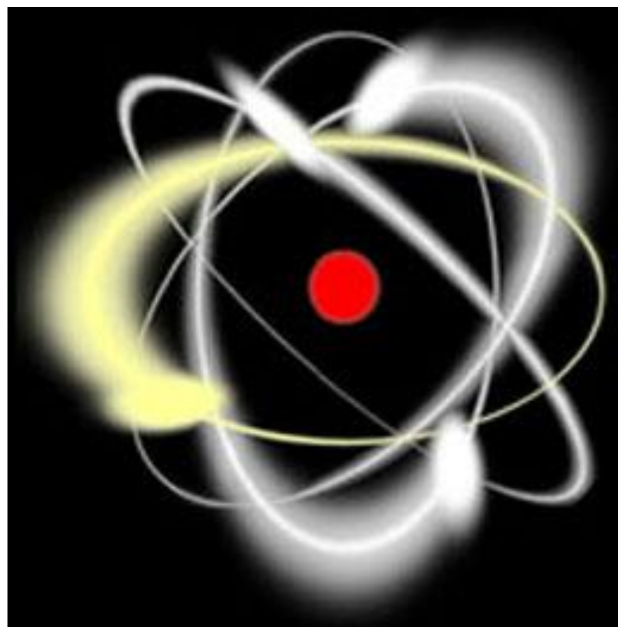
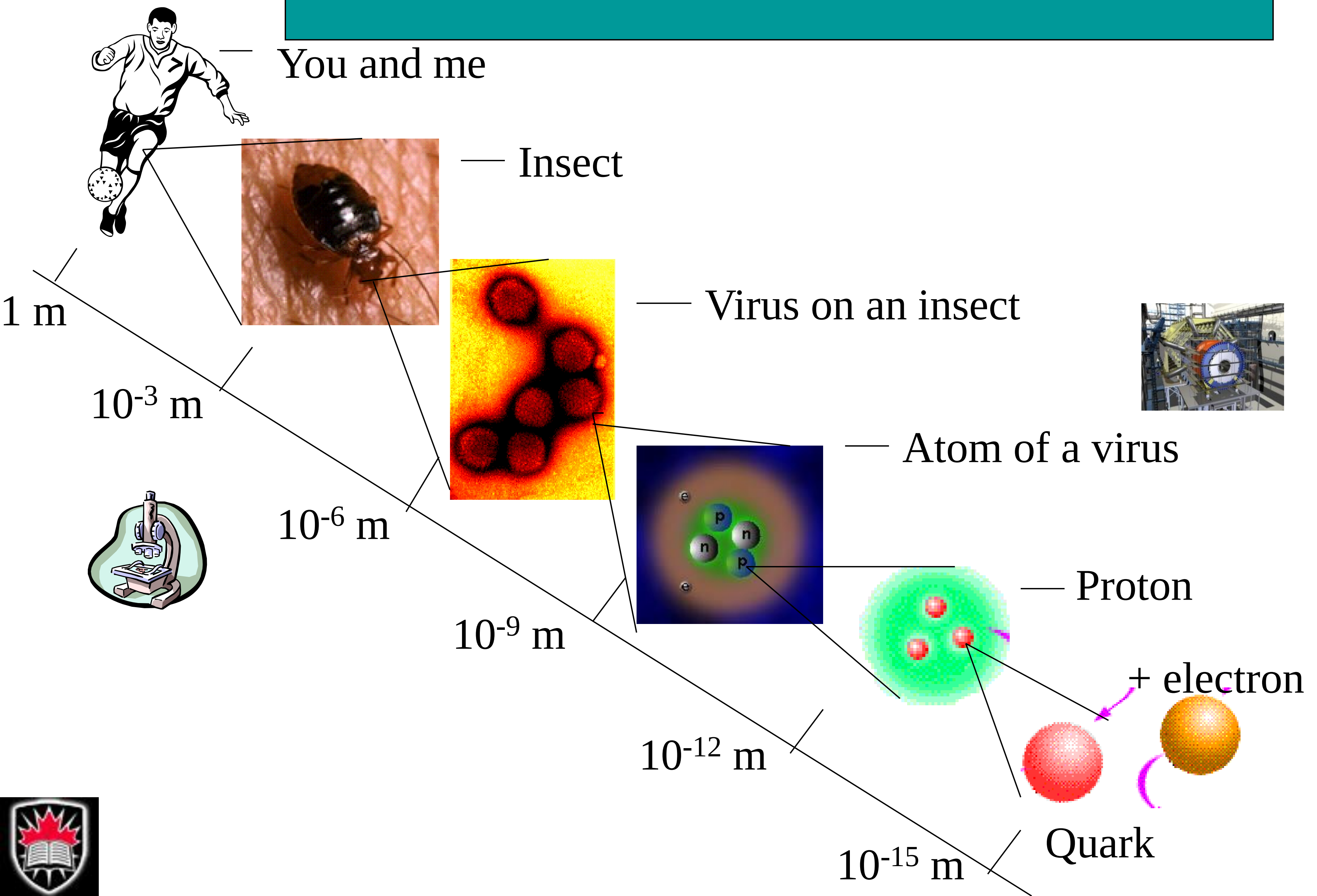
Measurement of Charge to Mass Ratio For an Electron



