Charge Threshold Theory

Consider that, instead of using a large mass for which the gravitational field can be detected in a manner that discerns which-way information in Figure 4.2 a charged object with charge $Q = Ze$ is used (it is remarked in [268] that this experiment was developed by Bohr but unpublished). Instead of measuring the gravitational force in Figure 4.2, the Coulomb force is measured. If Z is large enough, the Coulomb force can be detected in a manner that the accuracy is sufficient to discriminate which slit the charged object took. At that point, first-order interference must be lost. A detailed analysis of this experiment was also conducted in the paper [268]. The authors utilized much of the work of Bohr and Rosenfeld for which they proposed a specific apparatus composed of positive charge Q_B and negative charge $-Q_B$ separated by a distance. The negative charge is tethered to the box, while the positive charge is displaced at equilibrium by an electric field. The positive charge can move further in response to an external electric field. The motion can be detected depending on the parameters for which detailed analysis utilizing uncertainty relationships was completed by Bohr and Rosenfeld. It is found that the critical threshold of charge Z_{th} is given by

$$Z_{th} \cong \frac{1}{\sqrt{\alpha}}\frac{cT}{d}.$$

where α is the fine structure constant. Typically, it is found for most typical parameters of d and T, that $Z \gg 1$ which is why single electrons, protons and most molecules exhibit wave properties. However, once the charge is sufficiently large, such first order wave interference will be lost. Upon introducing a measure of distinguishability $\mathcal{D}$ that quantifies how well the Coulomb field of the two slits can be distinguished, it was found that

$$\mathcal{D} = \mathrm{erf}\left(\frac{Z}{2\sqrt{2}Z_{th}}\right),$$

where erf represents the error function. From the distinguishability, it is seen that the threshold $Z = Z_{th}$ is not a hard threshold, that is, although distinguishability decreases as Z decreases, the distinguishability does not reduce to zero except at $Z = 0$.

Now, in the case of the detection of the gravitational field, it was found that first-order interference was lost once the gravitational field could be discerned. Furthermore, the mechanism of first-order interference loss was due to the fringe separation distance falling below the Planck length. According to standard quantum mechanics, there must also be a loss of first-order interference for the case when the object is a Coulomb charge above threshold $Z > Z_{th}$. What then is the mechanism for first-order interference in the case when the object consists of charge?

In [268] it is argued that when the charge changes direction when passing through the slits, there will be radiation emitted by the charge which will disturb the charge's phase. This disturbance will reduce the visibility $\mathcal{V}$ of the interference pattern. A calculation is performed in [268] of the expected visibility $\mathcal{V}$ which indicates that such an explanation is consistent with the loss of first-order interference. Furthermore, the loss of first-order interference is shown to be consistent with the simultaneous increase in $\mathcal{D}$ found above, and for which it is shown $\mathcal{V} + \mathcal{D} \leq 1$ for which a similar general condition on the tradeoff regarding visibility and which-way information had been derived by [293].

In this case of Coulomb charge, like the previous gravitational case, the loss of first-order coherence comes at the expense of the production of a detectable Coulomb charge. In terms of the measurement problem, the unitary prediction of entanglement between slit path and Coulomb field would need to be experimentally distinguished from the measurement prediction of a product state of slit path and Coulomb field. Like the prior case of gravitational field, this does not appear to be a simple matter. On the other hand, experimentally demonstrating the loss of first-order interference at the expense of the production of the detectable Coulomb field would certainly be of interest, but such a demonstration (without further alteration) would not contribute to the resolution of the measurement problem. That is, there is no doubt that there will be loss of first-order coherence upon exceeding some threshold, but it is possible that such a demonstration would not distinguish entanglement from product-state, which is key to resolving the measurement problem. The dependence of the measurement problem on such minutiae, underscores why a thorough understanding of the issues involved is important.