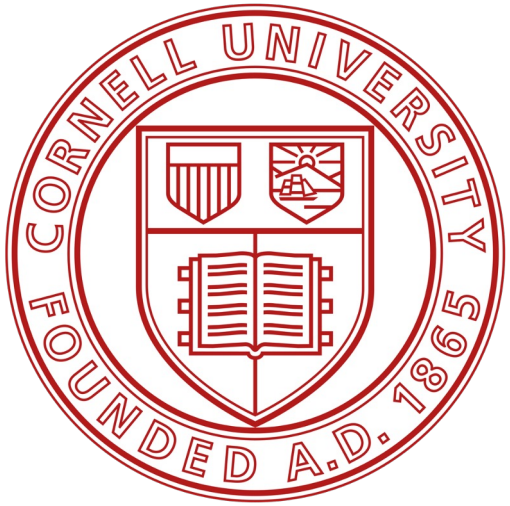


# Observing Moiré Patterns in the Classroom

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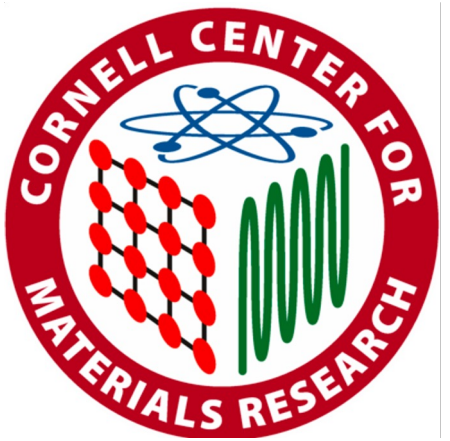
REACT 2023

