) The wire described in part (b) has an unstretched length of 3.0 m and cross-sectional area $2.8 \times 10^{-7}$ m$^2$. At a certain stage between the points A and B on the graph, the wire supports a load of 75 N. Calculate the extension produced in the wire by this load.

the Young modulus for the material of the wire = $2.1 \times 10^{11}$ Pa

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................
............................................................................................................................................

(2 marks)

Quality of Written Communication (2 marks)

END OF QUESTIONS
There are no questions printed on this page