

THE INTERACTION OF ELECTRONS WITH MATTER

The purpose of this experiment is to measure the attenuation of electrons in aluminum. The technique is to record the number of electrons passing through the aluminum as a function of its thickness. These results should be contrasted with those obtained for the interaction of gamma rays with matter. The "range" of the electrons will be measured for two different incident energies.

DISCUSSIONI. THE RANGE OF ELECTRONS IN MATTER

A charged particle moving through matter loses energy by electromagnetic interactions which raise individual electrons in the matter to excited energy states. In some cases an electron may receive enough energy to separate it from the parent atom and the atom becomes ionized. In any event the energy given to the electron is taken from the kinetic energy of the incident particle. As the charged particle proceeds through the material it makes many such collisions and steadily loses energy. The magnitude of the force between the charged particle having charge  $q$  and the electron in the atom having charge  $e$  is proportional to  $qe/r^2$ . The distance between the charges,  $r$ , changes as the charged particle flies by. The energy transferred to the electron is the net work done on the electron by that changing force. A calculation of that work (not done here) shows that the amount of energy transferred per unit distance is proportional to  $q^2e^2$  and inversely proportional to  $MV^2$  where  $M$  is the mass of charge  $q$  and  $V$  is its velocity. The effect of this is that an alpha particle ( $q = 2$ ) will lose four times the energy in a given material than will a proton of the same kinetic energy. It does not matter whether  $q$  is positive or negative, the energy transferred to the electrons is about the same for both. At very low energies the transfer of energy per collision is greater than it is at higher energies because it spends more time near the electron. Obviously, the denser the material the more energy will be lost per unit thickness, because there are more electrons with which to collide.

In the case of larger charged particles, such as protons and alpha particles (Helium nuclei), this mechanism is predominant. Particles of the same energy pass through the material in an essentially straight line, losing energy in small increments, until all the particles are stopped at approximately the same thickness. For this reason, alphas are useful in radiation treatment, since all the particles travel about the same distance and give up the majority of their energy right before they are stopped.

The process by which electrons are stopped as they travel through matter is relatively more complicated than that undergone either by alpha radiation or gamma radiation. The coulombic interactions that the electrons undergo as they pass through the matter means that they are continually losing energy over the path that they travel, as is the case for alpha particles. However, the electrons have such little mass that they are easily scattered through large angles by collisions with other electrons and the atomic nuclei in the matter. The ease with which the electrons are scattered and change direction means that the path they take is not likely to be straight. Therefore, like the gamma radiation in Experiment #7, electrons of a single initial energy will be removed from the beam as a function of the thickness of the material, since the chances of a catastrophic scattering event increase with thickness. The thickness of a given material at which all of the electrons will either have been removed from the beam or exhausted their initial energy is called the "range". The range corresponds to the maximum straightline distance that an average electron can travel in the material, and therefore can be estimated by considering only the coulomb interactions. (See question 2 in the the Prelab Questions.)

## II. SOURCE OF ELECTRONS

It is possible to get electrons with energies of about one MeV from the beta decay of radioactive nuclei. The electrons from beta decay are not monoenergetic, but have a spectrum of momenta ranging from zero up to some maximum value  $p_{\max}$ . Experiment #6 dealt with this momentum spectrum for the betas emitted from a  $Tl^{204}$  source. We will use a magnet to bend the betas and some heavy absorbers to collimate them, thereby selecting a small range of momenta with which to make our measurements.

The source we will use is  $Tl^{204}$  which has electrons with a maximum kinetic energy equal to 0.764 MeV. Within the magnet the electrons bend in a circle of radius  $R$  given by

$$R = \frac{P}{qB} \quad (1)$$

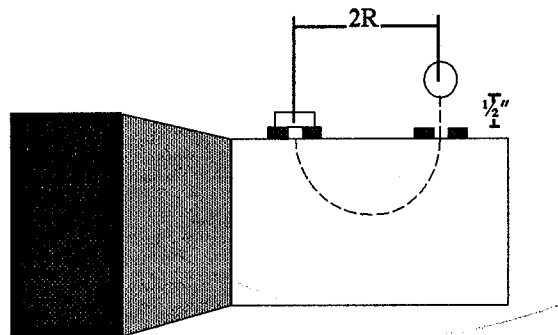
where  $P$  is the momentum, and  $B$  is the magnetic field which is assumed to be uniform. It turns out that Eqn. (1) also holds for relativistic particles.

THE EXPERIMENT

Run a curve of the number of counts per unit time as a function of the detector voltage using the  $Tl^{204}$  source placed about 5~10cm from the Geiger Tube (at the location where you obtain ~200 counts in 20 secs at ~900 Volts). Set the voltage to be in the middle of the plateau region. Measure the B field in between the pole pieces of the beta-ray spectrometer. It is essential that the magnetic field strength be no larger than .14 Tesla, and no less than .095T. The experiment is sensitive to the background levels. We will discuss how to properly account for them below.

