Simulation worksheets

Electron beam in electrical and magnetic field

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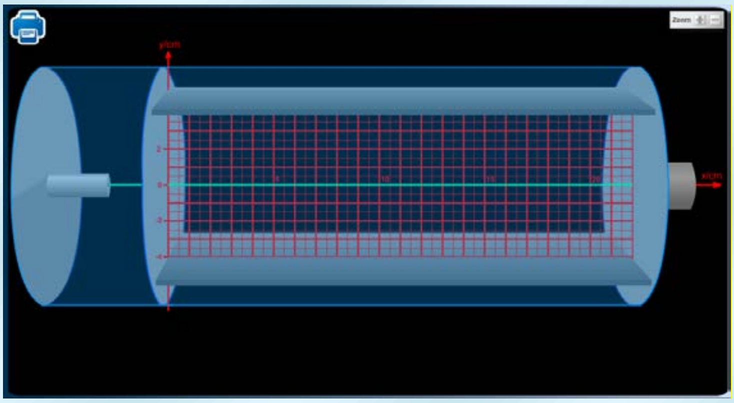
Electron beam in crossed electric and magnetic fields

With this and the following worksheets, you can use the electron beam simulation to learn how the motion of charged particles, in this case an electron beam, can be manipulated using homogeneous electric and magnetic fields. This is not only important from the point of view of technology (e.g. cathode ray tubes) but also from the point of view of physics. The experiment can be used to investigate the properties of electrons (especially the specific charge q/m). The conditions for manipulation can be investigated. With the simulation, the effects of a change in parameters can be observed immediately and investigated interactively.

1. Introduction to the simulation

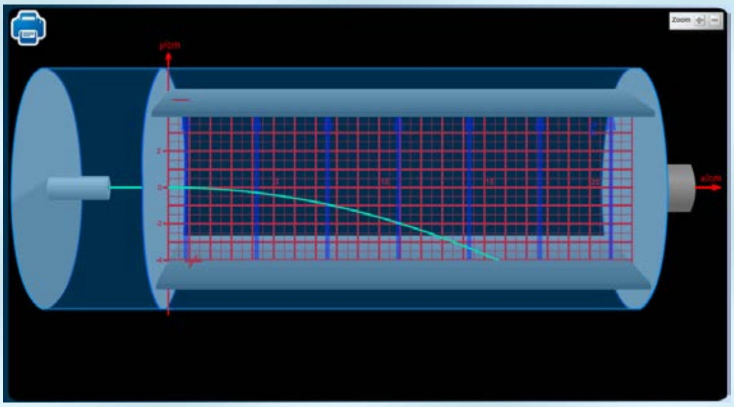
Start the simulation. The electron beam is shown in bluish green, the magnetic field in brown and the electric field in blue.

Using the controls, try to obtain the situations shown in the illustrations below:



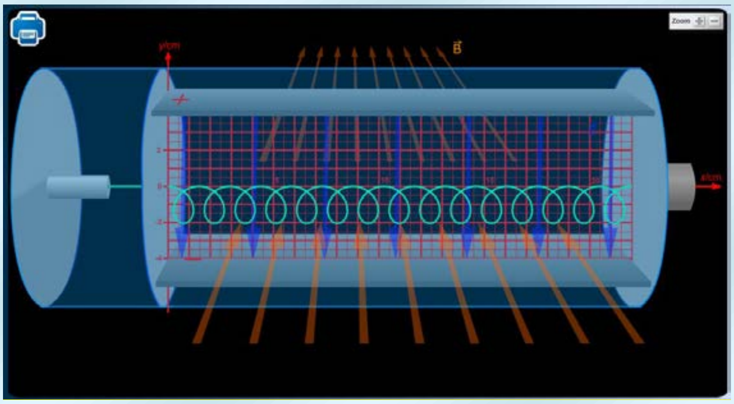
(Fig. 1)

The electron beam is on the x-axis



(Fig. 2)

The electron beam is bent downwards.



(Fig. 3)

The electron beam has the form of a "cycloid”.

2. Investigation and explanation of various beam paths

The forces acting on charged particles in electric and magnetic fields are described by the following formulae:

$$F_{el} = q\,E \qquad F_{mag} = q\,v\,B$$

Use these formulae to explain the following experiments. You must take the sign of the electric charge into account.

Start by using the controls to set the situation shown in Fig. 1 and

a) increase (reduce) the acceleration voltage U with $E = 0,\ B = 0$

Observations:

Explanation:

b) increase (reduce) the magnetic flux density B with $E = 0,\ U =$ constant

Observations:

Explanation:

c) increase (reduce) electric field intensity E with $E = 0,\ U =$ constant

Observations:

Explanation:

d) "If at least one of the fields (electric or magnetic) is not equal to zero, the electron beam will always be diverted". Investigate this statement using the simulation and explain your answer.

