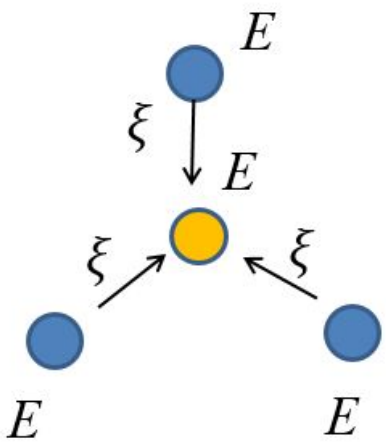
Exercise for “Semiconductors”

Problem setting:	14/04/2021	出題	2021 年 4 月 14 日
Solution submission deadline:	28/04/2021	解答提出期限	2021 年 4 月 28 日

The text part in the answer should be typed (not handwriting) in English or Japanese. The scoring does not depend on the language. It doesn't matter if you are good at grammar, vocabulary, or sentences, but if I cannot catch the meaning, the scoring will get deducted regardless of English or Japanese. The answer sheet should be in small-sized (hopefully less than 1 MB) PDF format, which can be appropriately displayed by Adobe Reader. The file of the answer should be submitted through ITC-LSM.

解答のテキスト部分は手書きでないようにお願いします．英語，日本語のどちらでも良く，採点は言語に依存しません．文法や語法，文章の上手下手は問題にしませんが，意味が取れない場合は，英語日本語にかかわらず，減点します．解答は，ファイルサイズのできるだけ小さな (1 MB 以下が目安)，Adobe Reader できちんと表示できる PDF ファイルにまとめ，ITC-LSM を通して提出してください．

Energy gap and symmetry of lattice



Energy gap opening in one-dimensional lattice can be easily understood by solving 2×2 Schrödinger equation:

$$i\hbar\frac{\partial}{\partial t}\boldsymbol{a} = \begin{pmatrix} E & \xi \\ \xi & E \end{pmatrix}\boldsymbol{a},$$

which gives eigenvalues $E \pm \xi$.

For systematic treatment, the space group theory is the best way to consider this kind of symmetry. But in the case of graphene, a simple consideration similar to the above is enough to understand why the off-diagonal terms in Hamiltonian leave degeneracy. Consider the case illustrated in the left figure and calculate the eigenvalues. Write a brief comment on why the degeneracy is not lifted.