Rewarding Learning

Centre Number

71	

Candidate Number

ADVANCED
General Certificate of Education
2009

Physics

Assessment Unit A2 2

assessing

Module 5: Electromagnetism and Nuclear Physics

[A2Y21]

A2Y21

THURSDAY 28 MAY, MORNING

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 five** 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 **5**.
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 Formulae Sheet which is inside this question paper.
You may use an electronic calculator.
Question **5** contributes to the synoptic assessment requirement of the Specification.
You are advised to spend about 45 minutes in answering questions **1–4**, and about 45 minutes in answering question **5**.

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

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.

Examiner Only	
Marks	Remark

Answer **all five** questions

1 Two capacitors, C_1 of capacitance 2.00 μF and C_2 of capacitance of 8.00 μF are charged so that the energy stored in **each** capacitor is 5.76×10^{-4} J. This energy remains stored in the capacitors as they are connected in the circuit of **Fig. 1.1** with switch S open.

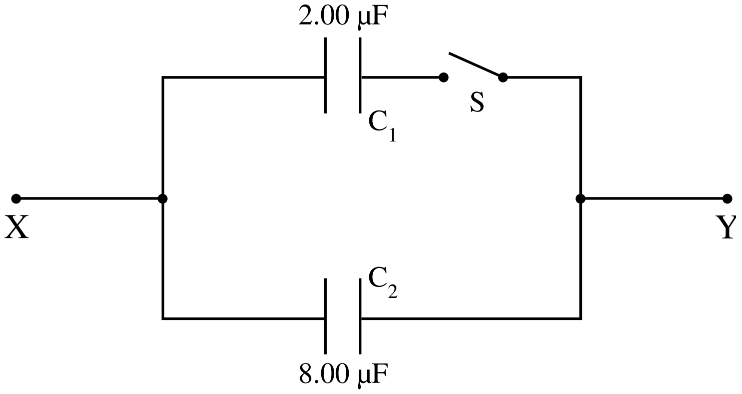

Fig. 1

(a) Calculate the potential difference across each of the capacitors.
Reminder: the switch is **open** at this stage.

Potential difference across C_1 (2.00 μF) capacitor = ____________ V

Potential difference across C_2 (8.00 μF) capacitor = ____________ V
[4]

(b) Switch S is now **closed**.

(i) Find the potential difference between the terminals X and Y after the switch is closed.

Potential difference = _________ V [5]

(ii) Describe and explain the transfer of charge between the capacitors after the switch is closed.

____

____

____

____

____

____ [4]

2 **(a)** **(i)** State, in words, Faraday's law of electromagnetic induction.

____

____

____ [2]

(ii) A flat coil of wire is placed with its plane perpendicular to a magnetic field.
The flux Φ through the coil is initially constant, but changes with time t as shown in **Fig. 2.1**.
On the blank axes below this graph, draw a graph to show how the induced e.m.f. E in the coil changes with time t from $t = 0$ to $t = t_f$

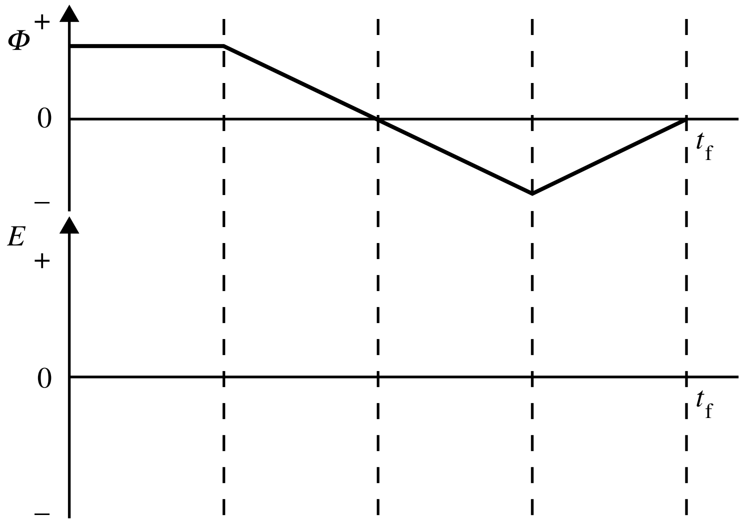

Fig. 2.1

[3]

(b) The output voltage E of a simple a.c. generator changes with time t as given by **Equation 2.1**.

$$E = 320 \sin (314t) \qquad \textbf{Equation 2.1}$$

(i) Calculate the frequency of the generator.