LASSP LABORATORY OF ATOMIC AND SOLID STATE PHYSICS



# Introduction

- Patterns or *periodic structures* are ubiquitous in nature

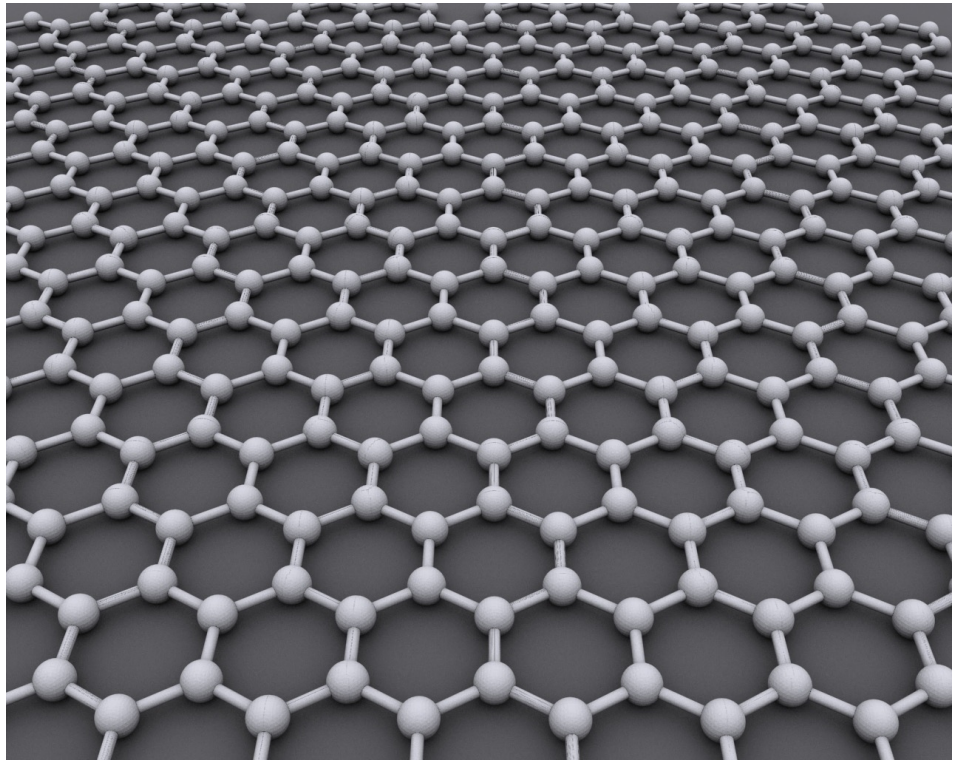
Ex. Wind Ripples in Sand

Ex. Beehive

# Introduction

- Materials are composed of periodic structures called *crystal lattices*

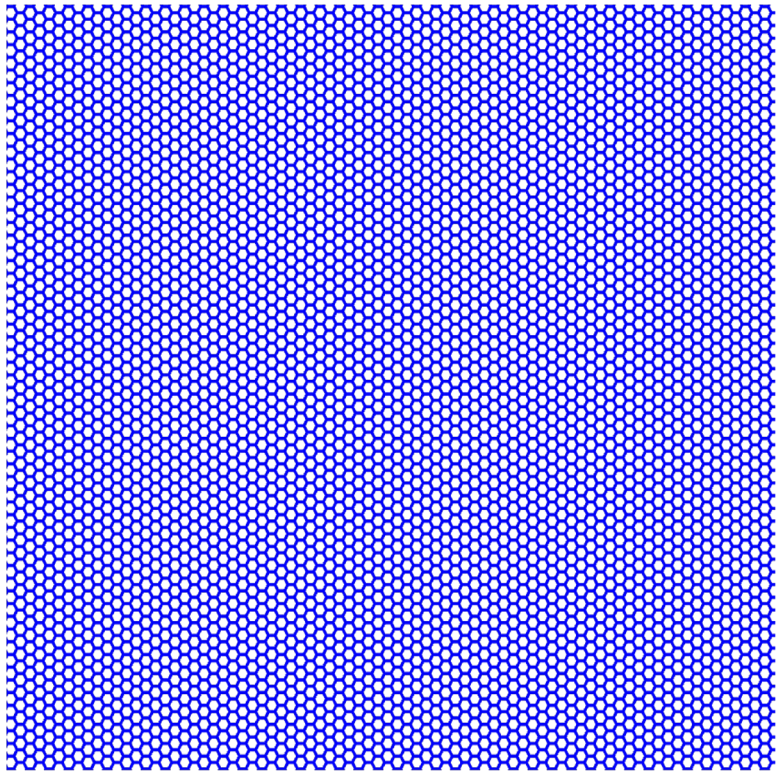
Ex. Graphene

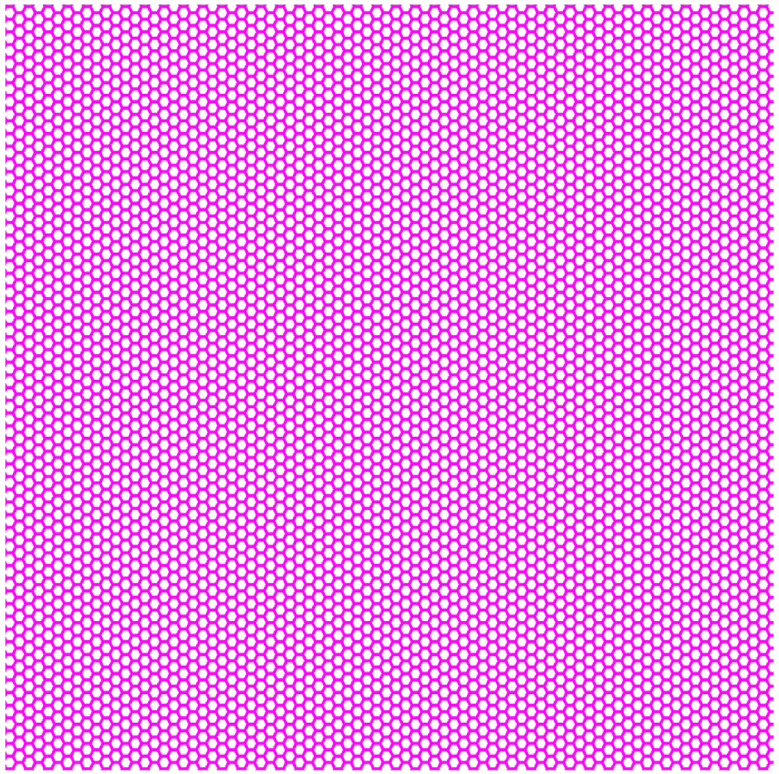


# Introduction

- When two periodic patterns are superposed with a slight misalignment, *Moiré patterns* emerge

