In the Bubble Track Experiment, I found that the relationship between the kinetic energy and the momentum of an electron traveling through liquid hydrogen in a magnetic field is much better described by Einstein’s theory of special relativity rather than the classical relationship between kinetic energy and momentum.

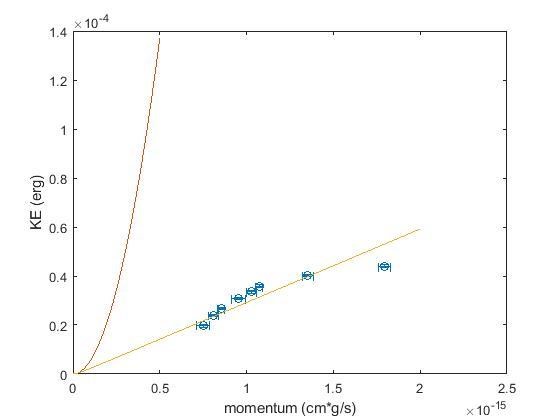


Figure 1: Theory curves for both classical (red) and relativistic (yellow) predictions of the electron’s Kinetic energy based on its momentum plotted with measured data points and their uncertainties (blue).

In Figure 1, the red line is what the classical equations:

*p=mu* , *E =1/2mu2* , *E=(p2)/2m* predict for the kinetic energy of the electron based on its momentum.

Similarly, the yellow line is what the relativistic equation: *E= ((mc2)2+(pc)2) -mc2* predicts for the kinetic energy of the electron based on its momentum.

As shown in Figure 1, the relativistic theory curve is a much better model for the data I have taken.

But, the model does not fit the data I have taken exactly. To calculate the standard errors of the data I calculated the standard deviation for each of the 8 points I took data from for both the radius and distance measurements. This involved taking the three measured values for each point, summing them, and then dividing the sum by the square root of the number of measurements, namely three. I then added to that quotient 0.1 for the radius measurements and 1.0 for the distance measurements. I added the extra uncertainty due to the measuring devices I used (a roller and a ruler, with smallest measurement divisions of 1 cm and 0.1 cm, respectively).

The following is a table showing the calculated uncertainties for both radius and distance for all points:

Point Radius Unc\_Radius Distance Unc\_Distance

8 5.1 0.245 67 2

7 5.5 0.2 82 1.882

6 5.8 0.133 92 1.577

5 6.5 0.276 106 1.333

4 7 0.2 116 2

3 7.3 0.133 124 2.202

2 9.2 0.215 140 1.333 1 12.2 0.245 153 1.882

Figure 2: A Table showing the average measured radius, uncertainty in the average measured radius, the average measured distance, and the uncertainty in the average measured distance for each point.

These results show that the classical equation linking kinetic energy and momentum only holds for low momentum, low energy objects. It does a poor job of modeling how much kinetic energy the electron had based on its momentum. Additionally, these results show that the relativistic equation linking kinetic energy and momentum is very accurate for high energy, high momentum objects.

Most all of the measured points fall on the relativistic theory curve within their accepted error, except for one clear outlier. That outlier is point 8, the first point chronologically in the electron’s path. This point is the one with the most momentum and energy, which means it had the largest radius and the furthest distance traveled, which makes it easier to introduce measurement and human errors. I believe that the reason for the outlier is human error, specifically a mis-measurement.

%% BubbleTrackDataAnalysis.m

%

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% Revised by: Daniel Opdahl

% Last modified: 9/24/19

%

% Purpose: Import, analyze, and plot electron bubble track data %

% Instructions: Follow the lab handout for details, but every line

% which has an instruction in CAPITAL LETTERS should be replaced by a % variable or equation. Remember to finish every line of code with a % semicolon ; .

%%

%% Import data into MATLAB

TITLE= 'Select the Excel file that contains the data you want to bring into MATLAB';

[filename,filepath] = uigetfile('\*.\*', TITLE); %Prompts the user to select a data file

full\_filename = fullfile( filepath, filename );

%Reading in the data from the file data\_matrix = xlsread(full\_filename)

% Extract the first column of data as a vector radius = data\_matrix(:,2)

% Extract the second column of data as a vector radius\_unc = data\_matrix(:,3)

% Extract the first column of data as a vector distance = data\_matrix(:,4)

% Extract the second column of data as a vector distance\_unc = data\_matrix(:,5)

%% Rename variables

%The variables below should be the imported direct measurements, not yet converted to the scale of % the paper.

r\_meas = radius; %units: cm, data type: column vector r\_meas\_unc = radius\_unc; %units: cm, data type: column vector s\_meas = distance; %units: cm, data type: column vector s\_meas\_unc = distance\_unc; %units: cm, data type: column vector

%% Convert distances measured by a ruler/roller to units of the picture

conversion\_factor = 0.707;

r\_actual = conversion\_factor \* r\_meas; r\_actual\_unc = conversion\_factor \* r\_meas\_unc; s\_actual = conversion\_factor \* s\_meas; s\_actual\_unc = conversion\_factor \* s\_meas\_unc;

%% Use r and unc\_r to calculate p (momentum) and unc\_p (unc in momentum) p = 2.08e-16\*r\_actual; %units: g\*cm/s, data type: column vector

p\_unc = 2.08e-16\*r\_actual\_unc; %units: g\*cm/s, data type: column vector

%% Convert s and unc\_s to KE (kinetic energy) and unc\_KE (unc in KE) slope = (0.04e-5); %units: erg/cm, data type: scalar intercept = 7e-7; %units: erg, data type: scalar

KE = slope\*s\_actual + intercept; %units: erg, data type: vector KE\_unc = slope\*s\_actual\_unc; %units: erg, data type: vector

%% Classical and relativistic KE %mass of the electron in cgs units m = 9.11e-31\*1000; %units: g %speed of light in cgs units c = 3e8\*100; %units: cm/s

%% Plot data with two theory curves: classical and relativitic theory

%Plot data with x and y error bars errorbar(p,KE,KE\_unc,KE\_unc,p\_unc,p\_unc,'o') hold on

%Plot theory curves with data

%Classical theory p\_class = 0:0.1e-16:5e-16;

KE\_class = p\_class.^2/(2\*m); %units: erg, data type: vector plot(p\_class, KE\_class)

%Relativistic theory p\_rel = 0:0.1e-16:20e-16;

KE\_rel = sqrt((m\*c^2)^2+(p\_rel\*c).^2)-(m\*c^2); %units: erg, data type:

vector plot(p\_rel, KE\_rel)

%ADD LABEL AXES xlabel('momentum (cm\*g/s)') ylabel('KE (erg)')

hold off