Experiment 7

Energy of Beta Particles

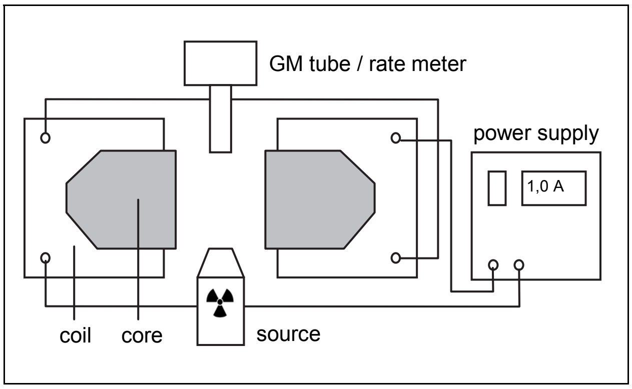
Name: ……………………………………………..

Aim

To measure the average speed and maximum energy of β particles emitted by a source of strontium-90.

Set-up

The set-up consists of an U-shaped electromagnet. A current through the coils provides a homogeneous magnetic field between the two magnetic poles. The beam of β particles from a source of strontium-90 (^{90}Sr) passes through the magnetic field, is deviated and is detected by a GM tube connected to a rate meter.



Read the introduction on page 9 of the booklet *ISP Experiments* about measuring the energy of β particles from the radius of their circular path in a magnetic field.

Measurements

1 Check if the source in the set-up is set at an angle of 30°.

2 Measure the intensity *I* of the radiation (in pulses per s) with increasing current *I* through the coils. The intensity is read from the upper scale of the rate meter in counts per second (cps). Record the results in the table below.

current *I* (A)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
intensity *I* (cps)										

current *I* (A)	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
intensity *I* (cps)										

Assignments

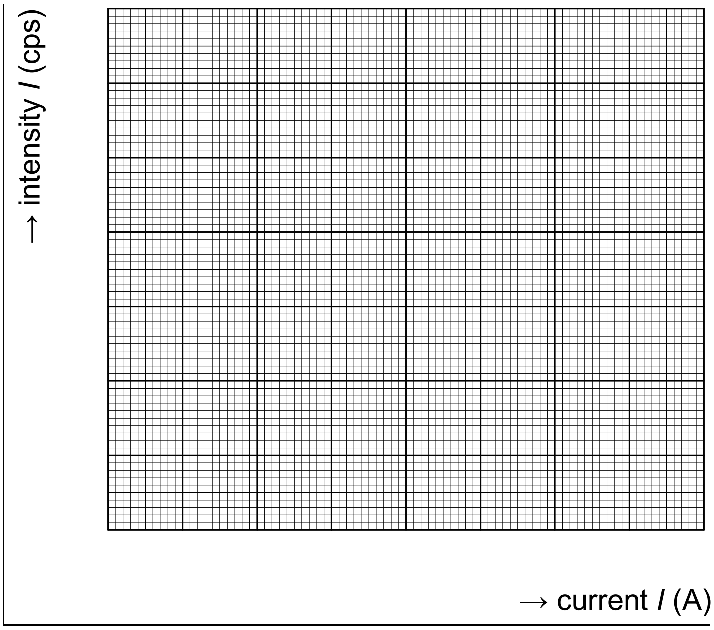
1 Plot your measurements (intensity *I* as a function of current *I*) in the graph (right).

2 From this graph, find the current *I* for which the β-radiation is at a maximum.

I = ……… A

3 The magnitude *B* of the magnetic field is determined by the current *I* through the coils. The relationship between *B* and *I* for the electromagnet in the set-up is plotted in the graph on page 4 of this worksheet. From this graph, find the magnitude *B* of the magnetic field that corresponds with the current *I* found in assignment 2.