Frequency = ________ Hz [2]

(ii) Calculate the minimum time, in ms, for the output of the generator to rise from zero to 160 V in each cycle of operation.

Minimum time = ________ ms [3]

3 **(a)** **(i)** State what is meant by the **specific charge** of the electron.

____

____ [1]

(ii) Obtain the magnitude of the specific charge of the electron to two significant figures and state its unit.

Specific charge = ____________

Unit = ____________ [3]

(b) The specific charge of an electron may be measured by passing a fine beam of electrons through an electric and a magnetic field which are at right angles to each other and the path of the electrons (i.e. crossed fields).

Fig. 3.1 indicates a fine beam of electrons travelling perpendicularly outward from the plane of the paper between two metal plates which create a uniform electric field. On **Fig. 3.1**, mark the polarity of these plates to create an electric field and mark clearly using an arrow head labelled **E** the corresponding direction of the electric field. Mark clearly with another arrowhead on **Fig. 3.1** the direction of a corresponding magnetic field **B** which would be needed to produce null deflection of the electron beam.

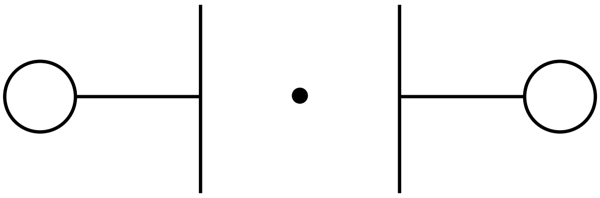

Fig. 3.1

[2]

The beam of electrons is replaced by an identical beam of positrons. (A positron is a particle identical to an electron, but with a positive charge.)
State and explain whether this beam would still experience null deflection for the **E** and **B** fields you have indicated.

____

____ [1]

(c) A fine beam of electrons moves through a region where an electric field and a magnetic field act perpendicularly to each other. The electrons in the beam are not deflected when passing through this region.
The magnetic field has a flux density of 1.50×10^{-3} T, and the electric field strength is 1.78×10^{4} V m^{-1}.
Calculate the velocity of the electrons in the beam.

Velocity = ____________ m s^{-1} [3]

4 **(a)** α-particles, β-particles and γ-radiation are the common types of radioactive emissions. Some of their properties are to be summarised in **Table 4.1**.
Possible magnitudes of their speed and range in air are stated below, along with their ionisation ability.

Speed/m s^{-1}: 3×10^8; 2×10^8; 2×10^7

Range/cm: 2×10^3; 2; 10

The ionisation ability can be classified as: low, medium, or high.

After considering the given information, complete **Table 4.1** below by selecting and entering the appropriate data in the blank spaces of the table.

Table 4.1

Radiation	Speed/m s^{-1}	Range/cm	Ionisation ability
α-particles			
β-particles			
γ-radiation			

[3]

(b) A uranium nucleus $^{238}_{92}\text{U}$ undergoes a series of radioactive decays before it attains a final stable state which is a nucleus of lead (Pb). The succession of particles emitted during its decay is listed below in the order in which they occur.
alpha, **beta**, **beta**, **alpha**, **alpha**, **alpha**, **alpha**, **alpha**, **beta**, **beta**, **alpha**, **beta**, **beta**, **alpha**
Find the nucleon number and the proton number of the final stable Pb nucleus.

Nucleon number = ____________

Proton number = ____________ [2]

(c) **(i)** Define the **becquerel**, the unit of activity for a radioactive sample.

____

____ [1]

(ii) Define the **decay constant** of a radioactive sample.

____

____

____ [2]

(iii) The half-life of bismuth-210 for β-particle emission is 5.0 days. Find the percentage loss of activity in a sample after 15 hours.

Percentage loss of activity = _____ % [4]

Examiner Only	
Marks	Remark

5 **Comprehension question**

This question contributes to the synoptic assessment requirement of the Specification. In your answer, you will be expected to bring together and apply principles and contexts from different areas of physics, and to use the skills of physics, in the particular situation described.

You are advised to spend about 45 minutes in answering this question.

Read the passage carefully and answer all the questions which follow.

In parts (c)(i) and (ii) and (d)(ii) of this question you should answer in continuous prose. You will be assessed on the quality of your written communication.

Thermal aspects of X-ray tubes

In X-ray tubes, fast moving electrons bombard metal targets to produce X-rays. This process is very inefficient and most of the energy of the electrons (about 99%) is converted to heat in the metal anodes of the tubes.

The anodes are designed to maximise heat loss by different methods.

