Please read the exam guidelines, rules, instructions and marking criteria at:
`http://www.hep.ucl.ac.uk/~markl/teaching/3c59/exam/final.html`
This exam is worth 50% of your final course grade. The duration of the exam is 3 hours. Students should upload their work using the web-form. A breakdown of the mark scheme is indicated.

An electron in a cathode ray tube is emitted from a heated cathode at the position (0,0,0) in Cartesian (x,y,z) coordinates, with velocity 10^6 ms^{-1} in the positive x direction. It travels through a uniform magnetic field of strength 5 μT in the positive z direction and a uniform electric field of strength 10 Vm^{-1} also in the positive z direction. A flat fluorescent screen is placed perpendicular to the x axis in the y-z plane at $x = 0.3$ m.

The position and velocity of the electron at a time t after it is emitted from the cathode can be determined by considering small Δt intervals. Within each short interval the change in position of the electron is:

$$\Delta\vec{\mathbf{r}} = \vec{\mathbf{v}}\Delta t$$

and the change in its velocity is:

$$\Delta\vec{\mathbf{v}} = \vec{\mathbf{a}}\Delta t$$

where $\vec{\mathbf{r}}$, $\vec{\mathbf{v}}$ and $\vec{\mathbf{a}}$ are the vectors representing position, velocity and acceleration respectively.

The force on a particle with charge q travelling through a magnetic field $\vec{\mathbf{B}}$ and an electric field $\vec{\mathbf{E}}$ is given by:

$$\vec{\mathbf{F}} = q(\vec{\mathbf{v}} \times \vec{\mathbf{B}} + \vec{\mathbf{E}})$$

The electron charge is 1.6×10^{-19} C and mass 9.1×10^{-31} kg.

A suitable time interval is ~ 1 ns. In order to avoid getting into an infinite loop, you should stop tracking the electron if it has not reached the screen after 1 μs.

PLEASE TURN OVER

- Determine the coordinate of the point at which the electron hits the screen. [**20/50 marks**]
- Modify your program to read the initial velocity and electron identifier from the URL: `http://www.hep.ucl.ac.uk/~markl/teaching/3c59/exam/electrons.txt` where each line contains the electron identifier and three numbers representing the electron's velocity (v_x, v_y, v_z). [**10/50 marks**]
- By considering the magnitude of the vector connecting (0,0,0) with the point at which the electron hits the screen, determine which electron (by reference to its identifier) travels the furthest. [**5/50 marks**]

Modify you existing code and define appropriate interfaces such that:

- electrons that start from an arbitrary (x,y,z) position [**5/50**] **marks**
- the code can use magnetic and electric fields that are not uniform (i.e. which vary with position) [**10/50 marks**]

END OF PAPER