B = ……… T



The magnitude *B* of the magnetic field in which the β particles reach the GM tube by a part of a circular path, is now known. The speed v_0 of the β particles emitted by the source can then be calculated with the help of the formulas for the centripetal force F_c and the Lorentz force F_L on moving β particles (electrons) in a magnetic field. The Lorentz force 'supplies' the centripetal force for the circular path of the β particles. Therefore, their speed v_0 can be calculated from the following formula:

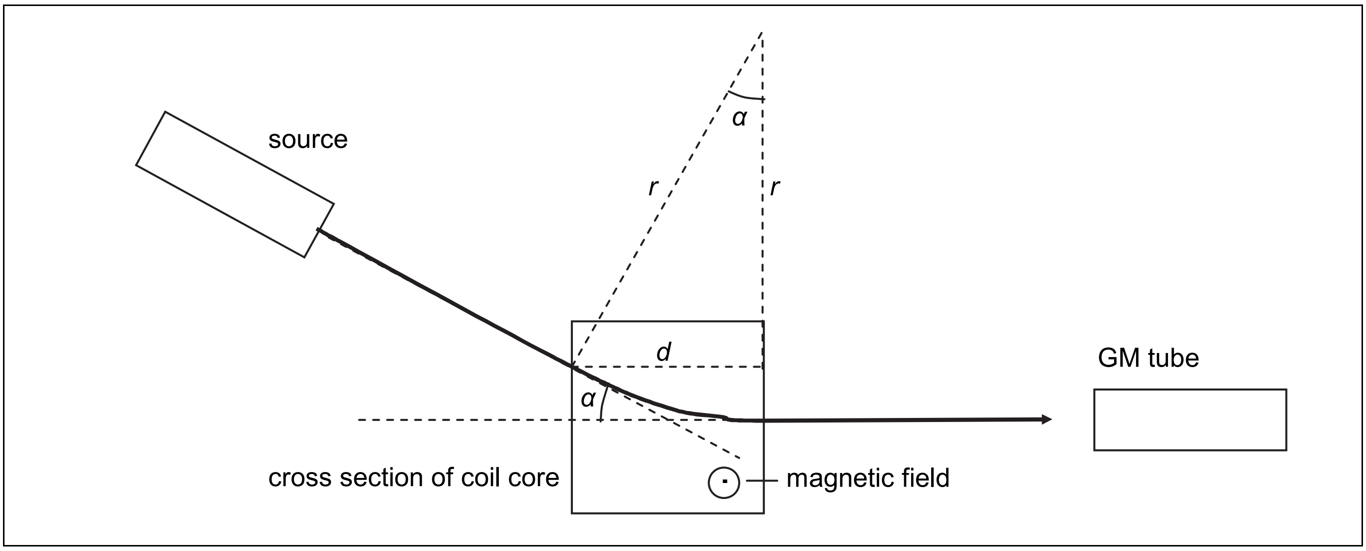
$$v_0 = \frac{B \cdot q \cdot r}{m_0} \qquad [1]$$

In this formula, B is the magnitude of the magnetic field, q the charge of an electron ($1.60 \cdot 10^{-19}$ C), r the radius of the circular path and m_0 the mass of an electron ($9.1 \cdot 10^{-31}$ kg).

The radius r of the circular path of the β particles can be calculated with the following formula:

$$r = \frac{d}{\sin\alpha} \quad \text{for } 0^\circ < \alpha < 45^\circ$$

In this formula, d is the distance between the coil cores ($4.0 \cdot 10^{-2}$ m) and α the angle between the source and the GM tube (30°) – see the drawing below.



4 Calculate the radius r of the circular path of the β particles in the set-up, and thus their speed v_0.

r = ……….. m

v_0 = ……….. m/s

If you calculated the speed correctly, the outcome will be much larger than the speed of light ($3.0 \cdot 10^8$ m/s). So, this outcome cannot be the real speed of the β particles. The explanation of this phenomenon was given by Albert Einstein (1875-1955). In his theory of relativity he noted that the mass of a body depends on its speed. Since the β particles have speeds relatively close to the speed of light, you cannot use the so-called rest mass m_0 in your calculation. Instead you have to use a larger mass m, that can be found using Einstein's formula:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad [2]$$

As long as the speed v is much smaller than the speed of light c, the mass m will be approximately equal to m_0. So, in everyday life these so-called relativistic effects are virtually unnoticeable. However, this does not apply to the β particles in this experiment. Below, we are going to find a formula which allows us to calculate the speed of those β-particles.