Heat transfer by conduction (mainly in solids), convection (only in fluids) and radiation (by electromagnetic waves) contribute to the removal of heat from the anodes of tubes to prevent thermal damage during operation. Two anode designs are considered here, the stationary type of anode and the rotating type.

Fig. 5.1 shows a labelled diagram of a stationary anode tube immersed in oil coolant within its housing enclosure.

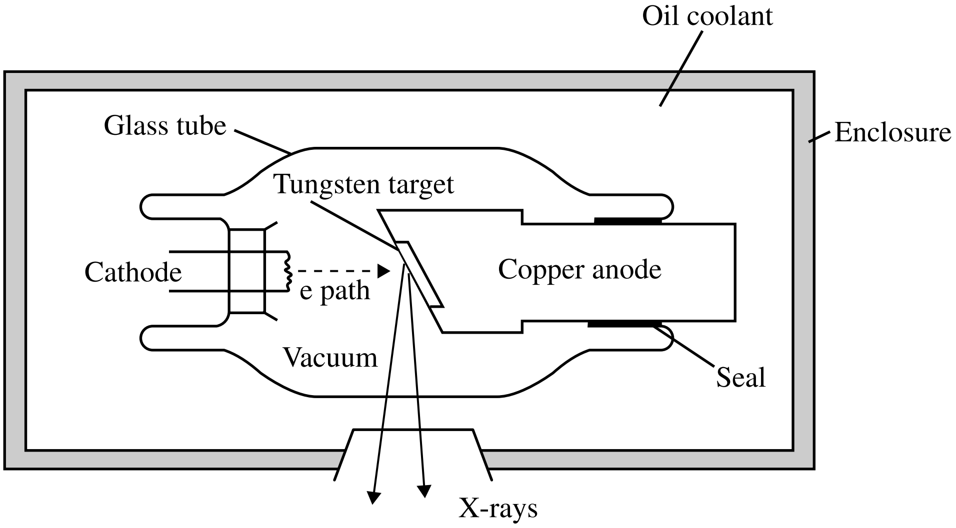

Fig. 5.1

When the tube is operating, the thin tungsten target embedded in the anode becomes very hot. It quickly transfers its heat to the massive copper anode which then transfers it to the oil. After further heat transfer processes, the heat eventually escapes to the surrounding air. Thermal expansion at the seal where the copper anode passes through the glass into the oil is an important consideration. The thermal expansion of materials is governed by **Equation 5.1**.

$$L_t = L_o(1 + \alpha t) \qquad \textbf{Equation 5.1}$$

where L_t is the length of an object at t °C, L_o is the length of the object at 0 °C, α is the coefficient of linear expansivity, i.e. the fractional increase of length per °C temperature rise and t is the temperature of the object in °C. The melting point of copper is 1083 °C and this imposes a practical limit on the amount of heat which may accumulate in the anode. This restricts the intensity of the X-rays the stationary anode tube can produce.

Fig. 5.2 is a labelled diagram of a rotating anode tube. This design permits the anode to withstand increased power input and higher temperatures. The target for the electrons to produce X-rays is a small area on the bevelled edge of the rotating anode disc. The tungsten anode disc is attached to the rotor of an induction motor which can rotate at different speeds.

