In the Bubble Track Experiment, I calculated the kinetic energy and the momentum of an electron traveling through liquid hydrogen in the presence of a magnetic field, and compared those values to relativistic and classical models. I took measurements of the electron’s distance to the center along its spiraling path and its instantaneous radius. I used a map roller to measure the distance from the center along the spiral. To measure the instantaneous radius, I used a ruler and selected points about a centimeter away from the point. I then found the tangent lines of the curve at those three points, found the normal to those tangent lines, and used those three normal to approximate where the instantaneous center of the curve was for the point selected for measure the instantaneous radius. I then found the distance between my selected point and the instantaneous center: the instantaneous radius.

In Table 1 below, Equation 1 is a classical equation describing the relationship between momentum (), mass (), and velocity (). Equation 2 is another classical equation describing the relationship between kinetic energy (), mass, and velocity. Equation 3 can be derived from Equations 1 and 2 by substituting in for in Equation 2. Equation 3 is how classical equations directly link kinetic energy and momentum for a single object of mass. Equation 4 describes the relativistic relationship between kinetic energy and momentum for a single object of mass, where is the speed of light.

|  |  |
| --- | --- |
| Equation 1: |  |
| Equation 2: |  |
| Equation 3: |  |
| Equation 4: |  |

Table 1: Classical momentum and kinetic energy Equations (1-3) and relativistic momentum and kinetic energy Equation (4)

In Figure 1, the red curve is a plot of Equation 3 and depicts what classical equations predict for the kinetic energy of an electron (m = ???) (?) based on its momentum. The yellow curve is a plot of Equation 4 and depicts what the relativistic equation predicts for the kinetic energy of an electron based on its momentum. The blue data points are my calculations for the electron’s momentum and kinetic energy based on my measurements of the instantaneous radius and distance along the curve to the center of the spiral. The method of calculation can be found in the MATLAB code provided.

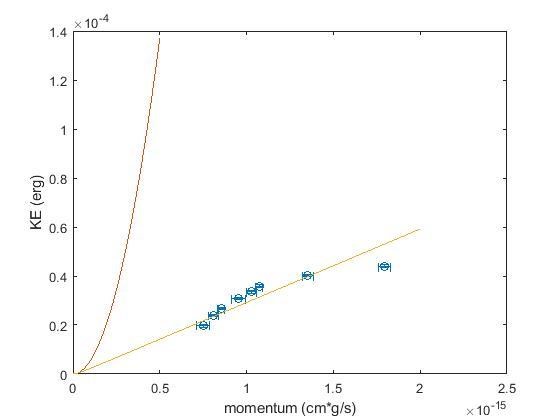


Figure 1: Theory curves for both classical (red) and relativistic (yellow) predictions of the electron’s kinetic energy based on its momentum plotted with measured data points and their uncertainties (blue).

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 eight 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 cm for the radius measurements and 1.0 cm 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 1.0 cm and 0.1 cm, respectively).

Table 2 shows the calculated uncertainties for both radius and distance for all points:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Point | Average Measured Radius (cm) | Uncertainty in Radius (cm) | Average Measured Distance (cm) | Uncertainty in Distance (cm) |
| 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 |

Table 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 accurate for high energy, high momentum objects.

Most all of the measured points fall on the relativistic theory curve within their accepted uncertainty range, 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 a mis-measurement.