(Thomson's Experiment)

The scale of the subatomic world



The Electron:

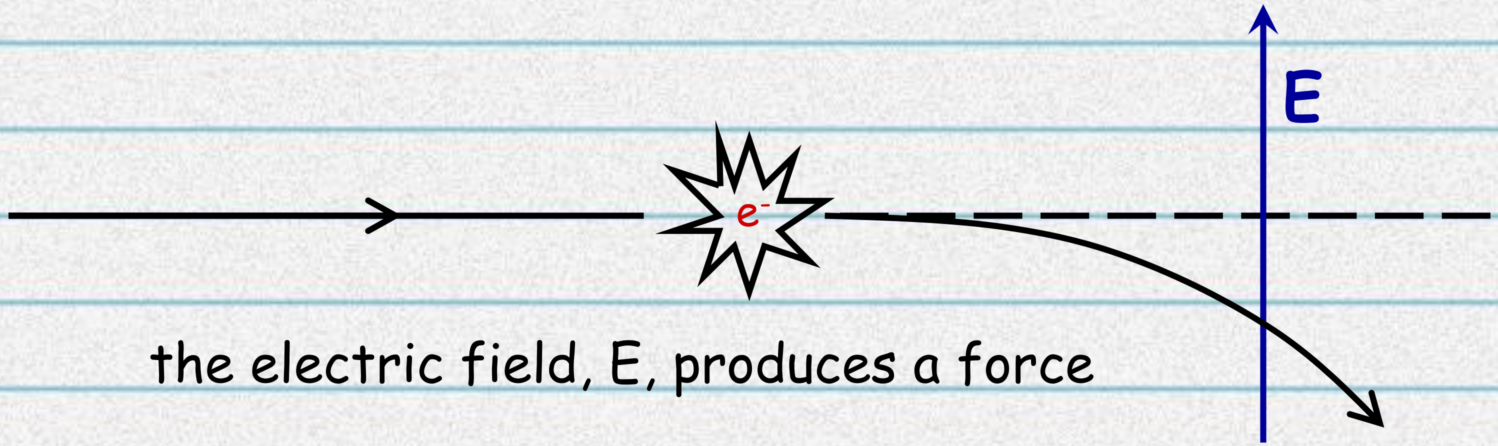
- is an elementary particle: smallest speck of matter
- is normally found in the immediate vicinity of a nucleus, forming an atom
  - Mass (m_e): 9.11×10^{-31} kg
  - Charge (e): 1.6×10^{-19} C (C = Coulombs)

- Charge is found by Millikan's Oil Drop experiment

- So, if we can find e/m_e, we can determine m_e
- In 1897, J.J. Thomson found this value
  - Ratio (e/m_e): -1.76×10^{11} C/kg
- Your Job: try to repeat that measurement today

Forces affecting the electron:

1. The electric field:

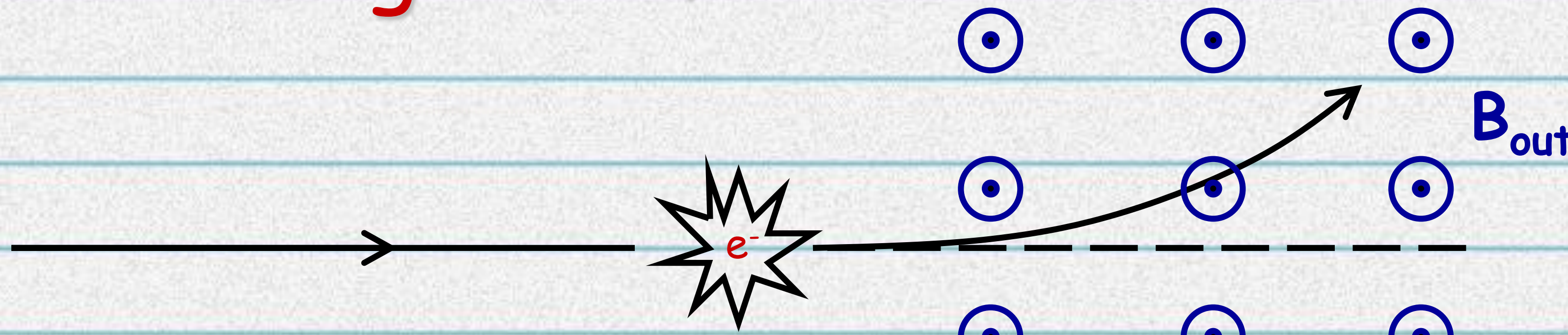


$F_E = q \cdot E$ (q = e, the charge of the electron)

The electric field, E, always points in the direction that a +ve charge would move if it were within the field.

Forces affecting the electron:

2. The magnetic field:



The magnetic field (B_{out}) produces a force:

$F_B = B_{out} \cdot e \cdot v$ (v is the velocity of the electron)

This force is perpendicular to both B_{out} and v.

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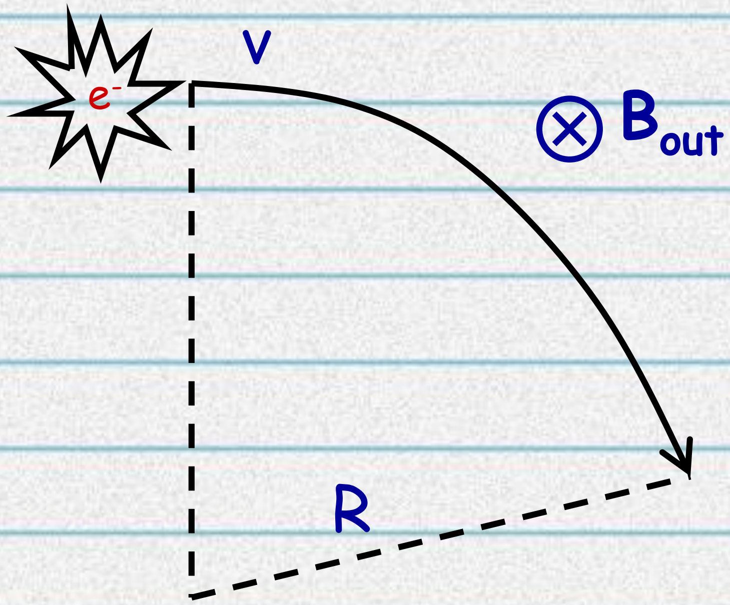
Finding e/m:

- Electrons move in circles in magnetic fields
- This motion produces a centripetal force

$$F = \frac{mv^2}{R}$$



- We can equate this to F_B:

$$Bev = \frac{mv^2}{R}$$

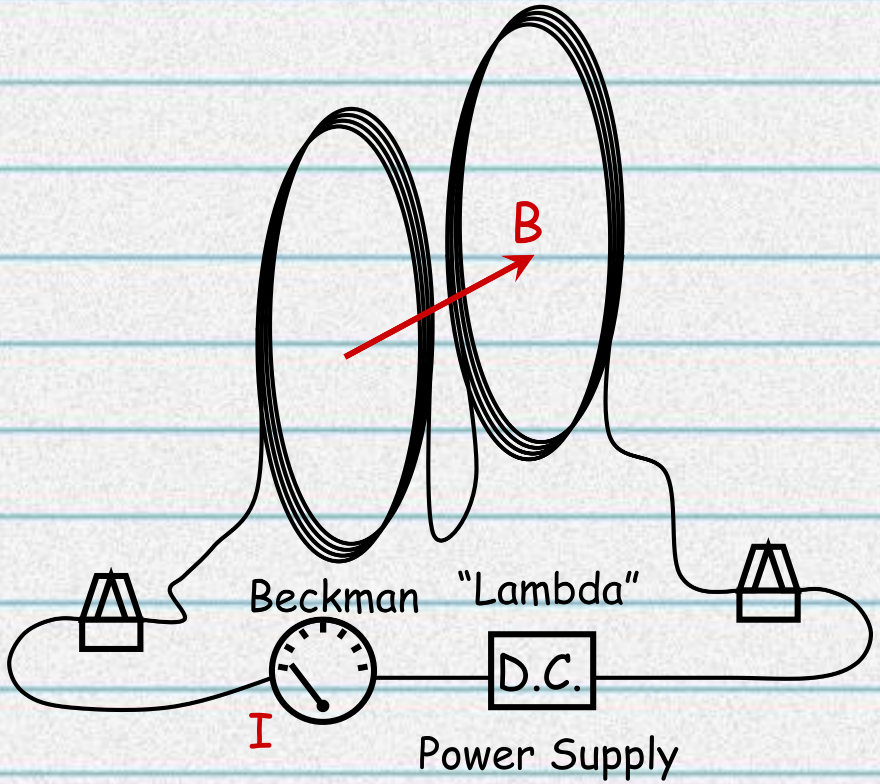
- Re-arranging:

$$\frac{e}{m} = \frac{v}{BR}$$

- *Thus, to find e/m we need to know 3 things: the magnetic field, B, the radius of curvature, R, and the velocity of the electrons, v.*

Finding the magnetic field, B:

- "Helmholtz" coil arrangement delivers uniform magnetic field



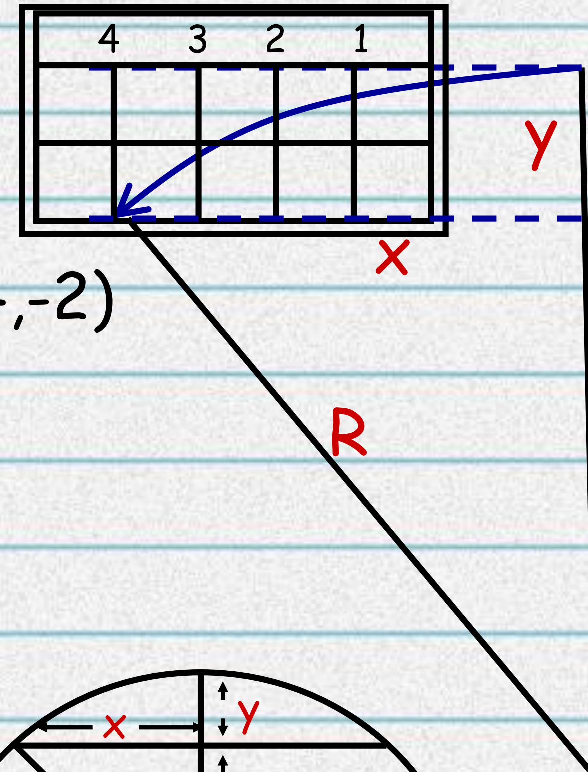
- B depends on current, and is calibrated to be:

$$B = I \times 4.23 \times 10^{-3}\ \text{Wb m}^{-2}$$

(I measured in Amps)

Determine the radius, R:

- Measure y - deflection at a distance, x, from the exit of the electron



$(x,y) = (4,-2)$

- Given (x,y) - find R

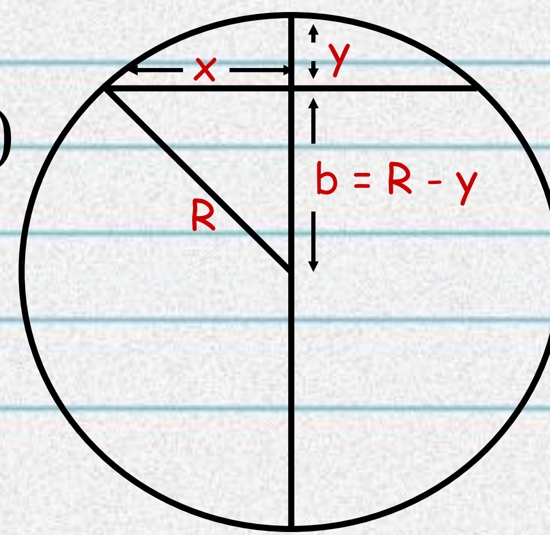
$$R = \frac{x^2 + y^2}{2y}$$

- To prove this, try Pythagoras:

$$(R - y)^2 = b^2 = (R^2 - x^2)$$

$$R^2 - 2Ry + y^2 = R^2 - x^2$$

$$R = \frac{x^2 + y^2}{2y}$$

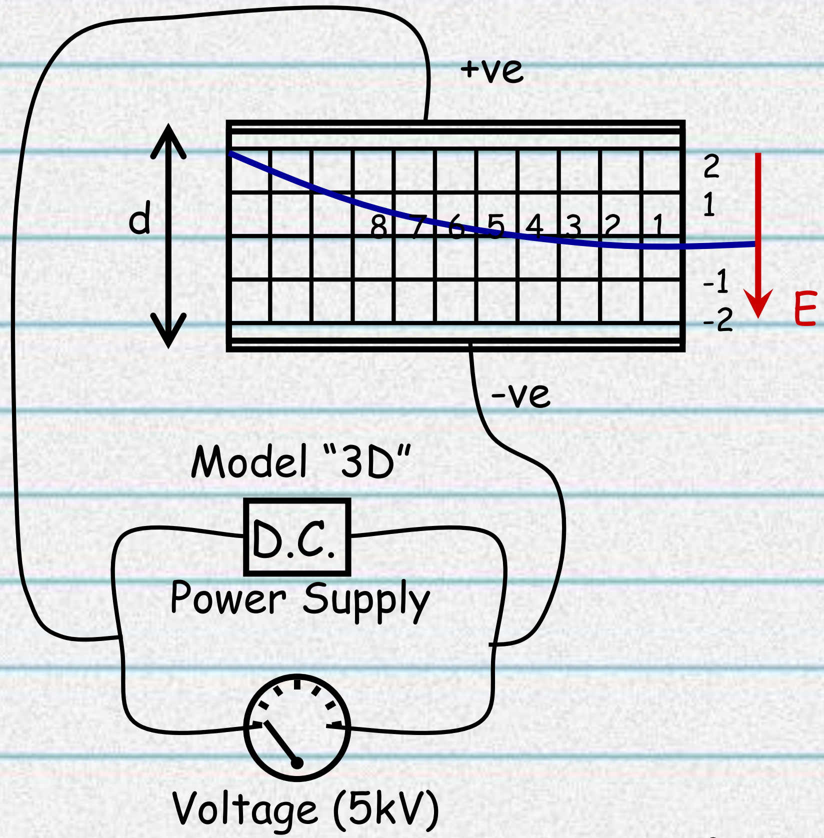


Determine the velocity, v:

- Now switch on the Electric Field
  - Use it to cancel the effects of the B field

$$E = \frac{V}{d} = \frac{V}{0.052}$$

- Use the Electric field to cancel the deflection at the x value where the magnetic deflection was measured



$$Ee = Bev$$

$$v = \frac{E}{B} \quad (\mathrm{m/s})$$

Procedure:

- Plug in transformer for cathode heater supply
- Switch on model "3D" D.C. supply to accelerate electrons down the tube and onto the screen

  set to ~3 kV   (3000 Volts)

- There should now be a blue trace on the screen

Procedure:

- Switch on Beckman meter and Lambda power supply unit connected to coils
  set to ~ 0.1 A (roughly)

- Determine B

- Measure (x,y):
  determine R

Procedure:

- Switch on second model "3D" DC supply connected to electrodes on top of mica screen
- Slowly increase potential to cancel deflection: determine v
- Fill in worksheet and calculate e/m
- Repeat with different current in coils
- Dial down all power supplies and switch off

Procedure:

- Compare your results to accepted values.
- What are the possible sources of measurement error?

Thomson's *e/m* experiment

Run #	Your measurements		units	Calculated quantities		units
Determine the radius of the track, R	x		metres	$R = \frac{x^2 + y^2}{2y}$		metres
	y		metres			
Determine the magnetic field, B	I		Amperes	$B = 4.23 \times 10^{-3}\ I$		Tesla
Determine the electric field, E	V		Volts	$E = \frac{V}{0.052}$		Volts/metre
Determine the electron's velocity, v				$v = \frac{E}{B}$		metres/s
Determine the electron's charge-to-mass ratio, e/m				$e/m = \frac{v}{BR}$		Coulombs/kg

Run #	Your measurements		units	Calculated quantities		units
Determine the radius of the track, R	x		metres	$R = \frac{x^2 + y^2}{2y}$		metres
	y		metres			
Determine the magnetic field, B	I		Amperes	$B = 4.23 \times 10^{-3}\ I$		Tesla
Determine the electric field, E	V		Volts	$E = \frac{V}{0.052}$		Volts/metre
Determine the electron's velocity, v				$v = \frac{E}{B}$		metres/s
Determine the electron's charge-to-mass ratio, e/m				$e/m = \frac{v}{BR}$		Coulombs/kg