International Journal of Engineering and Science Applications
ISSN 2406-9833

IJEScA

Utilization of Smartphones in Experiments of Measurement of Electron-Mass Charge Ratio

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ABSTRACT

In this work, the strength of the magnetic field produced by a Helmholtz coil was measured using a magnetic sensor on a smartphone and the Kelmscott Gauss meter app. The e/m ratio measurement is a well-known experiment in the physics curriculum. We demonstrate that the strength of the magnetic fields involved may be accurately measured by cell phones. In an electron diffraction experiment, the diameter of a circular ring can theoretically be determined using the same method. Our findings indicate that reliable measurements of the charge-to-mass ratio of electrons can be achieved using cell phone cameras and image processing software. When teaching contemporary physics, smartphones and image analysis software trackers can be extremely helpful resources.

Keywords: Helmholtz coil; smartphone; smartphone; physics

1. INTRODUCTION

Smartphones are effective teaching aids for physics because of the variety of sensors they contain [1]. They make it possible to do experiments in spectroscopy [2], electricity, magnetism, and mechanics for a fair price [3]. Students' motivation to learn physics can also be increased by incorporating smartphone experiments into the classroom [4].

Like this, the free and open-source image processing program Tracker has grown to be a crucial resource for physics [5]. In addition to monitoring the rate of solar rotation [6], it is frequently used in lectures to teach students about optical phenomena like reflection and diffraction [7], as well as to simulate air resistance on falling cupcake liners [8].

Here, we demonstrate the utility of Tracker and cell phones in contemporary physics investigations, namely the measurement of the electron's charge-to-mass ratio. We show how Tracker can improve the precision of calculating the e/m ratio.

2. RESEARCH METHOD

In this experiment, the magnetic field strengths are typically measured using a Hall probe. We demonstrate how cell phones can be used in place of these probes. In fact, there is a good deal of agreement between the performance of a magnetometer found in a phone and a calibrated, commercial Hall probe [9]. We also provide information on how to calibrate magnetic sensors on smartphones and the spectrum of magnetic field strengths that modern smartphones can measure to the rising number of smartphone magnetometer users.

Figure 1. Apparatus for determining the charge-to-mass ratio of the electron.

The setup (Figure 1) comprises of an electron cannon that produces and accelerates an electron beam inside of an evacuated Bainbridge glass tube. The magnetic field perpendicular to the electron track is produced by a pair of Helmholtz coils [10]. By adjusting the current flowing through the coils, the field's strength can be adjusted [11]. A luminous screen with a centimeter graticule is also present on the tube. Where the electron beam strikes the screen, a blue line will appear, and the particle's path can be seen.

Three measurements are required to calculate the charge-to-mass ratio of the electron: the magnetic field intensity, the radius of curvature, and the accelerating voltage [12]. The last one is immediately readable from the power source.

3. Result And Discussion

The magnetic sensor in the phone was first discovered. To do this, we placed a small permanent magnet (3.2 mm in diameter) in several locations on the back of the phone until the Kelmscott app displayed the value for the magnetic field strength that was the highest [13]. Then it was supposed that the sensor was directly behind the magnet.

For this investigation, we made use of the configuration in Figure 2. A platform was fastened on top of a coil of wire that was passing a current of various strengths through it [14]. At a specified spot on the platform, the Hall probe and the phone were used to measure the ensuing magnetic fields [15]. For the devices to measure the magnetic field of the same area of space [16], we had previously sketched on the platform where they should be placed [17]. The phone was positioned at the predetermined spot, the magnetic field was measured, the platform was removed, and the procedure was repeated using the Hall probe.

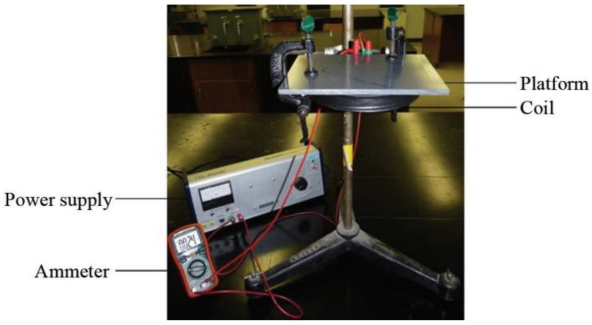

Figure 2. The configuration for comparing the magnetometer readings from the smartphone and the calibrated Hall probe.

The readings from the Hall probe and the smartphone coincide, according to our findings (Figure 3). Therefore, we have faith in the precision of the latter's magnetic field readings.

The sensor may de-calibrate while detecting magnetic fields with a phone after crossing a specific threshold [18]. In this case, the phone is shaken ferociously for a few seconds before being removed from the magnetic field [19]. Following that, it can properly measure magnetic field intensities [20]. The threshold for the one utilized here was 1000 µT. The sensor on the phone determines the strongest magnetic field that can be read [21]. Modern phones include sensors that can detect fields up to 6000 µT in strength.