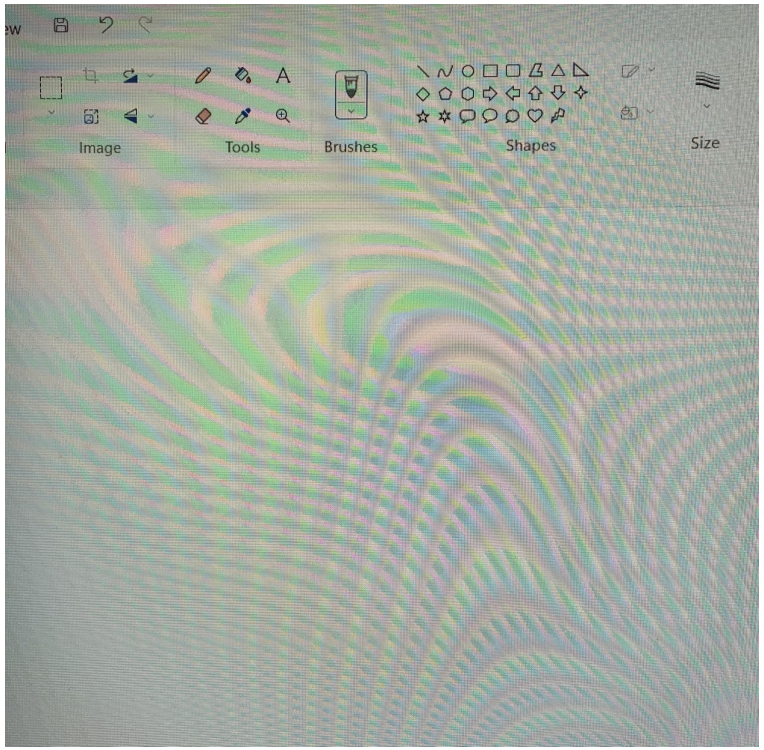
Ex. Twisted Bilayer Graphene





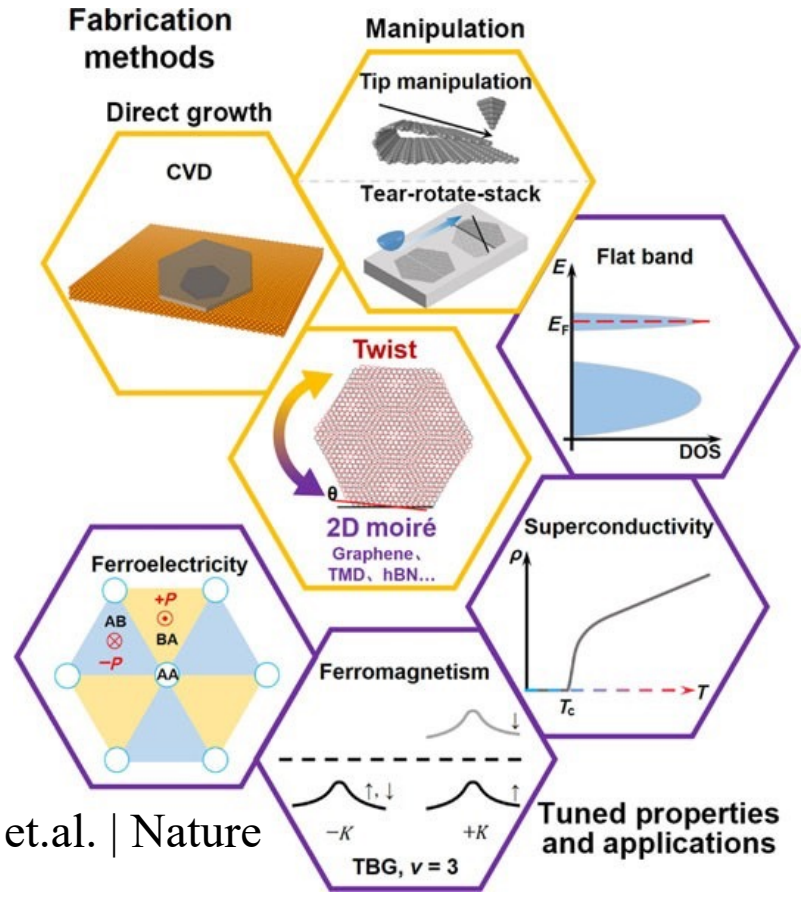
# Introduction

- Moiré patterns in real life

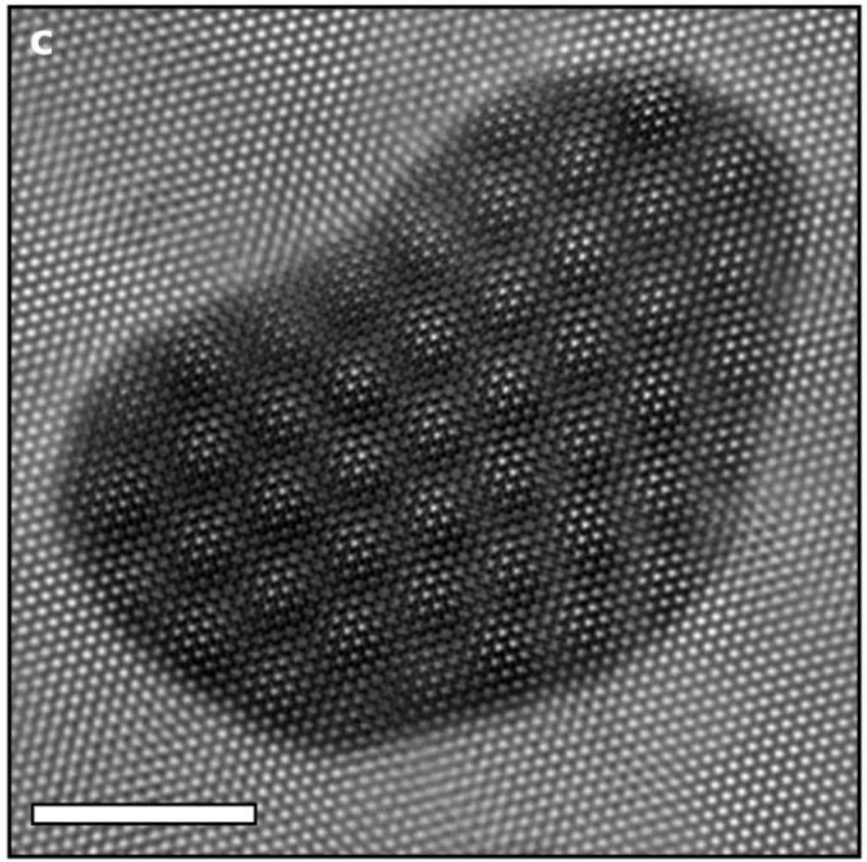



# Introduction

- Moiré patterns are harnessed in labs to manipulate properties of materials




Wang et.al. | Nature 2022




Reidy et.al. | Nat Commun 2021

# Motivations for Activity

- Our activity will enable students to practice
  - Pattern recognition
  - Measurement skills
  - Algebra skills

- Relevant to next-generation science standards for middle school
  - Crystal lattices ~ structure of matter (MS-PS1-1)
  - Periodic structures ~ wave properties (MS-PS4-1)

- We hope that a brief introduction to the physics of moiré materials after the activity will foster interest in science