For the speed of β particles in their circular path in the magnetic field it follows that:

$$v = \frac{B \cdot q \cdot r}{m} \qquad [3]$$

If we substitute Einstein's formula [2] for the 'relativistic mass' m in formula [3], we find:

$$v = \frac{B \cdot q \cdot r}{m_0} \sqrt{1 - \frac{v^2}{c^2}} \qquad [4]$$

Because $B \cdot q \cdot r / m_0$ in formula [4] is equal to v_0 (according to formula [1]), we can rewrite formula [4] as:

$$v = v_0 \sqrt{1 - \frac{v^2}{c^2}} \quad \rightarrow \quad \frac{1}{v^2} = \frac{1}{v_0^2} + \frac{1}{c^2} \qquad [5]$$

In this formula, v is the real speed of the β particles, v_0 the speed we calculated before in assignment 4 and c the speed of light ($3.0 \cdot 10^8$ m/s).

5 Calculate with formula [5] the speed v of the β particles in this experiment. Check if this speed is indeed lower than the speed of light.

v = ……….. m/s

6 Calculate the mass m of the β particles in this experiment.

m = ……….. kg

A stationary β particle has a rest energy $E_0 = m_0 \cdot c^2$. A moving β particle with speed v has an energy $E = m \cdot c^2$, in which m represents the 'relativistic mass' of formula [2]. The difference $E - E_0$ is the kinetic energy E_k of the β particle.

7 Calculate the kinetic energy (in J and in MeV) of the β particles in this experiment.

Note: 1 eV = $1.6 \cdot 10^{-19}$ J.

E_k = ……….. J = ……….. eV = ……….. MeV

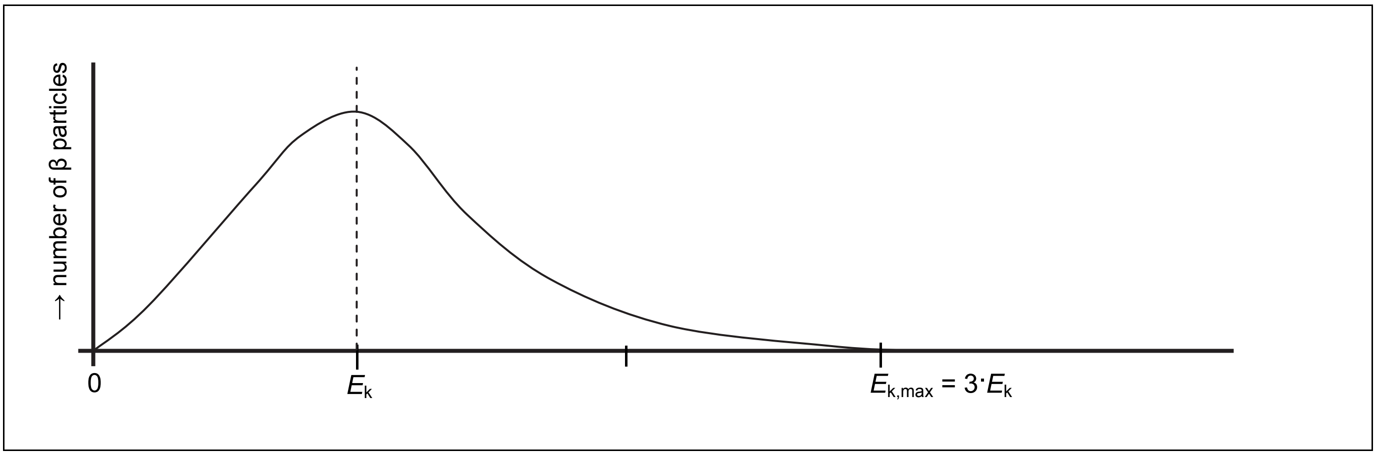
8 Because of absorption in the foil surrounding the source and in the layer of air between the source and the magnetic poles, we must apply a correction of 0.08 MeV to the kinetic energy E_k found in assignment 7.

E_k = ……….. MeV (after correction for absorption)

The β particles from a ^{90}Sr source do not all have the same kinetic energy. The graph below shows the number of β particles as a function of their kinetic energy. The kinetic energy found in assignment 8 is the energy value that occurs most (E_k in the graph). From other experiments it is known that the maximum kinetic energy $E_{k,max}$ is three times as large as the kinetic energy E_k that occurs most.

9 Calculate the maximum kinetic energy $E_{k,max}$ of the β particles in this experiment. Compare the results of your calculation with the literature value of 2.27 MeV for β particles emitted by ^{90}Sr.

