Solutions to Problem Sheet 3

3C24

February 23, 2001

1. (i) Which quantum number must particles have in order to be detected in a tracking detector? [1]

   Charge

   (ii) What characteristic of the particle is measured in a tracking detector? [1]

   The particle's position

   (iii) What is measured in a calorimeter? [2]

   the energy deposited by the particle

   (iv) Which particles can be detected in a hadron calorimeter? [2]

   Both charged and neutral hadrons. Also most charged particles.

   (v) Which particles are typically measured in an EM calorimeter? [2]

   Electrons and π^0s, but all charged particles can be detected *in an EM calorimeter.*

   (vi) Can you measure the particles in (v) in a hadron calorimeter? [1]

   You can measure electrons and π^0s in a hadron calorimeter although the absorber thickness is usually too thick for a very meaningful energy measurement.

   (vii) Can you detect the particles in (iv) in an EM calorimeter? [1]

   Yes, you can but it would be rather inefficient becasue the absorber thickness in an EM calorimeter is probably not thick enough to allow the primary hadron interaction to occur very often.

2. Write down the Bethe-Bloch formula

$$\frac{dE}{dx} = \frac{4\pi N_0 z^2 e^4}{mv^2}\frac{Z}{A}\left[ln\left(\frac{2mv^2}{I(1-\beta^2)}\right) - \beta^2\right] \tag{1}$$

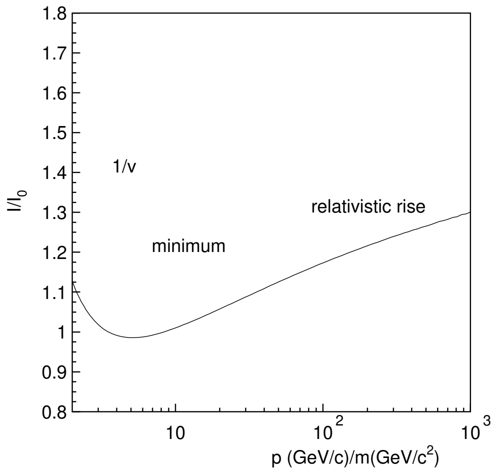
   (i) Identify the terms and describe to what this equation applies[4]

   m is the electron mass, z and v are the charge (in units of e) and velocity of the particle, $\beta = v/c, N_0$ is Avogadro's number, Z and A are the atomic number and mass number of the atoms of the medium and x is the path length in the medium measured in gcm^{-2} or kgm^{-2}. I is an effecitive ionization potential, averaged over all electrons, with approximate magnitude $I = 10ZeV$. This equation applies to energy loss of charged particles traversing matter.

   (ii) What does this equation say about the energy loss as a function of the mass of the incident particle? [1]

   This equation shows that $\frac{dE}{dx}$ is independent of the mass M of the particle.

   (iii) Sketch the shape of this function and identify the interesting regions [4]



Binding energy per nucleon as a function of the mass number A.

The energy loss varies as $1/v^2$ *at non-relativistic velocities and after passing through a minimum for* $E \approx 3Mc^2$, *increases logarithmically with* $\gamma = E/Mc^2 = \frac{1}{\sqrt{1-\beta^2}}$.

3. (i) Which fundamental force is important for the detection of high energy particles? [1]

   The Electromagnetic force

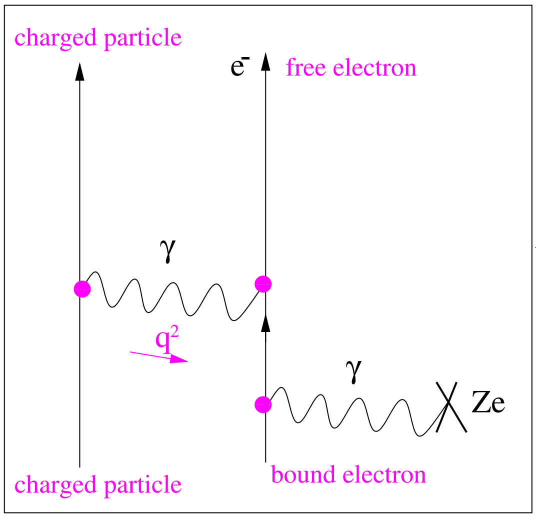
   (ii) What are the two types of particle which are actually detected? [2]

