Titel

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***Abstract*— Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.**

I. One-dimensional charge density waves

Materials in which the electron density $\rho(x)$ is modulated with a wave of wavelength $\lambda = \frac{2\pi}{Q}$ are said to contain a charge density wave. In this paper, we will treat a simple model for a one-dimensional chain of atoms containing such a charge density wave:

$$H = -t\sum_x (c_x^\dagger c_{x+a} + c_x^\dagger c_{x-a}) + \sum_x (\mu + \Delta\cos(Qx+\phi))c_x^\dagger c_x$$

The first term describes hopping between sites, and the second term contains the chemical potential and the charge density wave. From the fact that at a band gap opens at μ, it follows that $\mu = -2t\cos(\frac{Qa}{2})$.

If $\lambda = na$ with n integer and a the lattice spacing, the charge order is said to be commensurate, i.e. the charge modulation is neatly periodic in n lattice sites. Otherwise, the charge order is called incommensurate.

After imposing periodic boundary conditions, commensurate charge order is the only option, and the total amount of lattice sites N must equal a multiple of λ.

To diagonalize H, we first apply the canonical Fourier transform:

$$c_x = \frac{1}{\sqrt{N}}\sum_{0\le k<\frac{2\pi}{a}} e^{ikx}c_k$$

The hopping term and the chemical potential both give contributions diagonal in k. After writing $\cos(Qx+\phi) = \frac{1}{2}(e^{i(Qx+\phi)} + e^{-i(Qx+\phi)})$, we see that the charge wave in real space gives an off-diagonal contribution in k. The resulting Hamiltonian in Fourier space is:

$$H = \sum_{0\le k<\frac{2\pi}{a}} (\frac{1}{2}\varepsilon_k c_k^\dagger c_k + \Delta_\phi c_k^\dagger c_{k+Q} + \text{H.c.})$$

Where $\varepsilon_k = -2t\cos(ka)+\mu$ and $\Delta_\phi = \Delta e^{i\phi}$, i.e. Δ acquires a phase corresponding to the offset of the charge distribution.

Matrix:

$$\begin{bmatrix} \varepsilon_k & \Delta_\phi & 0 & \dots & 0 & \Delta_\phi^* \\ \Delta_\phi^* & \varepsilon_{k+Q} & \Delta_\phi & & & 0 \\ 0 & \Delta_\phi^* & \ddots & \ddots & & 0 \\ \vdots & & \ddots & & & \vdots \\ 0 & & & & & 0 \\ \Delta_\phi & 0 & 0 & \dots & 0 & \varepsilon \end{bmatrix}$$

II. Bruno Stukje

Letś rewrite this Hamiltonian in a nice Matrix form:

$$\begin{aligned}\hat{H} &= \sum_{0\le k<\frac{2\pi}{a}} (\frac{1}{2}\varepsilon_k c_k^\dagger c_k + \Delta_\phi c_k^\dagger c_{k+Q} + \text{H.c.}) \\ &= \sum_{0\le k<\frac{2\pi}{qa}}\sum_{p=0}^{q-1} (\frac{1}{2}\varepsilon_{k+\frac{2\pi p}{qa}} c^\dagger_{k+\frac{2\pi p}{qa}} c_{k+\frac{2\pi p}{qa}} + \Delta_\phi c^\dagger_{k+\frac{2\pi p}{qa}} c_{k+\frac{2\pi p}{qa}+Q} + \text{H.c.})\end{aligned}$$

III. Topological classification

The charge density wave Hamiltonian in k-space can be divided in different classes. Originally the classification was developed for translational or rotational invariant systems, but because the dihedral group is the only nontrivial space group another classification is made. When symmetries are taken into account a topological classification can be made. If a system behaves in the same way when time is reversed on can say that the system has a time symmetry. For time symmetry there are 3 options. Either the system is not time symmetric ($T = 0$), or it is time symmetric ($T^2 = 1$) or the system is time anti-symmetric ($T^2 = -1$). Another symmetry is charge conjugation C. When this is observed as particle-hole symmetry one can distinguish an occupation of the hole or an empty hole. When there is a symmetry the charge conjugation can be plus ($C^2 = 1$) or minus ($C^2 = -1$) and when there is no symmetry the charge conjugation number is zero ($C = 0$). Because both the time reversal operator T and the charge conjugation number C are topological invariant their multiplication $S = T * C$ is also a topological invariant. As a first guess one would find $3*3 = 9$ topological invariant sectors. But when there is no time reversal ($T = 0$) and no charge conjugation ($C = 0$), S can have two values. When a system is symmetric in the combination of time and particle hole symmetry S is given the value of 1. When it is not symmetric in the combination of them the value is 0. All together there are than 10 different topological sectors where S is an invariant. This Tenfold Way classifies the allowed topologies of all gapped, disordered, quadratic fermion theories into ten classes based on the dimension

of the parameter space, see ???. The advantage of this classification is that these sectors have edge states which are classified by a nonzero Chern number. Because these edge states do not depend on small perturbations in the bulk of the material it is possible to measure variables at the edge that give information of the whole material.

A. *Figures and Tables*

Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation Fig. 1, even at the beginning of a sentence.

class	C	P	T	$d=0$	1	2	3	4	5	6	7
A				$\mathbb{Z}$		$\mathbb{Z}$		$\mathbb{Z}$		$\mathbb{Z}$	
AIII	1				$\mathbb{Z}$		$\mathbb{Z}$		$\mathbb{Z}$		$\mathbb{Z}$
AI			1	$\mathbb{Z}$				$2\mathbb{Z}$		$\mathbb{Z}_2$	$\mathbb{Z}_2$
BDI	1	1	1	$\mathbb{Z}_2$	$\mathbb{Z}$				$2\mathbb{Z}$		$\mathbb{Z}_2$
D		1		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$				$2\mathbb{Z}$	
DIII	1	1	-1		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$				$2\mathbb{Z}$
AII			-1	$2\mathbb{Z}$		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$			
CII	1	-1	-1		$2\mathbb{Z}$		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$		
C		-1				$2\mathbb{Z}$		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$	
CI	1	-1	1				$2\mathbb{Z}$		$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}$

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity Magnetization, or Magnetization, M, not just M. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write Magnetization (A/m) or Magnetization A[m(1)], not just A/m. Do not label axes with a ratio of quantities and units. For example, write Temperature (K), not Temperature/K.

IV. CONCLUSIONS

A conclusion section is not requiblack. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.