I. MEASUREMENT OF THE ATTENUATION OF ELECTRONS IN Al

Fig. 1. is a sketch of the experimental set-up. Note that the source is placed face down and that the electrons bend in a semi-circle and exit through the slot in the aluminum collimating plate and may enter the Geiger Tube above.



**Figure 1.** Experimental set-up.

The aluminum foil which will serve as our target material will be placed over the hole in the collimator bracket below the geiger tube. The beta-ray spectrometer allows one to select the momentum, and therefore the energy, of the betas which will be directed into the aluminum target. You will measure the number of counts at the same measurement position for various thicknesses of aluminum foil in order to determine the range of the betas at that energy.

In Experiment #6, we determined that the betas with the highest energy of .764 MeV will perform a semi-circle in the spectrometer with the largest radius, which we called  $R_{\max}$ . At that radius, however, the number of counts obtained was just slightly above the background count. Since the relative accuracy of our measurements varies with the inverse square root of the number of counts, we should take the measurements at values of  $R$  which select betas with energy near the peak of the spectrum (See Exp. 6, Fig. ). By using  $R = \frac{1}{2}R_{\max}$  and  $R = \frac{3}{4}R_{\max}$ , you will be selecting betas with energies just below and just above the energy of the peak. Your initial number of counts should be approximately equal at these two positions, but the difference in energy of the betas is large enough to see significantly different behavior in terms of their "range".

To locate these two positions, you must first determine the value of  $R_{\max}$  for your experimental set-up. Measure the magnetic field in between the pole pieces of your magnet using the gaussmeter. Calculate the value of  $R$  for a magnetic field of this strength, assuming that the betas have an energy equal to the maximum energy of .764 MeV. This is your expected value of  $R_{\max}$ . Place your  $\text{Ti}^{204}$  source at a distance greater than twice this value and move it in slowly until you begin to obtain counts above your background rate. Use the measured distance as your value for  $D_{\max} = 2R_{\max}$ . If you never obtain counts significantly above the background, what could be wrong?

Since your geiger tube must be elevated above the collimator bracket, there is a chance that stray electrons may enter the tube without having passed through the magnetic field. To account for this possibility, you should measure the background rate at each of the measurement positions, separately. After you have set-up the experiment at the  $R = \frac{3}{4}R_{\max}$  and  $\frac{1}{2}R_{\max}$  positions, respectively, and before you begin to take measurements, place a thick slab of aluminum over the hole in the collimator bracket and record the number of counts over a 2 minute period. This background rate should account for any additional counts due to the closeness of the source to the tube. All counts obtained for the number of betas passing through the Al foil should be corrected for the background rate at that measurement position.

The absorber to be used is household Al foil about 0.02 mm thick. By folding the foil you can make up absorbers of various thicknesses. The thickness you will use depends a lot on the experimental set-up, but you might start working with sheets folded 4 times. At each of the measurement locations you have chosen, measure the rate in 60 seconds as a function of absorber thickness from zero up to the thickness at which the electrons are completely stopped. Record the measurements in tabular form. Make sure that you take into account the error of the background in determining the error in the corrected number of counts. Be sure that your beginning reading is the direct reading with no absorber.

For the two sets of data plot the counting rate versus A1 thickness, remembering to include error bars. Estimate the apparent stopping thickness (range) and the uncertainty in that quantity from your graph. The accepted method for obtaining the range is to ignore the long tail on your graph and extrapolate the curve from the initial and middle sections of the graph until it intersects the zero line for corrected counts. Calculate the momentum and the kinetic energy (in MeV) for each of the values of R used, using your measured value of the B-field strength, and indicate the energy on each curve.

- Q.1 If the electrons all followed the same straight vertical path through the absorber, what curve of counts vs. thickness would be expected? (Illustrate.)
- Q.2 Why do not all the electrons stop at exactly the same thickness as alphas do? What contributes to the spread?
- Q.3 Compare your results for the two different momenta used. Does the difference in range seem reasonable? Explain.

### PRELAB QUESTIONS

- Q.1 Calculate the quantity  $pc$  for an electron with kinetic energy of 0.764 MeV.
- Q.2 Assuming that the incoming electrons have low enough momentum so that  $\frac{1}{2}MV^2$  is a reasonable estimate of the initial kinetic energy, determine the stopping distance for electrons as a function of the initial energy. (Hint: proceed as in the discussion for Experiment #7 on gamma rays. Instead of considering the incremental loss in the number of particles per thickness  $dx$ , set up an equation for the incremental loss of energy,  $dE$ , per  $dx$ . The integral is not difficult.)