   Charged particles and photons

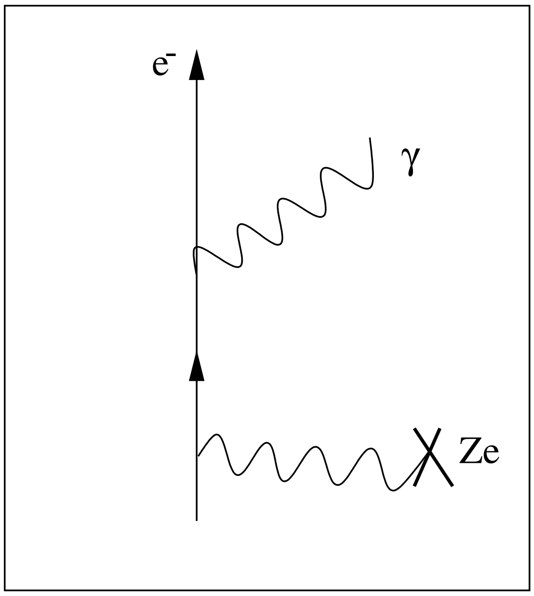
   (iii) Describe Ionization loss, Coulomb Scattering and Bremstrahlung radiation and state to what these apply and their relative importance. [5]

   Coulomb scattering is the scattering of the incident charged particle by the positively charged nuclei in the medium. Each scatter is very small and the particle does not lose much energy this way, but it does change the direction of the charged particle. Charged particles are affected by Coulomb Scattering. Bremstrahlung Radiation is important when the energy of the particle E>>m

   (iv) Draw the Feynman Diagrams for the three processes in (iii) above. [6]



Feynman Diagram for Ionization energy loss for a charged particle.



Feynman Diagram for Bremsstrahlung Radiation.

(iv) Which particles are affected by Coulomb Scattering? [1]

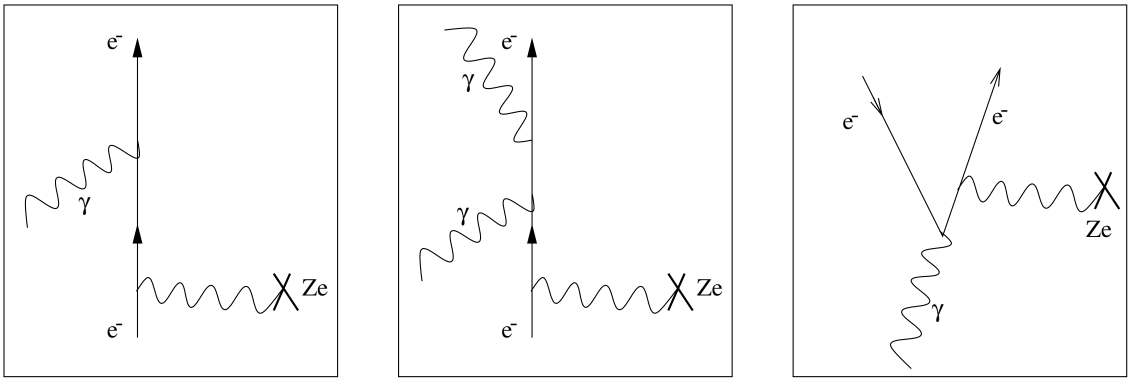
all charged particles

4.

(i) Explain what is meant by the **radiation length**[1]

Its the thickness of the medium which reduces the energy of a beam of electrons by a factor e

(ii) Draw the Feynman digrams for the three processes by which photons lose energy [4]



The three processes by which a photon loses energy traversing a medium. From left to right, photoelectric absorption, Compton Scattering and pair-production