$E_{k,max}$ = ……….. MeV



10 Even if the current in the coils is zero, the GM tube still detects β particles. Explain why.

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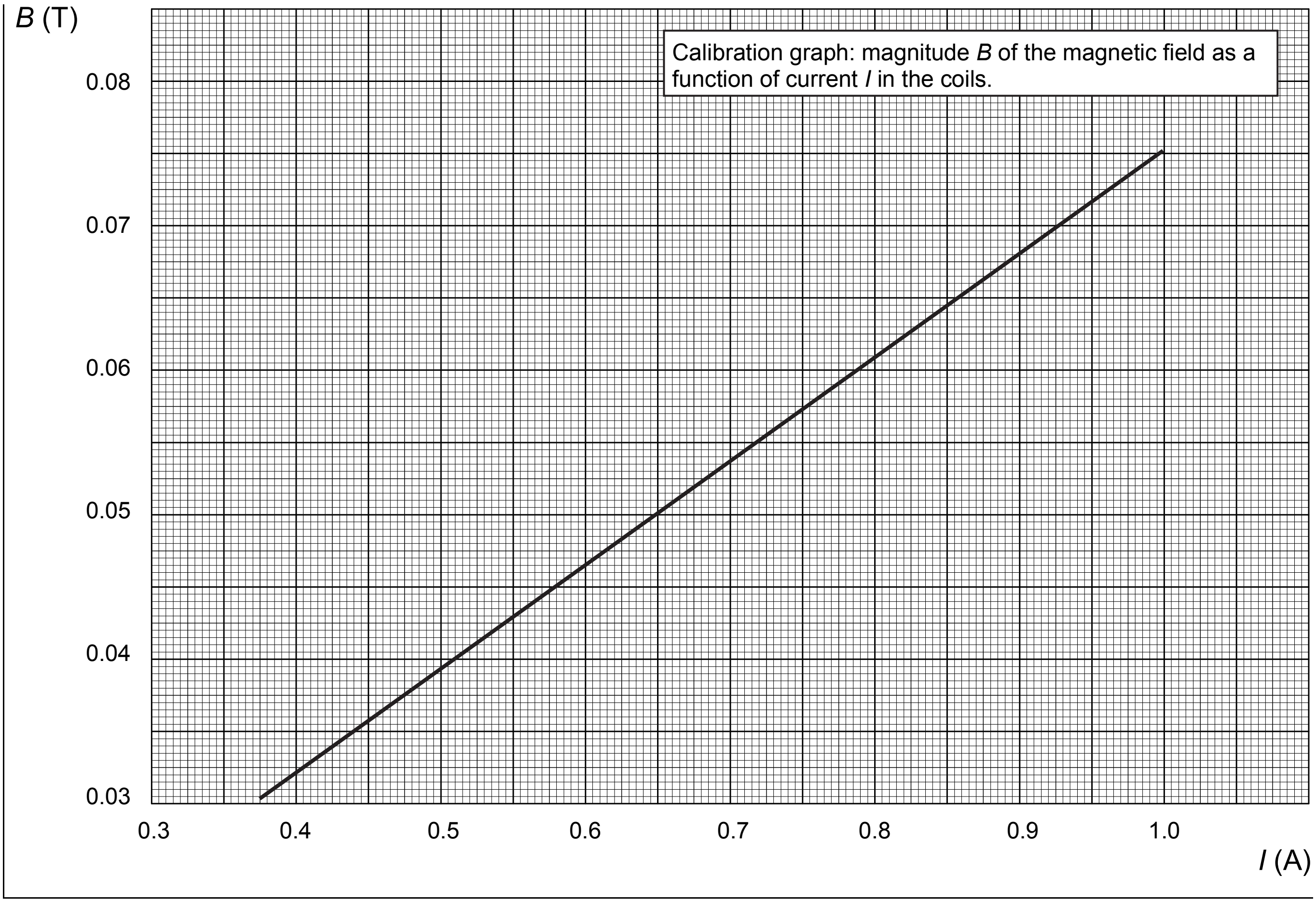
B (T)
Calibration graph: magnitude B of the magnetic field as a function of current I in the coils.
0.08
0.07
0.06
0.05
0.04
0.03
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
I (A)