# Outline of Presentation

1. Warmup activity: interfering sound waves and beat frequencies

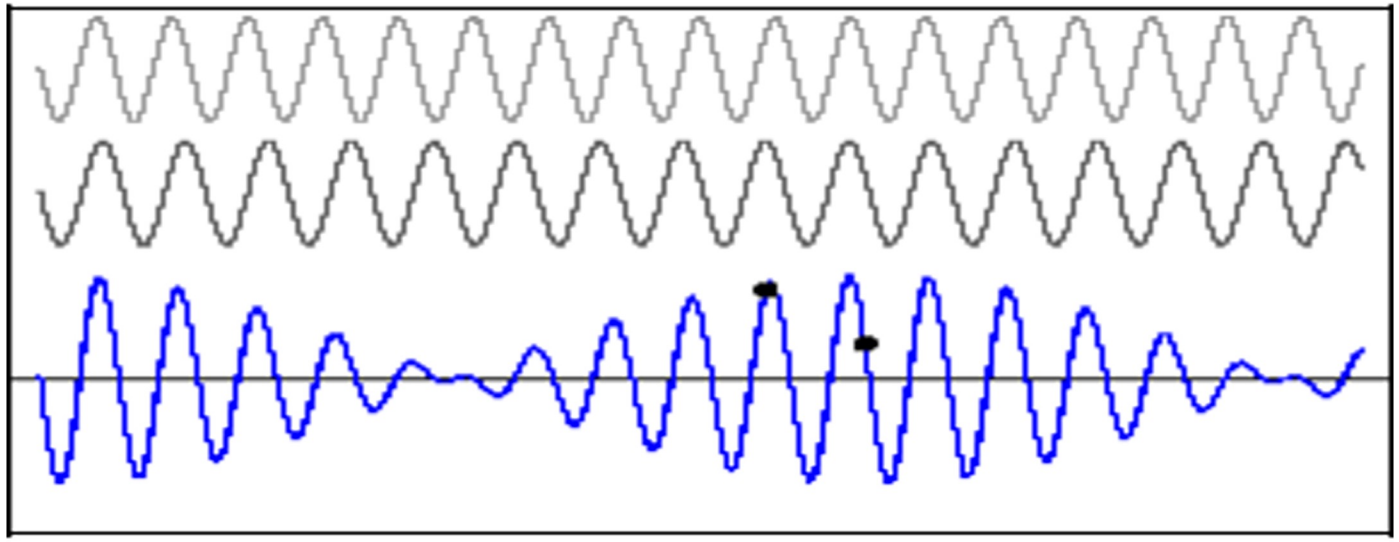
2. Main activity: moiré patterns with crystal lattice printouts

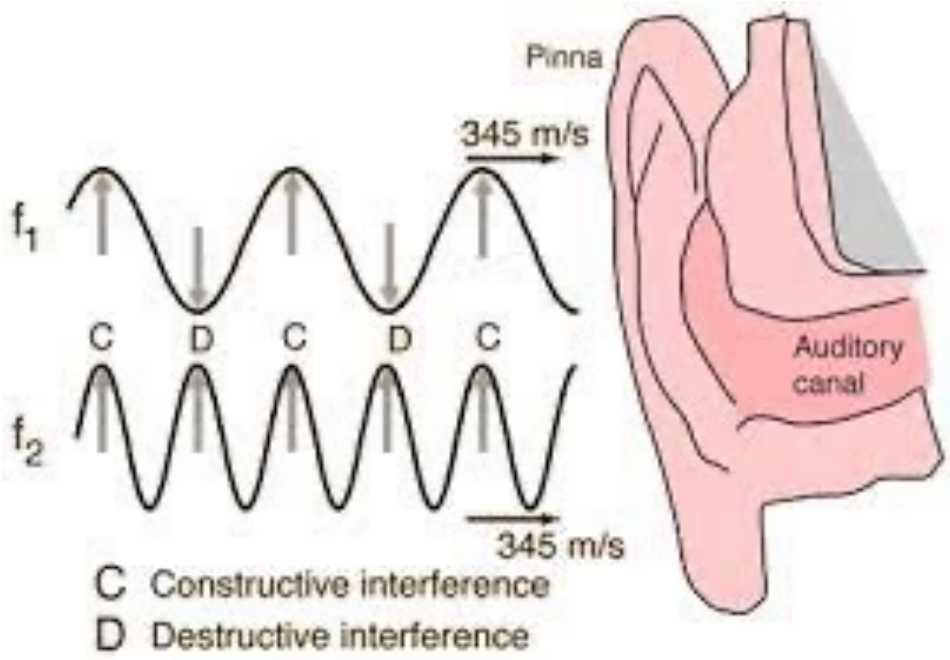
3. Moiré patterns in modern day physics research - *twistronics*

