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MOTION OF CHARGED PARTICLES IN A MAGNETIC FIELD

Kosimov Asroridin Sadievich
Head of the Department of Physics, Termiz State University,
Candidate of Physics and Mathematics, Associate Professor

ANNOTATION
The article reveals the meaning of the movement of charged particles in a magnetic field. The movement of charged particles in a magnetic field should be studied in the topic "Magnetic field" when considering the effect of a magnet on a current. By this time, the following will be studied: circular motion, properties of electron beams, electric current in gases. The teacher can rely on the knowledge of these questions when studying a new topic and conduct a lesson in the form of a conversation.

KEY WORDS AND CONCEPTS: *induction, current strength, speed, particle, motion.*

DISCUSSION

Based on the definition of the magnetic induction as a quantity measured by the force acting per unit length of the conductor with a current equal to unity, for the case when the field lines and the current are mutually perpendicular, we write:

$$B = \frac{F}{Il}.$$

where B is expressed in tesla, F is in newtons, I is in amperes and l is in meters.

The force acting on a conductor with current is:

$$F = IlB.$$

If one charged particle moves in a magnetic field, then the current generated by it is equal to:

$$I = \frac{e}{t}.$$

and since l = vt, the force acting on a particle moving in a magnetic field (Lorentz force) is:

$$F_{л} = \frac{e}{t} vtB\sin a = evB\sin a.$$

For the case when v ⊥ B, t, i.e. the particle moves in the direction perpendicular to the magnetic field lines:

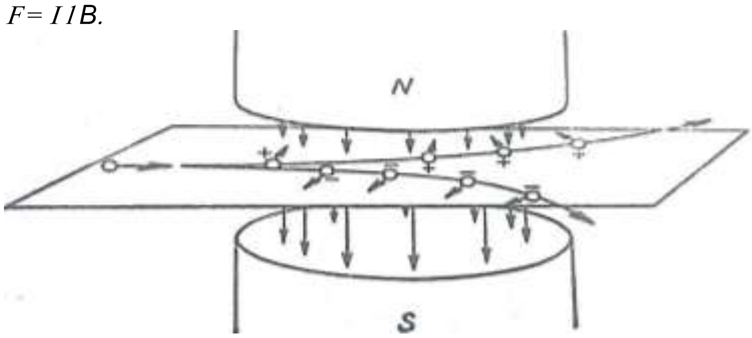

Figure: 1. The movement of charged particles in a magnetic field

It is very important to show students that the Lorentz force is always perpendicular to the direction of the particle's velocity, i.e. that it is a centripetal force (Fig. 1).

This implies the fact that the trajectory of the particle is an arc of a circle, and the fact that the Lorentzian force changes the velocity of the particle only in direction, but not in magnitude, and,

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therefore, does not produce work and does not change the energy of the particle.

We prove the perpendicularity of the Lorentz force to the speed using the left-hand rule to determine the direction of the force acting on a conductor with a current in a magnetic field.

Having established the fact that the Lorentz force is a centripetal force, we can write:

$$F_{л} = F_{ц.с} \ и \ evB = \frac{mv^{a}}{t}.$$

From the last equality, we obtain a formula for determining the radius of curvature of the particle trajectory:

$$r = \frac{m\,v}{B\,e}.$$

The smaller the radius of curvature of the trajectory, the greater the deflection of the particle in the magnetic field. Therefore, the analysis of the dependence of the magnitude of the deviation from the charge, mass and velocity of the particle can be carried out on the basis of the obtained formula or the formula for the centripetal force, but it is also possible to derive a formula for the magnitude of the deviation of a particle in a magnetic field.

Using the geometry theorem about the perpendicular dropped from any point of the circle to the diameter (Fig. 2), we have:

$$t^2 = 2rs_{м}.$$

or, substituting the value for r:

$$s_{м} = \frac{l^2 Be}{2mv}.$$

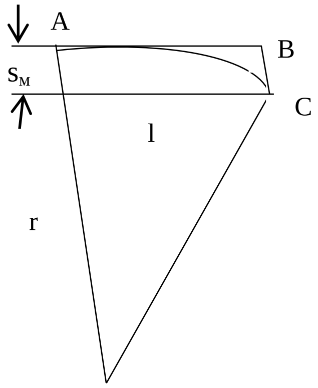

Figure: 2. To the determination of the non-magnitude of the deflection of an ion in a magnetic field

We analyze the formula for various cases (electrons, protons and ions). We note that, while the deflection of a charged particle in an electric field is determined by the magnitude of its kinetic energy, its deflection in a magnetic field is determined by the magnitude of its momentum (momentum):

$$s_{м} = \frac{l^2 Be}{2p}.$$

where p = mv is the momentum of the particle.

