Physics PreLab 212-5

Colliding Particles!

Name ________________________________

Section _____________ **Date** ________

And now for something completely different

In the microscopic world of the high-energy physicist, discoveries of new elementary particles like the electron or the positron are very rare. In the most recent decades, tiny "point-like" particles inside the proton termed *quarks* have been found. As the discovery process unfolded, it was learned that three families of pairs of quarks exist in nature. The names of these particles are whimsical: "up, down; strange, charm; bottom and top." All but the last one, the "top," had been found until a team of Illinois physicists together with hundreds of others from around the world at last sighted this elusive object using a massive particle detector and a huge proton (and antiproton) accelerator, located at Fermilab in the suburbs of Chicago.

One way that physicists identify properties of elementary charged particles is by observing their radii of curvature in a uniform magnetic field. How do you obtain that field? For large-volume devices, you very often build a giant solenoid magnet. The magnetic field inside such a magnet is fairly uniform and is given in magnitude by the formula

$$B = \mu_o n I \qquad \text{(Eq. 1)}$$

where n is the number of wire turns per unit length, I is the current, and the permeability of free space $\mu_o = 4\pi \cdot 10^{-3}$ G·m/A or $\mu_o = 4\pi \cdot 10^{-7}$ T·m/A.

We know that the force on a moving charged particle in a magnetic field is given by

$$\boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B} \qquad \text{(Eq. 2)}$$

where q is the charge, $\boldsymbol{v}$ is the velocity of the object and $\boldsymbol{B}$ is the magnetic field. The direction of this force is given by the right-hand rule, and it is perpendicular to both the direction of the magnetic field and the direction of motion. The magnitude of the force is given by

$$F = qv_{\perp}B \qquad \text{(Eq. 3)}$$

where $v_{\perp}$ is the component of the velocity of the particle *perpendicular* to the magnetic field B.

A generic particle detector might look like Figure 1. Collisions of fast moving protons (positively charged) and antiprotons (negatively charged) occur inside a solenoid magnet. Sometimes these collisions result in the formation of something new which, after a very brief existence, decays into a pair of other oppositely charged particles, such as a positive and a negative muon. (Muons are basically very massive electrons.) Instruments inside the cylinder monitor the particles, especially those traveling perpendicular to the line defined by the colliding beams of protons and antiprotons.

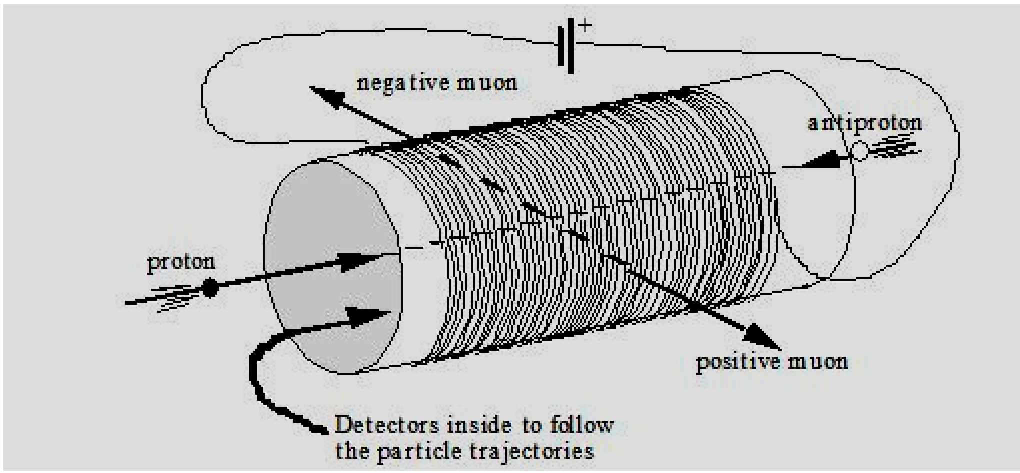

Figure 1. A particle detector

Consider the solenoid as wound in Figure 1. Answer the following questions.

Q1[10'] What is the direction of the magnetic field *inside* the solenoid? Draw a big fat arrow directly on Figure 1 indicating the direction of the magnetic field *inside* the solenoid.

Q2[2'] The proton enters the detector along its axis from the left in Figure 1. Does the magnetic field exert a force on the proton?

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Q3[2'] The antiproton enters the detector along its axis from the right in Figure 1. Does the magnetic field exert a force on the antiproton?

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Consider the oppositely charged muons (remember that a muon is a heavy version of the electron) that emerge from the sides of the detector after the collision. An end-on view is shown in Figure 2, with the proton beam coming out of the page. The outgoing muons are drawn straight as if *no* magnetic field affected them (the solenoid is not turned on).

Q4[6'] When the solenoid is turned on, which direction (into or out of the page) does the magnetic field point? Indicate this direction directly on Figure 2.

Q5[20'] Sketch the actual trajectories of the positive and negative muons in Figure 2 for the case where there is a strong magnetic field in the direction indicated in your answer above. Note that your sketch should show the trajectories both inside and outside of the solenoid.

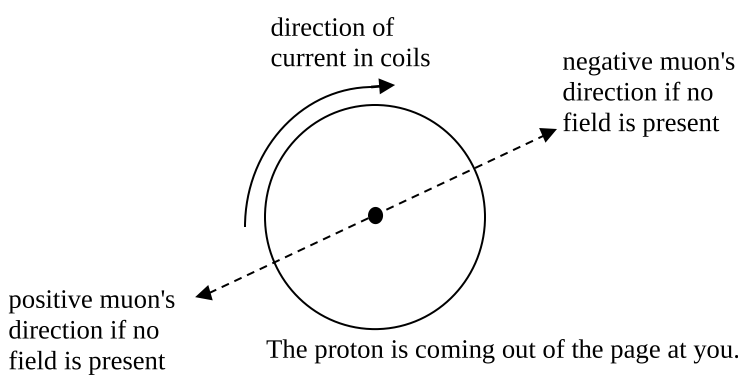

Figure 2. Beam line view of solenoid

Q6[8'] The large CDF (Collider Detector Facility) at Fermilab features a solenoid 3 m in diameter, 5 m long having 1164 turns of superconducting cable. The central field is 1.4×10^4 G. Given this data, what current is running through the coil?

I_{coil} = _________ [A]

Q7[2’] What length of superconducting cable is used to wind this solenoid?

L_{coil} = ________ [m]