(iii) Explain why scintillator is a good detector for electrons and photons

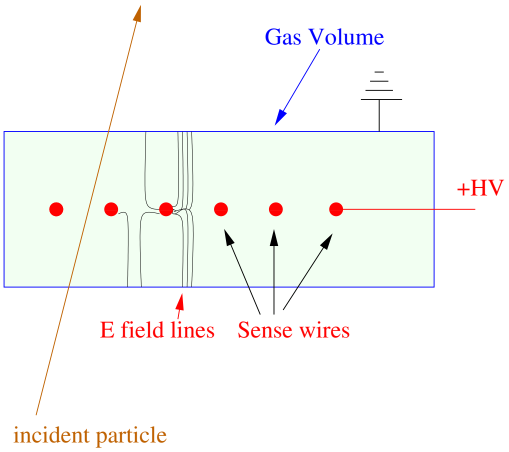
The ionization level for scintillator is very high and the molecules can absorb a lot of energy (from charged particles or photons) without ionizing electrons from the outer atomic shells. Instead, the energy is transformed into lower energy photons which can be detected by photon sensitive detectors. A charged particle traversing a block of scintillator excites the electrons in the scintillator molecules by way of its electromagnetic field. The excited electrons drop down into lower energy levels emitting visible light of a sharacteristic frequency. Photons entering the scintillator will be absorbed by the outer shell electrons and reabsorbed with a characteristic frequency of the scintillator.

5. i) Draw a diagram of the simplest multi-wire proportional chamber. Label: [3]

a) Anode Wire

b) Cathode

c) Electric Field lines



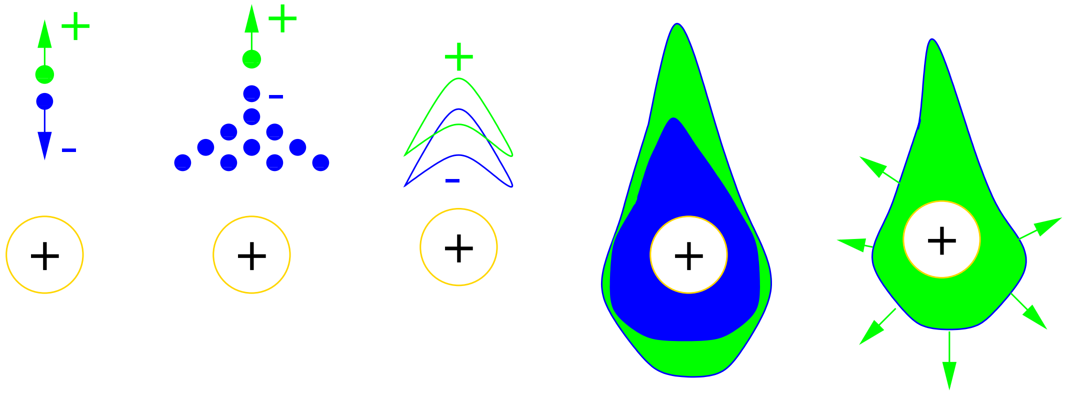
Schematic of a multiwire proportional chamber

ii) Explain what happens to the gas when a charged particle traverses the gas [4]

As a charged particle travels through the gas, it undergoes electromagnetic interactions with the electrons (according to the Bethe-Bloch formula) in the atoms of the gas which result in outer shell electrons being emitted.

iii) Explain what happens close to the anode wire [3]

When the electrons get very close to the wire they undergo acceleration under a very high electric field. The field is high enough here to induce avalanching, whereby the electrons are given enough energy to liberate new electrons from the gas in this region. As the gas is ionized, the positive ions which are produced start to move very slowly away from the wire and this induces an electrical signal on the wire as shown in the Figure.



Time development of an avalanche around the sense wire of a wire chamber

iv) Explain how the signal is extracted from the chamber. [4]

The electrical signal from the electrons and positive ions is extracted from the HV wire by means of a decoupling capacitor. A capacitor will isolate the electronics from the high voltage while letting through a rapidly changing signal. The decoupling capacitor also serves to "choose" the length of time over which the signal is integrated. The positive ions are of particular importance here because the electrons are all collected in the first nanosecond. The electrons typically constitute one hundredth of the total signal.