3. Measurement of specific charge q/m and velocity filter

Note the following assumptions for the simulation:

- The magnetic field and the electric field are both homogeneous (the direction and intensity of he fields at all points between the plates of the diversion capacitor are the same.)
- The electric and magnetic fields are perpendicular to each other.
- The electrons enter from the left, perpendicular to the electric and magnetic fields.

a) Before the electrons enter the diversion condenser and the magnetic field (from the far left in the figure), they are accelerated by voltage U to velocity v (initially in the horizontal direction).

Remember: $W_{\text{kin}} = \frac{1}{2}\, m\, v^2$, $W_{\text{el}} = q\, U$

Using the law of the conservation of energy, explain why the velocity the electrons on entering the diversion condenser is given by:

$$v = \sqrt{2 \frac{q}{m} U}$$

b) For certain values of U, B and E, the electrons are not diverted and the electron beam remains horizontal (see Fig. 1). As this is geometrically the simplest case, it makes sense to investigate this situation first. Some sample values are already given in the table below:

Values with non-diverted electron beam						
	1	2	3	4	5	6
U [V]	300					
B [T]	0,0004					
E [V/m]	4100					
v [m/s]	10250000					
q/m [C/kg]	$1{,}75104 \cdot 10^{11}$					

Find other possible settings with the same beam path and enter the values of U, B and E in the first three lines of the table.

c) For a non-diverted beam must always apply, explain why:

$F_{\text{el}} = F_{\text{mag}} \quad \Leftrightarrow \quad v = \frac{E}{B}$ and therefore $\frac{q}{m} = \frac{E^2}{2U\,B^2}$

Calculate and insert the values missing from the bottom two lines of the table.

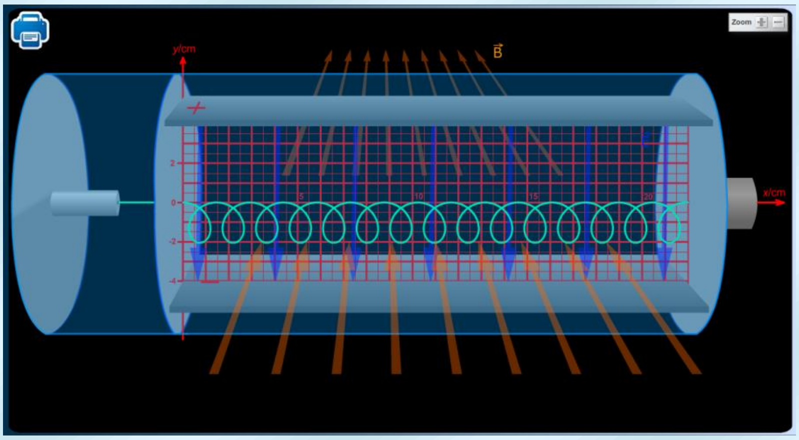
Determine from the data an approximate value for: $q/m \approx$

d) On the right-hand side of the diversion condenser, there is a wall with a small hole in the centre. Investigate when the electrons can pass through this wall by varying the value of the acceleration voltage U while E and B remain constant. Explain why this setup represents a velocity filter for the electrons.

4. Cycloidal paths

A straight line is the simplest path that can be obtained for $E \neq 0$ and $B \neq 0$. All the other possible paths look considerably more complicated. Can they be described mathematically? Can they be explained? These are the questions considered by this assignment.

a) Find possible values for U, E and B which result in the situation shown in Fig. 3:



(Fig. 3)

Discuss the mathematical properties of the path (e.g. periodicity and symmetry). Explain why a path of this type cannot be described by a function.

b) We therefore need another tool for the mathematical description. Research the term "cycloid" and tae a close look at the file "Zykloide.html" in the simulation directory. Then complete the following statements:

A **cykloid** is also called ______________________. It can be constructed geometrically by marking the path of a______________________ point on a ______________________ wheel. Depending on the distance between the marked point and the centre of the wheel, we can distinguish ______________________, ______________________ and ______________________ cykloids.

c) Change the parameters in the electron beam simulation. Investigate the types of cycloids produced under different conditions.

Now that it is clear that these paths are cycloids, you still need to explain why this is the case. Although it is theoretically possible to calculate the entire path, the mathematics are rather complicated. This is why the comparison with a rolling wheel is helpful. It can be seen that the path is a result of the superposition of the displacement of the centre of the wheel (in the x direction) and the rotation of the wheel about its centre. In qualitative terms, these components are relatively easy to understand:

d) Explain: Which field is probably the main cause of rotation? What values would have to be set in the simulation and in the file "Zykloide.html" in order to obtain pure rotation without displacement?

e) A special case of the cycloid results in an especially simple path: the straight-line motion from assignment 3. Which parameters do you need to set in the file "Zykloide.html" in order to obtain this path? What is the velocity of the centre?

f) In order to understand why the path shown in Fig. 3 is more tightly bent at the bottom than at the top, sketch a full loop (full period) of the path. Mark the highest and lowest points of the path. What can you say about the velocity of the electron at these points? Why is the path more tightly bent at the bottom?