Massachusetts Institute of Technology

Department of Physics

Course: 8.701 – Introduction to Nuclear and Particle Physics
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Discussion Problems

from recitation on **December 1st, 2020**

Problem 1: Bubble Chamber

Carl David Anderson discovered positrons in cosmic rays. The picture below shows a cloud chamber image produced by Anderson in 1931. The cloud chamber is positioned in a magnetic field of 1.5 T with field lines pointing into the plane of the paper. A cosmic ray particle enters the chamber from below and leaves a circular track. There is a 6 mm thick lead plate in the cloud chamber visible as a horizontal line. The radius of curvature is 15.5 cm before and 5.3 cm after the passage through the lead plate.

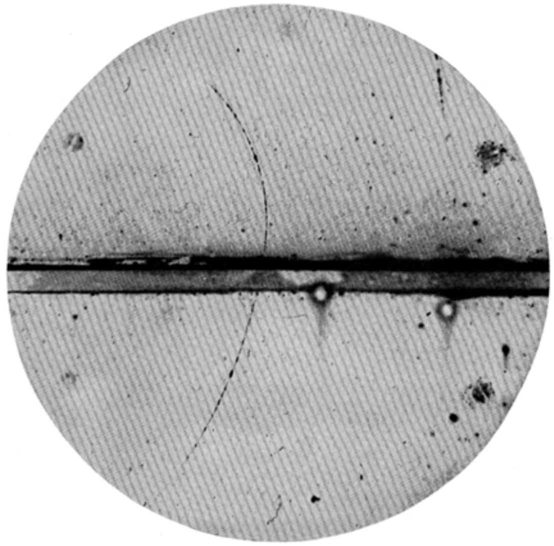

Figure 1: Cloud-chamber image of a positron.

a)

Estimate the momentum of the particle before and after the passage through the lead plate. What is the charge of the particle?

b)

Compare the energy loss during the passage through the lead plate for a proton, a pions, and an electron. For the energy loss calculation, you can use the approximate Bethe formula below and assume constant energy loss.

$$\left\langle \frac{\mathrm{d}E}{\mathrm{d}X} \right\rangle_{\mathrm{Ion}} = -4\,\pi\,N_\mathrm{A}\,r_\mathrm{e}^2 m_\mathrm{e}\,c^2\,z^2 \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot \ln\left(\frac{m_\mathrm{e}\,\gamma^2\,\beta^2\,c^2}{I}\right) \tag{1}$$

Explain why this is sufficient to exclude the proton and pion hypothesis. The constants in the equation are $N_\mathrm{A} = 6,022 \times 10^{23}\,\mathrm{mol}^{-1}$, $\epsilon_0 = 8,85 \times 10^{-12}\,\frac{\mathrm{A\,s}}{\mathrm{V\,m}}$, $m_\mathrm{e} = 511\,\mathrm{keV}$, $r_\mathrm{e} = \frac{\mathrm{e}^2}{(4\,\pi\epsilon_0)m_\mathrm{e}\,c^2}$, $Z = 82$, $A = 207$, and $I = 820\,\mathrm{eV}$, the ionisation energy in lead.

c)

To further aide the hypothesis, calculate the energy loss of the particle through bremsstrahlung.

$$\left\langle \frac{\mathrm{d}E}{\mathrm{d}X} \right\rangle_{\mathrm{brem}} = -4\,\alpha\,r_\mathrm{e}^2 N_\mathrm{A}\,\frac{Z^2}{A} \cdot \ln\left(\frac{187}{Z^{\frac{1}{3}}}\right) \cdot E = -\frac{E}{X_0}\,,$$

Use $X_0 = 0.56\,\mathrm{cm}$ for the radiation length in lead.

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