"Fine Structure of the Hydrogen Atom by a Microwave Method" Presented by: Yuichi Okugawa

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This is part of a weekly journal club series held by the Society of Physics Students under the University at Buffalo chapter.

For the original paper discussed at this meeting, click: here

1 Introduction

The discussion for this weeks meeting was centered on the original paper written by Willis E. Lamb Jr. and Robert C. Retherford, in which they outline means to detect the energy difference between $^2\mathrm{S}_{1/2}$ and $^2\mathrm{P}_{1/2}$ for the n = 2 level. This is necessary, because the Dirac theory that lead to the fine structure and spin-orbit coupling, produces the claim that $^2\mathrm{S}_{1/2}$ and $^2\mathrm{P}_{1/2}$ should result in having the same energy when measured. This is inconsistent with our expectations since they have different values for orbital angular momentum.

Our meeting began with a quick review of how fine structure predictions were achieved, how this led to the "splitting" of energy levels, and the notation used to describe these states.

2 Discussion

Dirac theory claims that there is no difference in the energy of $^2\mathrm{S}_{1/2}$ compared to $^2\mathrm{P}_{1/2}$ - this is against our expectations, for they differ in comparison by their values for orbital angular momentum, the former has a value of $l = 0$, while the later has a value of $l = 1$.

In order to test this conflict between theory and our expectations, we need to go about measuring the difference in energy associated with the respective states. Lamb and Retherford proposed using the "microwave technique" which splits H_2 gas molecules into single hydrogen atoms. These single hydrogen atoms have their electrons in excited energy states. Given the large amount of atoms that are in these excited states, there are bound to be a measurable quantity that have their respective electron in the $^2\mathrm{S}_{1/2}$ state, another amount that have theirs in the $^2P_{1/2}$ state, and others that have theirs in other various states that are not of direct concern for the purposes of the experiment. As the electrons undergo de-excitation, i.e., fall back down to lower energy levels, they will emit a photon. The frequency of light that results from these emitted photons can be recorded, and if there is a difference in frequency between those that dropped from the $^2S_{1/2}$ state compared to those that dropped from the $^2P_{1/2}$ state, then one can conclude that these states are in fact associated with different energy levels, confirming our expectations as opposed to Dirac's theory.

The trouble arose with how would we know which states the electrons were transitioning from, and it was concluded that since most other transitions had already been recorded and observed in prior power-spectrum experiments on hydrogen, that we would know which transitions belonged to the states that are not in question, so we can rule out these extrema, as well as noting that such transitions from these other states would differ in energy by a large / appreciable amount, whereas the energy for $^2S_{1/2}$ and $^2P_{1/2}$ would only differ - if it did - by a much smaller amount than any other state we could compare with.

The results were that $^2S_{1/2}$ and $^2P_{1/2}$ do have different energy levels, and the difference between them being $\Delta E = 4.35 \times 10^{-6}$ eV. It should be noted that the observed difference in frequency for these states, due to the relationship $E=h\nu$, is the Lamb Shift, which gets its namesake from Willis E. Lamb.

3 Conclusion

We conclude that our expectations for the difference between the states to be correct, but this does not make Dirac theory less credible - upon further discussion we realized that this energy difference is on the order of α^5, which is much too small to expect Dirac theory to predict such an energy difference. Dirac theory is still consistent with other possibilities, this being an exception due to the energy scale.