Interplay of excitonic correlations with quantum spin hall effect and superconductivity

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It has been proposed that in band-inverted electron-hole bilayers the excitonic correlations arising due to Coulomb interactions lead to phase transitions from a trivial insulator phase to an insulating phase with a spontaneously broken time-reversal symmtery and finally to a non-trivial quantum spin hall insulator phase as a function of increasing electron and hole densities. Importantly, in contrast to the standard paradigm of topological phase transitions,the trivial insulator phase is connected to a quantum spin Hall insulator without an energy gap closing appearing in the fermionic spectrum. Here, we show that it is possible to realize Majorana Zero Modes (MZMs) in the time-reversal symmetry broken phase in the presence of proximity-induced superconductivity in the absence of magnetic field. We demonstrate that the Majorana zero modes can be detected in superconductor/time-reversal symmetry broken insulator/superconductor Josephson junctions through the measurement of a 4π Josephson current. For a better understanding of our numerical results, we develop an effective low-energy theory in the presence of time-reversal symmetry breaking order parameter and obtain analytically the Majorana zero modes and the Andreev bound states localized at the junction using a scattering-matrix formalism. We find a good agreement between the numerical and analytical results in the limit of weakly-broken time-reversal symmetry.