Direct Measurement of the Bohr Magneton Using the Zeeman Effect

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Abstract

We use the Zeeman effect to measure the Bohr magneton, using both the Lummer-Gehrcke Plate interferometer apparatus and the Fabry-Pérot Etalon. Both set-ups were used to produce interference patterns of light emission from a cadmium lamp subjected to a magnetic field. Pixel intensity analysis was then achieved on interference patterns to obtain distance between peaks of constructive interference. Early data analysis using the Lummer-Gehrcke apparatus revealed the Lummer-Gehrcke plate too badly damage to produce any reliable measurements. First measurements obtained from the Fabry-Pérot Etalon are much more promising, as the diffraction patterns are clearer and split accordingly to the change in magnitude of the magnetic field in which the cadmium lamp is submerged. The calibration of the electromagnet was successfully performed using a Hall probe.

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1 Apparatus

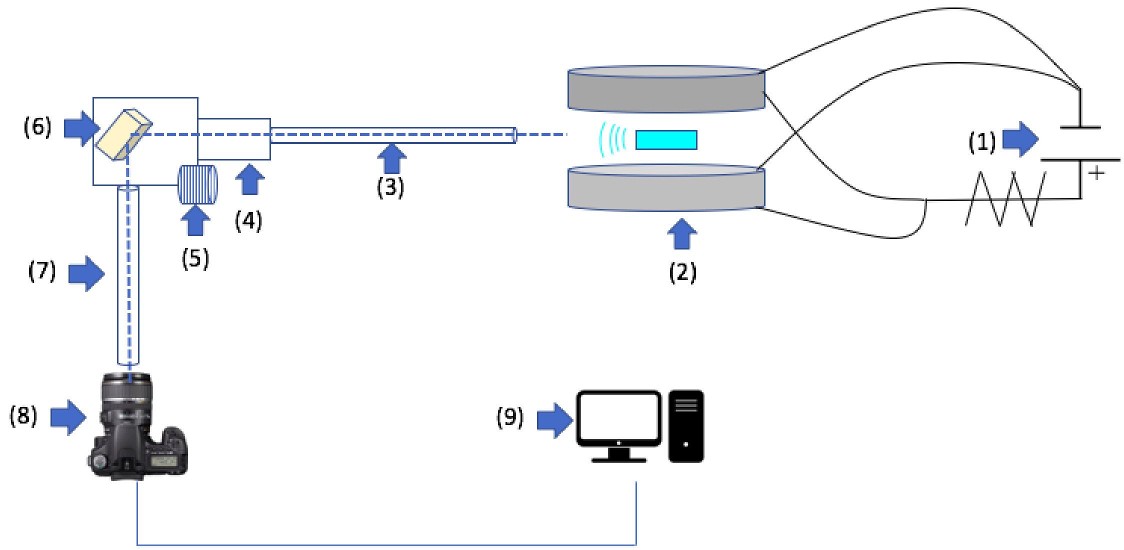
Figure 1a shows the basic set up for both experiments. Calibration of the magnetic field in the middle of the electromagnets (2) was performed using a Hall probe. To ensure proper emplacement of the Hall probe in the centre of the two coils, we moved it along the axis of the coils until we measure minimal voltage in the probe, and then proceed to move it perpendicularly until we measured maximal magnetic field.

To perform the Lummer-Gehrcke (LG) measurements, we add to our initial set up a collimator and a semi-circular lens in front of the cadmium lamp (3), as well as the Lummer-Gehrcke plate (4) before the deviation prism. The light emitted by the cadmium lamp therefore gets diffracted by the LG plate, and the diffraction pattern can be observed by the camera. By adjusting the deviation prism (6), we can then focus on the specific pattern produced by the 643.8 nm red line of the emission spectrum of cadmium. Applying a magnetic field on the cadmium lamp then results in different diffraction lines spacing, and such effect can be analyzed on the computer.

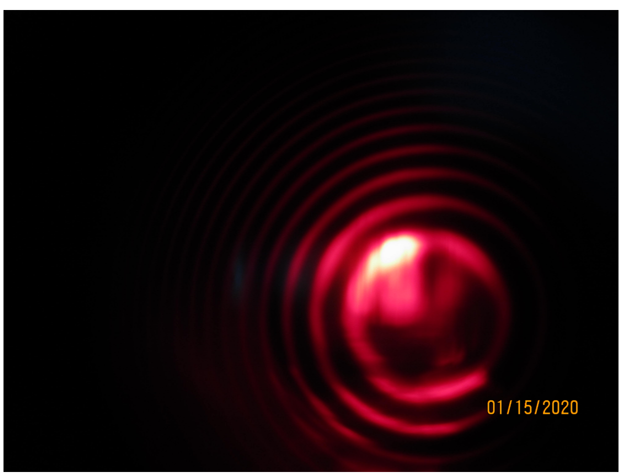
On the other hand, the Fabry-Pérot (FP) Etalon apparatus is obtained by adding the Fabry-Pérot interforometer and a red filter after the deviation prism in our initial set up. Figure 1b shows an example of the circular diffraction pattern observed with this set up. Similarly as in the LG case, the radii of the different diffraction rings will change accordingly to the magnitude of the magnetic field surrounding the cadmium lamp.