# Warmup: Beat Frequencies and Sound Waves

- Moiré patterns are analogous to beat frequencies in sound waves

- Beat frequencies emerge when sounds waves of slightly different frequencies interfere





# Beat Frequency Activity: Live Demo

1. Go to https://www.szynalski.com/tone-generator/ and duplicate tab

2. Play 150 Hz and 151 Hz in each tab (beware of volume)

# Beat Frequency Activity: Live Demo

3. Ask students to count how many beats they hear over a 10s interval

- Beat Frequency = # of beat cycles/10 s
- Has units of Hz (Hz = cycles/s)
- Compare to predicted value using: $f_{\text{beat}} = |f_1 - f_2|$

$$f_{\text{beat}} = |151\text{Hz} - 150\text{Hz}| = 1\ \text{Hz}$$

# Beat Frequency Activity: Live Demo

4. Repeat with 150 Hz and 150.5 Hz

- Ask students to calculate the new beat frequency using

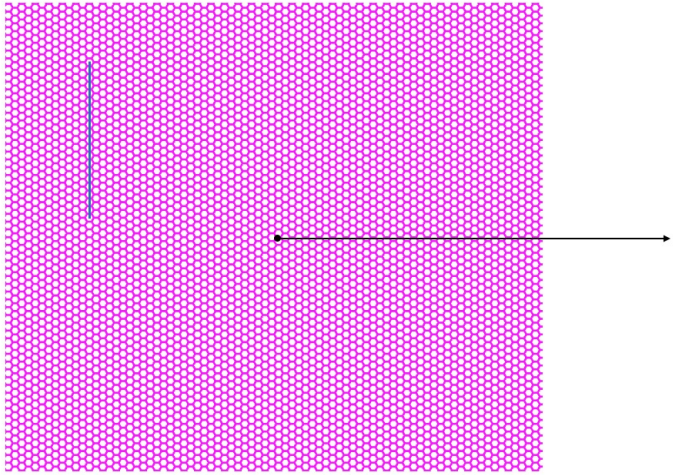
$$f_{\text{beat}} = |f_1 - f_2|$$

- Ask students to compare their calculation result to what they hear

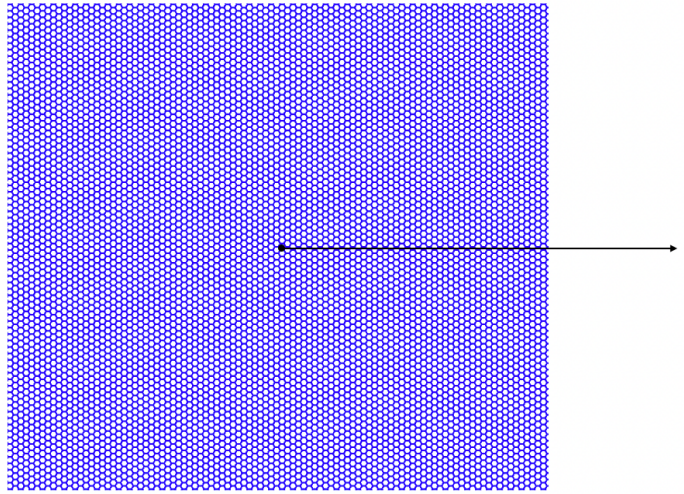
# Main Activity: Moiré Pattern Handouts

- Our activity involves printouts of honeycomb/graphene lattice patterns
- Each moiré pattern activity kit comes with:
  - A translucent graphene lattice printout used as a reference
  - Graphene lattice printouts in three different sizes relative to reference

