Nonlinear Optics of Dirac Fermion Systems

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Abstract : Graphene has been recognized as a promising 2D material with many new properties. However, pristine graphene is gapless which hinders its direct application towards graphene-based semiconducting devices. Graphene is a zero-gapp and linearly dispersing semiconductor. Massless charge carriers (quasi-particles) in graphene obey the relativistic Dirac equation. These Dirac fermions show very unusual physical properties such as electronic, optical and transport. Graphene is analogous to two-level atomic systems and conventional semiconductors. We may expect that graphene-based systems will also exhibit phenomena that are well-known in two-level atomic systems and in conventional semiconductors. Rabi oscillation is a nonlinear optical phenomenon well-known in the context of two-level atomic systems and also in conventional semiconductors. It is the periodic exchange of energy between the system of interest and the electromagnetic field. The present work describes the phenomenon of Rabi oscillations in graphene based systems. Rabi oscillations have already been described theoretically and experimentally in the extensive literature available on this topic. To describe Rabi oscillations they use an approximation known as rotating wave approximation (RWA) well-known in studies of two-level systems. RWA is valid only near conventional resonance (small detuning)- when the frequency of the external field is nearly equal to the particle-hole excitation frequency. The Rabi frequency goes through a minimum close to conventional resonance as a function of detuning. Far from conventional resonance, the RWA becomes rather less useful and we need some other technique to describe the phenomenon of Rabi oscillation. In conventional systems, there is no second minimum - the only minimum is at conventional resonance. But in graphene we find anomalous Rabi oscillations far from conventional resonance where the Rabi frequency goes through a minimum that is much smaller than the conventional Rabi frequency. This is known as anomalous Rabi frequency and is unique to graphene systems. We have shown that this is attributable to the pseudo-spin degree of freedom in graphene systems. A new technique, which is an alternative to RWA called asymptotic RWA (ARWA), has been invoked by our group to discuss the phenomenon of Rabi oscillation. Experimentally accessible current density shows different types of threshold behaviour in frequency domain close to the anomalous Rabi frequency depending on the system chosen. For single layer graphene, the exponent at threshold is equal to 1/2 while in case of bilayer graphene, it is computed to be equal to 1. Bilayer graphene shows harmonic (anomalous) resonances absent in single layer graphene. The effect of asymmetry and trigonal warping (a weak direct inter-layer hopping in bilayer graphene) on these oscillations is also studied in graphene systems. Asymmetry has a remarkable effect only on anomalous Rabi oscillations whereas the Rabi frequency near conventional resonance is not significantly affected by the asymmetry parameter. In presence of asymmetry, these graphene systems show Rabi-like oscillations (offset oscillations) even for vanishingly small applied field strengths (less than the gap parameter). The frequency of offset oscillations may be identified with the asymmetry parameter.

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