For the lesson in which the movement of particles in a magnetic field is studied, it is useful to repeat "The movement of particles in an electric field", and then conduct a survey in a comparative plan, finding out how and why the trajectories of movement in these fields differ, what are the reasons for the deviations of particles, how the magnitude will change deviations in both cases with increasing speed.

Note that the dependence of the deviation of a particle on its mass and charge can be explained not only by a ready-made formula, but also by using the second law of dynamics.

Examples of such an explanation:

A) Let an electron and a monovalent ion fly into the magnetic field with the same velocities, then e1 = e2; v1 = v2; m1 <m2. Since the Lorentz force does not depend on the mass of the particle, it will be the same for an electron and an ion, but on the basis of the second law of dynamics, the electron will receive a greater centripetal acceleration than an ion, and the radius of curvature of its trajectory will be less, and the magnitude of the deflection is greater.

B) Two ions having the same mass, but different degrees of ionization, fly into the magnetic field with the same speed (m1 = m2; v1 = v2; e1 <e2;)

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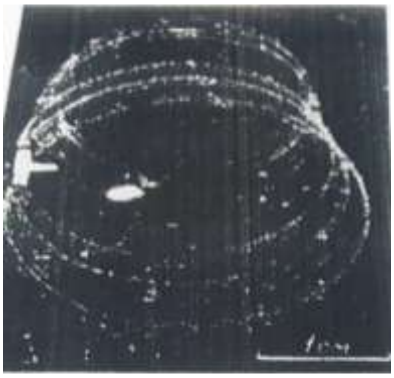

Figure A. Trajectory of motion of an electron in a magnetic field in the Wilson chamber.

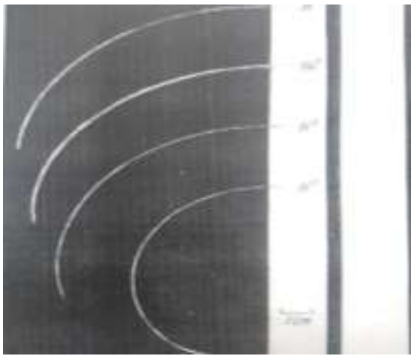

Figure: B. Tracks of nuclei of light elements and magnetic field.

In this case $F_1 < F_2$, and therefore $r_1 > r_2, \frac{r_1}{r_2} = \frac{e_2}{e_1}.$

C) Two identical ions have different speeds, i.e. m1 = m2; e1 = e2; v1 <v2.
This case is interesting in that the Lorentz force depends on the magnitude of the velocity (this must be borne in mind when explaining), and therefore

$$\frac{r_1}{r_2} = \frac{v_1}{v_2}.$$

General conclusions. The deflection of a charged particle in a magnetic field depends on its mass, charge, and speed. The deviation from the rectilinear path will be the greater, the greater the charge of the particles and the less its mass and velocity. By the deflection of a particle, one can judge the values of its mass, charge and speed.

The period of a complete revolution of a particle is calculated by the formula:

$$T = \frac{2\pi r}{v}.$$

and, therefore, is equal to:

$$T = \frac{2\pi\, m\, v}{v\, B\, e} = \frac{2\pi\, m}{B\, e}.$$

As you can see, the period of a particle's revolution does not depend on its velocity. This is due to the fact that with an increase in speed, the radius also increases, and hence the circumference, i.e. the path traveled by a particle increases in proportion to its speed.

If the particle moves with a speed comparable to the speed of light, then the increase in speed will increase the period, as the mass of the particle increases. It is imperative to dwell on the case of the relativistic motion of a particle, since this creates the preconditions for further study of the acceleration principle of high-energy particles.

The studied material acquires concreteness if it is accompanied by a demonstration of pictures of particle trajectories in a magnetic field. You can demonstrate the shape of the trajectory (incl. 1, Fig. A), the dependence of the radius of curvature on the kind of particle (incl. 1, Fig. B.), the change in the radius of curvature with the ability to speed due to deceleration (Fig. 3).

Figure: 3. Trajectory of motion of an electron in a bubble chamber filled with a liquid waterfall.

Students will be able to independently draw some of the simplest conclusions from the analysis of particle trajectories: compare their velocities, masses, and determine the direction of motion.

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