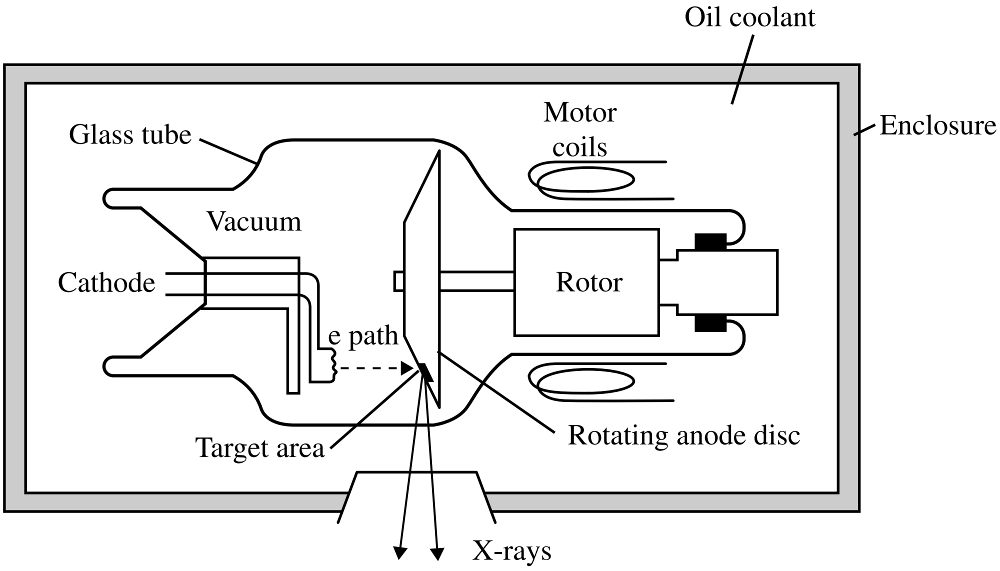

Fig. 5.2

The anode disc is tungsten with a melting point of 3380 °C. As the disc rotates, each area on the anode is exposed to the bombarding electron beam for only a short time in each revolution. Each successive area on the anode can radiate X-rays when impacted by electrons, but cools by radiation for most of the time in one revolution. The anode can thus withstand a higher mean temperature and consequently generates higher intensity X-rays from a higher energy electron beam. Similar methods of heat removal apply to this tube as for the stationary type, but radiation is the main agent of heat loss. The anode may operate safely at a temperature higher than the melting point of copper, in fact the anode may reach a high enough temperature to glow without causing thermal damage. The greatest heat loss from the hot rotating surface is controlled by Stefan's law of radiation (**Equation 5.2**)

$$Q = \sigma T^4 \qquad \textbf{Equation 5.2}$$

where Q is the rate of emission of radiation energy from unit area of a surface in $\mathrm{W\,m^{-2}}$. T is the temperature of the surface in K and σ is the Stefan constant, $5.70 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$.

To avoid damage due to overheating the anode of an X-ray tube, rating charts are used. These charts indicate appropriate safe limits for the operation of the tube. A rating chart displays tube current in mA on its vertical axis and tube operating time in seconds on its horizontal axis. Each curve on a chart indicates the limit of safe operating conditions for a given tube anode voltage.

Answer ALL the following questions

Examiner Only	
Marks	Remark

(a) Write a few words, or a short sentence, to show the meaning of the following words or phrases as they are used in the passage.

(i) bombard (*line 1*)

____

____ [1]

(ii) anode/s (*lines 3, 4, 6 & others*)

____

____ [1]

(iii) oil coolant (*line 9*)

____

____ [1]

(iv) seal (*line 14*)

____

____ [1]

(v) melting point (*lines 20 and 29*)

____

____ [1]

(vi) intensity (*lines 22 and 34*)

____

____ [1]

(vii) bevelled edge (*line 26*)

____

____ [1]

(viii) glow (*line 37*)

____

____[1]

(b) (i) An electron current of 75.0 mA strikes the anode of the X-ray tube shown in **Fig. 5.1** for a time of 1.50 s. Estimate the number of these electrons which generate X-rays (*line 2*).

____

____

____

Number of electrons = ______________________________[4]

(ii) The tungsten target (*line 11*) has a mass of 11.3×10^{-4} kg and its specific heat capacity is $142\,\mathrm{J\,kg^{-1}\,K^{-1}}$. Electrons which strike the target have been accelerated through a potential difference of 60.0 kV. Calculate the temperature rise in the tungsten target when a single electron loses **all** its energy to heat.

Temperature rise = ________ K [4]

(iii) How many simultaneous electron impacts similar to those in **(ii)** are required to raise the temperature of the target by 1.30 K?

No. of impacts = __________ [2]

(c) The tube of **Fig. 5.1** has been operating for a period of time and the tungsten target in the anode has reached a high temperature. You are to consider how the heat at the hot end of the anode may be removed (*line 6*). For example, it could be stated that some of the energy is radiated (by electromagnetic waves) away from the anode through the vacuum to the glass of the tube. However, your task is to consider **Fig. 5.1** carefully, then identify and state the direction of heat flow in two instances in the fixed anode tube where the process of conduction is used to transfer heat energy. You will then identify and state the direction of heat flow in one instance of convection for the tube.

(i) Conduction considerations

Identify and state the direction of heat flow in two instances of conduction for the tube.

1. ______________________________

____

2. ______________________________

______________________________ [4]

(ii) Convection considerations

Identify and state the direction of heat flow in one instance of convection for the tube.

____

______________________________ [2]

Examiner Only	
Marks	Remark

(d) (i) In **Fig. 5.1**, the copper anode at the end where there is a seal with the glass has a diameter of 48.5 mm at 0 °C. The internal diameter of the glass at the seal is also 48.5 mm at 0 °C. Differential expansion occurs between the copper anode and the glass, i.e. the copper and the glass expand by different amounts for any temperature change.