2 Data

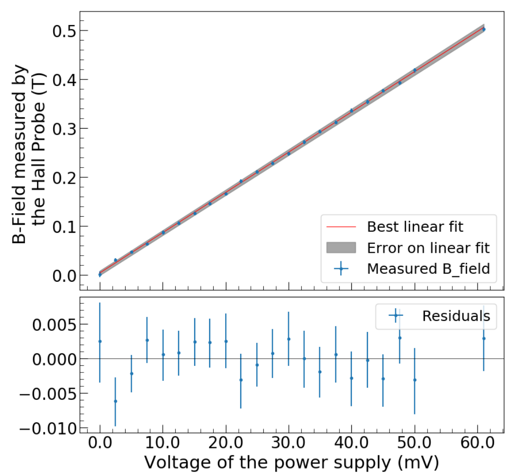
In this experiment, data is retrieved by measuring the voltage across a shunt resistor on the power source and associated pictures of diffraction patterns observed by the camera. The calibration measurements relate the power source voltage to the Hall probe voltage, which is in turn associated to the magnitude of the magnetic field via the conversion chart found in the lab manual. We then use a univariate spline interpolation to complete the data set given for those points. Error propagation for the interpolation is based on the standard variation [1]. The uncertainty of the voltage measured by the Hall probe corresponds to the



(a) Schematics of the apparatus for both interferometer set ups. The spectral tube is placed in the middle of the electromagnets (2), connected to the power supply (1). The light emitted by the spectral tube (represented by the blue dashed line) is redirected by the constant deviation prism (6) (which can be rotated with the milled ring (5)) towards the camera (8), which is placed on a stand for proper adjustment. The observed spectrum can then be transferred to the computer (9) to perform pixel intensity analysis. The set up can either be used with a collimator (3) and a Lummer-Gehrcke plate (4) or a Fabry-Pérot Etalon (7) to produce interference pattern allowing to observe the Zeeman effect.



(b) Interference pattern given by the Fabry-Pérot Etalon when observing the 643.8nm spectral line of a cadmium lamp placed in a magnetic field of 0.169±0.006 T.



(c) Calibration of the power supply to determine the magnetic field produce by the electromagnets ((2) in 1a) for a certain voltage read on the shunt resistance of the power supply.

uncertainty of the multimeter used for the measurement [2] and the ohmic residual voltage of the Hall probe [3]. We then perform a least-square fit assuming a linear relation between the voltage at the power supply and the interpolated magnetic field which can be seen in Fig1c. A chi-squared analysis of the fit gives a p-value of almost 1 for the fit which is really improbable, hinting toward the fact that we are overestimating our uncertainties. However, this shows convincing indication that the choice of a linear fit is appropriate.

For the LM data, images of the linear diffraction pattern are taken at different values of the magnetic field. Then, the distance between the principal diffraction lines and the secondary ones is measured using a line profile analysis with a computer (intensity of the pixels along a chosen line in the image).

For the FP data, at different magnetic fields, images of the diffraction pattern are taken. For each of these, the radii of the constructive interference rings are measured using the computer. These measurements are hard since the centre of the diffraction pattern is not well defined in the images. To find this centre, the distance between the few first orders of diffraction is computed and then, using a least square fit, the radius of the first ring is found.

3 Next Steps

- Repeat measurement of the FP experiment by taking the pictures when the pattern is clearly defined (not blurry) rather than at evenly spaced voltage settings in the power supply (results in some images being blurry when the diffraction lines are really close to one another).

- Find the best way to extract the data taken from the picture taken in the FP experiment (fit circles to the images?, fit the radius of the first ring with a least square fit? Use machine learning?, ...). Put these radius fits in a table (and convert pixels to length).

- Try to retake LG measurements as to see if it is possible to get clear better results (or as to confirm that the apparatus in too badly damaged).

- Results for FP experiment : Display the result for the Bohr magneton obtained for each measurement (value of magnetic field) in the same graph with errors (along with LG results if applicable).

References

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