HOLY CROSS COLLEGE

12 ATAR Physics

Electromagnetism Investigation

Part 2 - Quiz

Mark: $\frac{\quad}{50}$

Name: SOLUTIONS

You should have your Research section of the investigation with you.

1. State what the betatron is mainly used for. [3 marks]

- Provides high energy beam electrons around 300 MeV.
- A source of X-rays and γ-rays when electrons hit a metal plate.
- X-rays produced can be used in industrial and medical fields.
- High energy electrons can be used in particle physics.
- Possible solar flare mechanism.

[Any 3 – 1 mark each]

2. What is the value of the speed mentioned as $\boldsymbol{v}$ = 0.999987$\boldsymbol{c}$ where $\boldsymbol{c}$ is the speed of light? Give your answer to 5 significant figures. [2 marks]

$V = (0.999987)(3.00\times10^{8})$ (1)

$= \underline{2.9996\times10^{8}\ ms^{-1}}$. (1)

3. Show that 1 Volt = 1 Weber/second. [3 marks]

$EMF = -N\dfrac{\Delta\phi}{\Delta t}$ (1)

Assume N = 1,

$\therefore$ If $\dfrac{\Delta\phi}{\Delta t} = 1.0$ Wb/s, then EMF = 1.0 V.
(1) (1)

4. Explain why an electron-volt can be considered to be a unit of energy. [2 marks]

- The work done by a potential difference is given by: $W = Vq$. (1)
- If an electrons moves through a potential difference of 1·0 V, then $W = 1{\cdot}0\,eV$.

  $\Rightarrow$ eV is equivalent to J, a unit of energy. (1)

5. Can an induced current ever establish a magnetic field ***B*** that is in the same direction as the magnetic field inducing the current? Justify your answer. [3 marks]

- No (1)
- If it was possible, the fields would add together, creating a stronger field. (1)
- This would increase the induced current and continue to infinity, which is impossible. (1)

  [Could also mention that this violates the law of conservation of energy.]

6. Suggest a suitable material for the magnetic core of the betatron. Justify your answer. [2 marks]

- Soft iron core. (1)
- This concentrates the magnetic field.
- It is easily magnetised and demagnetised.

  ] Either OK. (1)

7. In the betatron, the magnetic core is made of laminated sheets rather than of solid material. Explain why this is so. [3 marks]

- Laminated sheets produce small eddy currents. (1)
- Power loss is much lower, since $P_{loss} = I^2R$. (1)
- Solid core, eddy current is very large, as it the power loss. (1)

8 (a) Explain how the magnetic field guides the electrons in a circular path. [2 marks]

- Magnetic field produces a force acting on the electrons at right angles to the direction of movement. (1)
- This pushes the electrons into a curved path, with the force acting towards the centre. (1)

(b) Explain how the changing magnetic field produces an induced electric field in the electron chamber. [2 marks]

- From Faraday's law: $EMF = -N\frac{\Delta\phi}{\Delta t}$
  $\Rightarrow EMF \propto \frac{\Delta\phi}{\Delta t}$ (1)
- The changing flux ($\frac{\Delta\phi}{\Delta t}$) induces an EMF in the chamber, creating an electric field. (1)

9. You want to increase the radius of the circular path by imposing an additional magnetic flux $\Delta\Phi$. Should the lines of ***B*** associated with this increase be in the same direction as the lines shown in the figure or in the opposite direction? Explain your answer. [3 marks]

- Same direction. (1)
- This increases B. (1)
- Since $\Delta\phi = \Delta B.A$, $\Delta\phi$ is increased. (1)

10. (a) State the direction of the force acting on the electron on the right-hand side of the betatron (Fig. 1 of Research handout) [1 mark]

Toward the centre. (1)

(b) Explain how you arrived at your answer. [2 marks]

- Field generated by the moving electron interacts with the external field. (1)
- This creates a force towards the centre of the circle. (1)

11. In a 100-MeV betatron, the orbit radius $\boldsymbol{R}$ is 84 cm. Assume that the orbit is circular. The magnetic field in the region enclosed by the orbit rises periodically (60 times per second) from zero to a maximum value $\boldsymbol{B}_{max} = 0.8\text{T}$ in an accelerating interval of one-fourth of a period, or 4.2 ms.

(a) What is the maximum magnetic flux, $\boldsymbol{\Phi}_{max}$, attained during the accelerating interval? [2 marks]

$$\phi_{orbit} = B_{orbit} A$$
$$= (0.800)\pi(0.84)^2 \quad (1)$$
$$= \underline{1.77 \text{ Wb}} \quad (1)$$

(b) Using the answer to (a), determine the rate of change of flux (induced emf) during the time interval of acceleration. [2 marks]

$$\frac{\Delta\phi}{\Delta t} = \frac{1.77}{4.20\times10^{-3}} \quad (1)$$
$$= \underline{421 \text{ Wbs}^{-1} \text{ (V)}} \quad (1)$$

(c) Given that 1.0 eV (electron volt) is the energy gained by an electron moving across a potential difference of 1.0V, show that the number of revolutions required for an electron to reach its final energy of 100 MeV is approximately 238,000 revolutions. [2 marks]

$$\#\text{revolutions} = \frac{100\times10^6}{421} \quad (1)$$
$$= 2.375\times10^5 \quad (1)$$
$$\approx 238{,}000$$