The coefficients of linear expansivity (*line 19*) of copper and glass are $1.71 \times 10^{-5}\,°\text{C}^{-1}$ and $1.63 \times 10^{-5}\,°\text{C}^{-1}$ respectively.

It is possible this seal may fracture when the difference in expansion between the copper and the glass diameters is 4.50×10^{-3} mm.

Using this value and **Equation 5.1**, calculate the temperature at the seal when this difference in diameter size occurs.

Temperature = __________ °C [4]

(ii) Normally the X-ray tube is immersed in oil. It is also possible to remove the oil and operate the tube in air. If the tube were used in air when the seal fractured, write a brief account of how this would affect the operation of the tube as it generated X-rays.

____

____

____

____

____

____

____ [4]

Quality of written communication [2]

(e) The rotating anode of the tube shown in **Fig. 5.2** rotates at high speed when the tube is in operation. A glowing ring is completely visible around the bevelled edge of the anode. The temperature of this glowing ring is 1200 °C. The ring has a mean radius of rotation of 42.0 mm and is 2.30 mm wide.

(i) Calculate the area of the glowing ring around the anode.
Hint: consider the mean circumference and the width of the ring.

Area = __________ m^2 [2]

(ii) Use Stefan's law (**Equation 5.2**) to calculate the total radiation heat loss from the glowing area of the anode in 1.50 s.

Heat loss __________ J [3]

(iii) The absolute temperature of the glowing ring is reduced by 10%.

Calculate the corresponding percentage reduction in the rate of emission from the glowing ring for this temperature decrease.

Percentage reduction = __________ % [2]

Examiner Only	
Marks	Remark

(f) You are now to consider curves on an X-ray tube rating chart (*lines 45–48*). On **Fig. 5.3** is a curve which shows the limit of safe operating conditions to avoid overheating the anode in a given tube for an anode operating voltage of 60 kV.

(i) On **Fig. 5.3**, starting at the point **P** (150 mA), sketch another curve for an anode operating voltage of 40 kV. Label the curve you have drawn "40 kV". [2]

(ii) On **Fig. 5.3**, considering the curve you have drawn and the given curve, shade the area which indicates the safe operating region for the anode for **both** operating voltages, 40 kV and 60 kV.

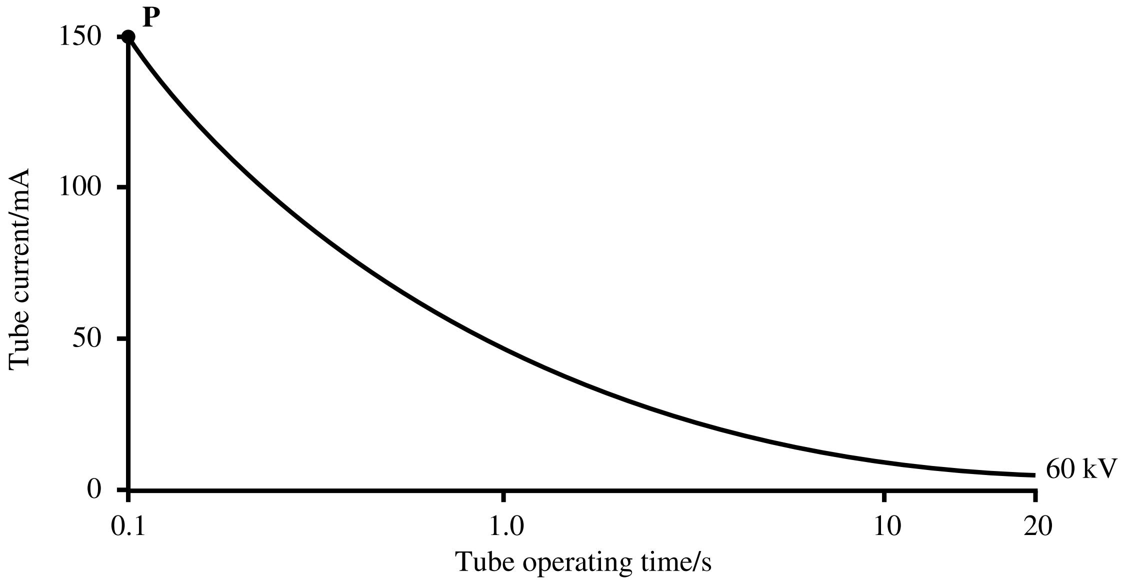

Fig. 5.3 [2]

THIS IS THE END OF THE QUESTION PAPER