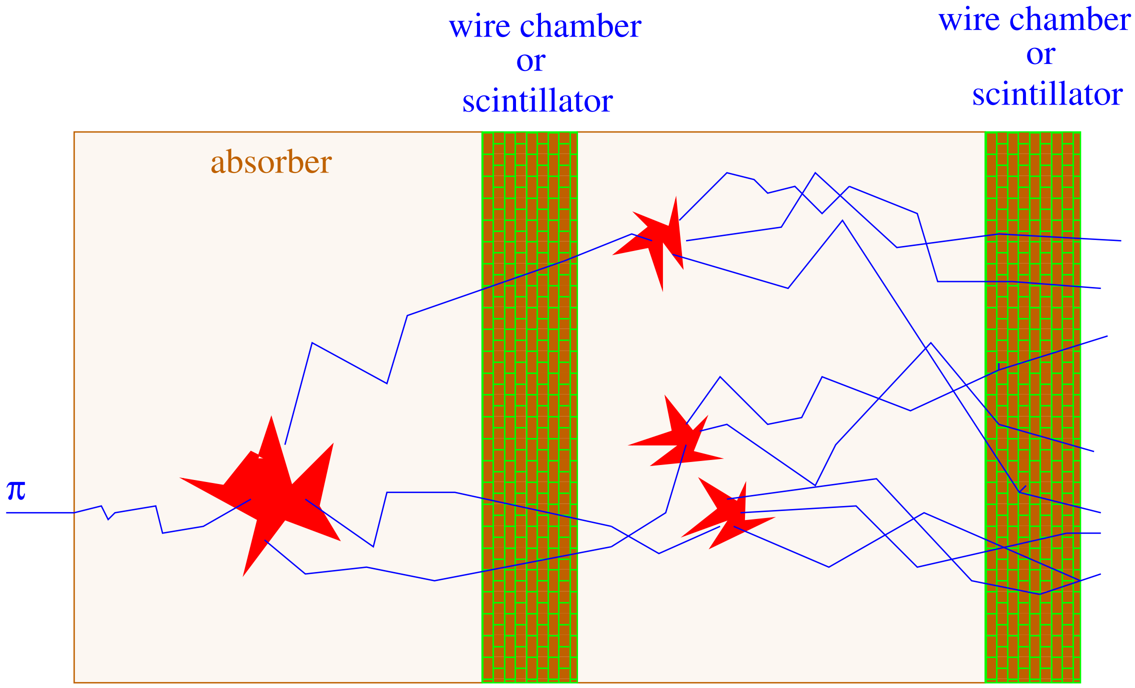
v) What happens if a neutron traverses the gas volume?[1]

It will not ionize the gas

6.

i) Describe briefly the construction and mode of operation of a calorimeter with the help of a diagram. [6]

Calorimeters are usually constructed out of layers of absorber, some dense material such as iron, lead or uranium, where the particle is encouraged to interact, and active detector such as a multiwire proportional chamber or scintillator. The active detector is there to detect the charged particles and photons which are the products of the primary interaction in the absorber.



Schematic of a calorimeter

(ii) The energy actually measured in a calorimeter by summing up the energy deposited in the active detector layers is proportional to the energy of the primary particle. On what does this proportionality factor depend (name three things)? [3]

Material of absorber, width of the absorber and type of active detector

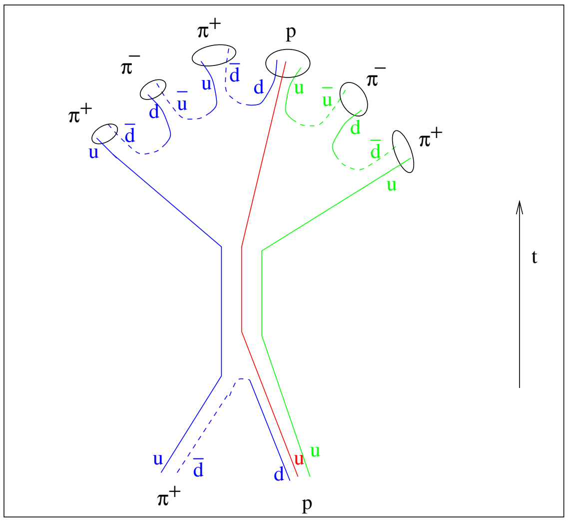
(ii) How would you measure this proportionality factor? [1]

with a beam of known energy hadrons such as pions or protons

(iii) What is the most likely interaction that a hadron will undergo in a piece of absrber such as lead or iron? (The typical distance a hadron travels before an interaction in a given material is called the *absorption length*). [2]

A hadron will be most likely to undergo a strong interaction in lead or iron

(iv) Draw the Feynman diagram for this interaction. [4]



The Feynman diagram for a strong interaction of a pion with the absorber nucleon.