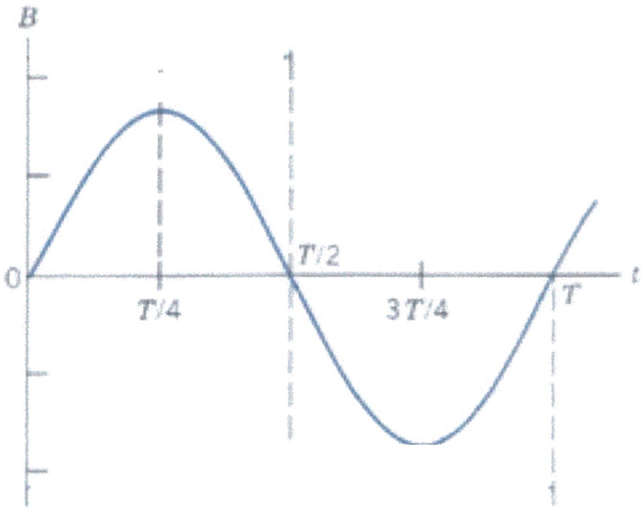
(d) Find the total distance travelled by an electron along its circular path before reaching its full energy of 100 MeV. [2 marks]

$$d = \#\text{revolutions} \times 2\pi r$$
$$= (2.375\times10^5)2\pi(0.840) \quad (1)$$
$$= \underline{1.25\times10^6 \text{ m}} \quad (1)$$

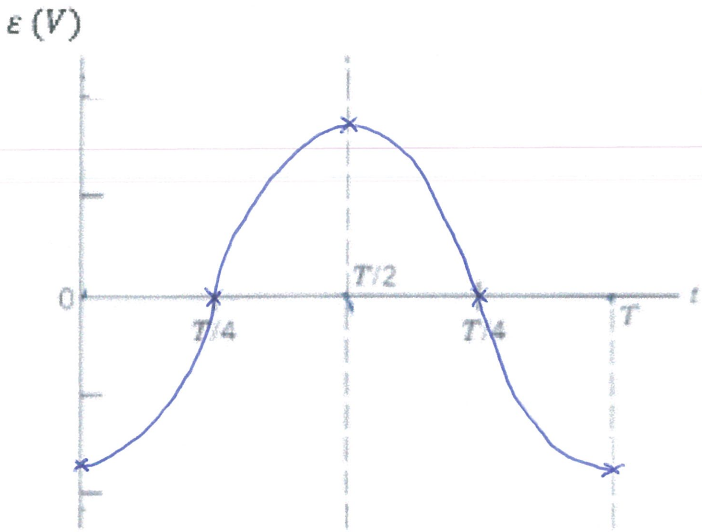
(e) Calculate the average speed of the electron as it travels the total distance needed to reach 100 MeV during the acceleration time interval of 4.2 ms. [2 marks]

$$v = \frac{d}{t} = \frac{1.25\times10^6}{4.20\times10^{-3}} \quad (1)$$
$$= \underline{2.98\times10^8 \text{ ms}^{-1}} \quad (1)$$

12. The varying magnetic field in the betatron can be represented by the graph below.



On the axis below, sketch the shape of a corresponding graph of induced EMF versus time as the B field varies. [3 marks]



Shape (1)
Correct maxima (1)
T/4 phase shift (1)

13. Once accelerated, the electrons are directed out of the doughnut chamber, or inwards, towards a metal target to produce x-rays. X-rays are a form of electromagnetic radiation. They have a wavelength ranging from 0.0100 to 10.0 nm. What are the highest and lowest frequencies of x-rays? [3 marks]

$c = f\lambda$

$\Rightarrow f = \frac{c}{\lambda}$

$= \frac{3.00 \times 10^8}{0.0100 \times 10^{-9}}$ (1)

$= \underline{3.00 \times 10^{19}\ \text{Hz}}$ (1)

$f = \frac{c}{\lambda}$

$= \frac{3.00 \times 10^8}{10.0 \times 10^{-9}}$

$= \underline{3.00 \times 10^{16}\ \text{Hz}}$ (1)

14. The betatron can be thought of as a transformer. Transformers have a primary and secondary coil. The magnetic field is changed by passing alternating current to the primary coil. A current is induced in the secondary coil by Faraday's Law.

[2 marks]

(a) State which part of the betatron behaves like the primary coil of a transformer.

- Coils C (1)

(b) State which part of the betatron behaves like the secondary coil of a transformer.

- Ring of electrons in the tube. (1)

15. Referring to the values given in Question 11, suggest ***TWO*** strengths of the design of a betatron as a particle accelerator. [2 marks]

- Small size ($r = 0.84$m) (1)
- Value of B (0.800T) is small compared to other particle accelerators. (1)

16. Describe ***TWO*** ways that you can increase the energy of radiation emitted by the betatron? [2 marks]

- Increase the alternating current. (1)
- Increase the frequency of injection of electrons. (1)

END OF TEST