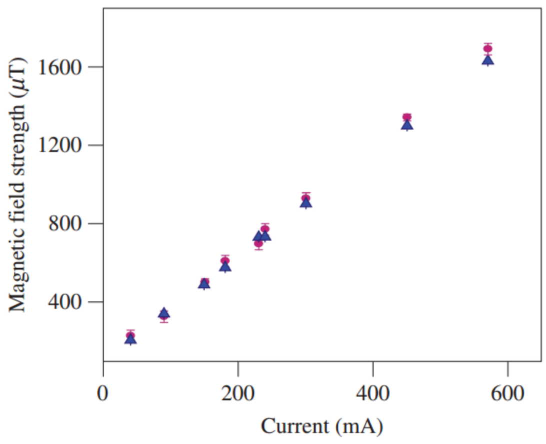

Figure 3. A comparison between the magnetometer on a smartphone and a Hall probe.

The error bars for the smartphone sensor's sensor correspond to the variations in its readings, whereas those for the Hall probe data were determined from the uncertainty stated in the owner's manual.

We can accomplish this goal with the use of mobile devices and the program Tracker. Using the camera on a smartphone, a picture of the electron journey as it appears on the fluorescent screen is shot and then loaded into Tracker [22]. The "calibration tape" in the software (click Track > New > Calibration tools) is used to calibrate the length scale as the initial step in the analysis [23]. To achieve this, we employ two points on the centimeter graticule (see the white horizontal line in Figure 4). Following the selection of the "circle-fitter" tool (by selecting Track > New > Measuring Tools), three or more sites along the electron trajectory are chosen [24]. The tracker calculates the radius by fitting a circle through these points (green curve in Figure 4).

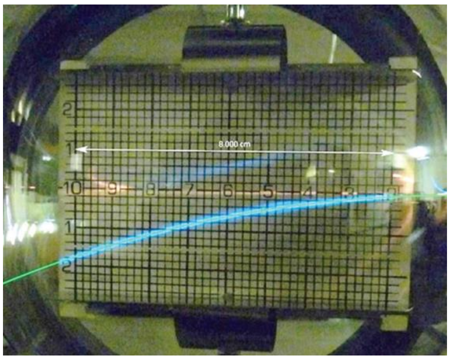

Figure 4. Using Tracker's circle-fitter tool to fit the electron trajectory (green curve)

The electron beam in this instance had a kinetic energy of 2.41 keV and was moving through a 550 μT magnetic field.

Our method using the smartphone and Tracker results in a radius of 30.0 cm for the experimental settings shown in Figure 4, which results in an electron charge-to-mass ratio of $1.77\text{x}10^{11}$ C kg^{-1}. The apparatus's owner's manual includes an equation that users can use to calculate the radius of curvature [25]. The centimeter graticule is used to read the coordinates of one or more places along the trajectory [26], which are then entered into the equation [21]. For the identical experimental settings, this approach yields an average radius of 28.3 cm, resulting in an e/m value of $1.99\text{x}10^{11}$ C kg^{1}. The ratio's recognized value is $1.76\text{x}10^{11}$ C kg^{-1}.

The assumption made to construct the equation is the cause of the difference in the radius between the two approaches. No matter the experimental settings, it has been assumed that the electrons start to curve at the same location along the x-axis [27]. This assumption is incorrect; the magnetic field intensity and the accelerating potential difference determine where the beam begins to curve [28]. Since it uses points selected along the electrons' route to perform least squares fit, the Tracker approach does not rely on any assumptions [29]. As a result, it offers R values that are more accurate.

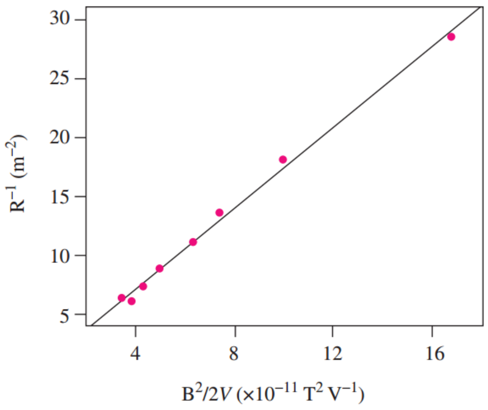

Figure 5. Illustrates how to calculate the electron's charge-to-mass ratio

We measured the radius of curvature R for accelerating voltages ranging from 0.9 kV to 4.5 kV while maintaining a constant magnetic field strength of 550 μT to estimate our quantity of interest [30]. Then, as a function of $B^2/2V$, we displayed $1/R^2$ (Figure 5).

For the charge-to-mass ratio of the electron, the slope of the best-fit line through our data yields (1.71 ± 0.05) x 10^{11} C kg^{-1}. The acceptable value of e/m is within the margin of error of our conclusion. Instrumental uncertainties are not included in the reported uncertainty, which is statistical in nature.

4. CONCLUSIONS

In summary, we may improve the analysis of particle trajectories required to calculate the charge-to-mass ratio of an electron by using the phone's camera and Tracker's circle construction tool. In an electron diffraction experiment, the diameter of a circular ring can theoretically be determined using the same method. When instructing students in current physics, smartphones and image analysis software trackers can be extremely helpful.

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