Exercise E-7-4

Consider electrons in graphene under magnetic field. Let us treat the motion semi-classically.

Cyclotron frequency expression $\omega_{\mathrm{c}} = \dfrac{eB}{m}$ cannot be applied due to $m{=}0$.

Instead use the relation $E = pc$.

(1) Express the cyclotron radius with momentum and e and B.
(2) A circular motion of electron gives kinetic phase and AB phase to the electron. Replace the momentum in (1) with $\hbar k$ and express the total phase acquired by the electron within a circular motion with the flux through the cyclotron circle and the flux quantum.
(3) The acquired phase should be integer times 2π. Obtain the expression for cyclotron radius and energy.