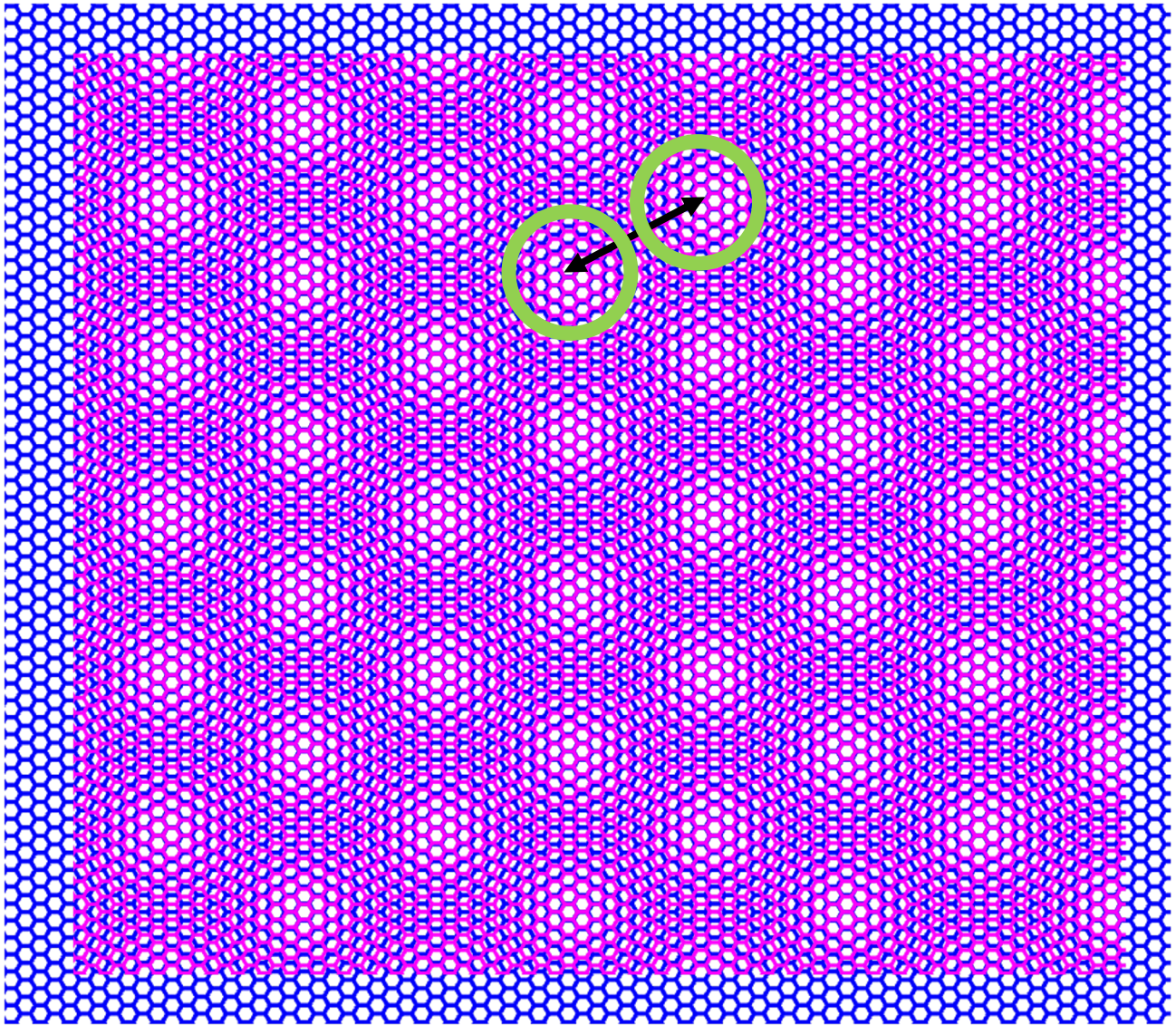
Scale: 1.0



Scale: 0.8

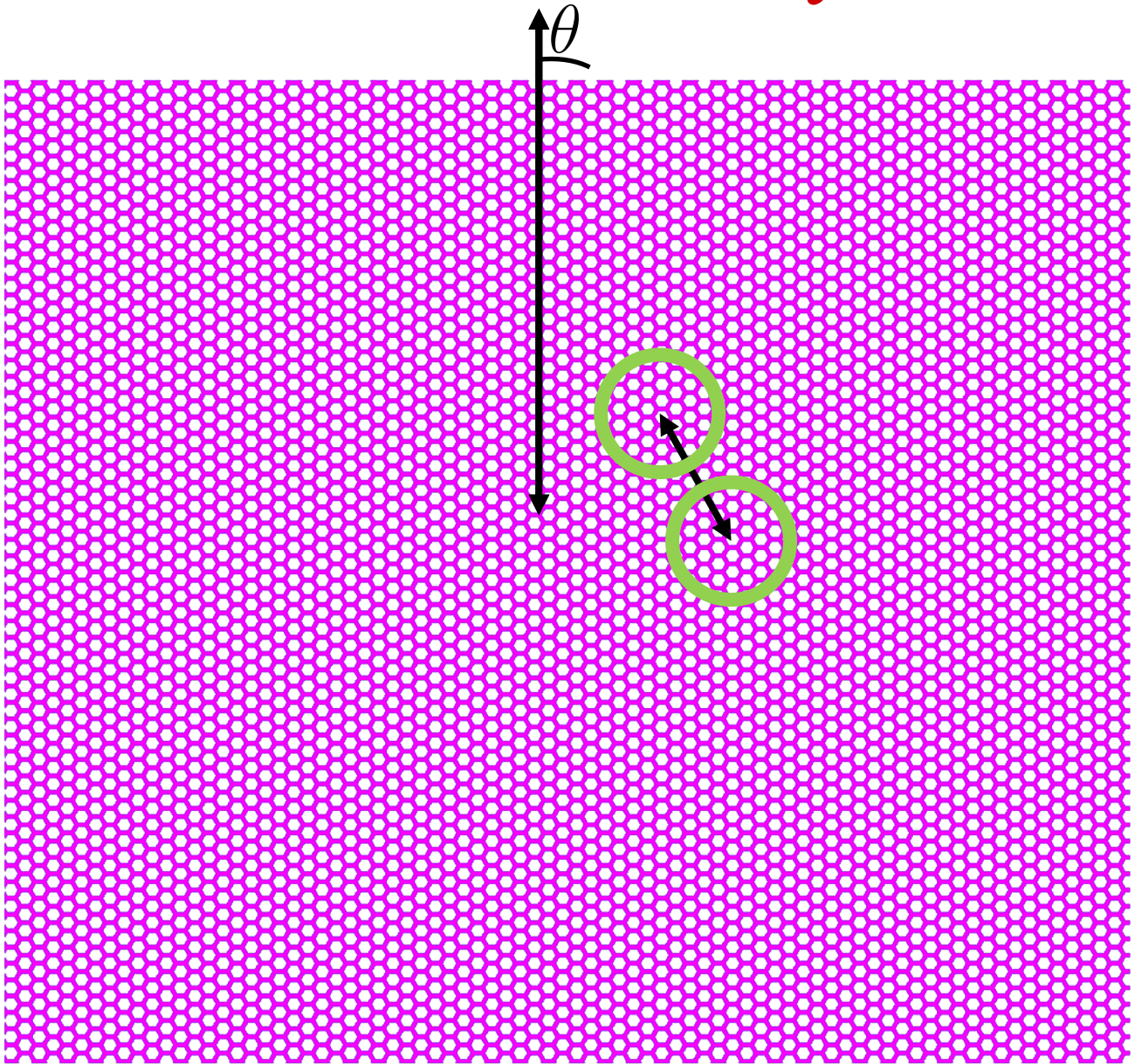


# Moiré Pattern Activity: Lattice Mismatch



$$\lambda_{\text{moiré}} = \frac{1}{\left|\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right|}$$

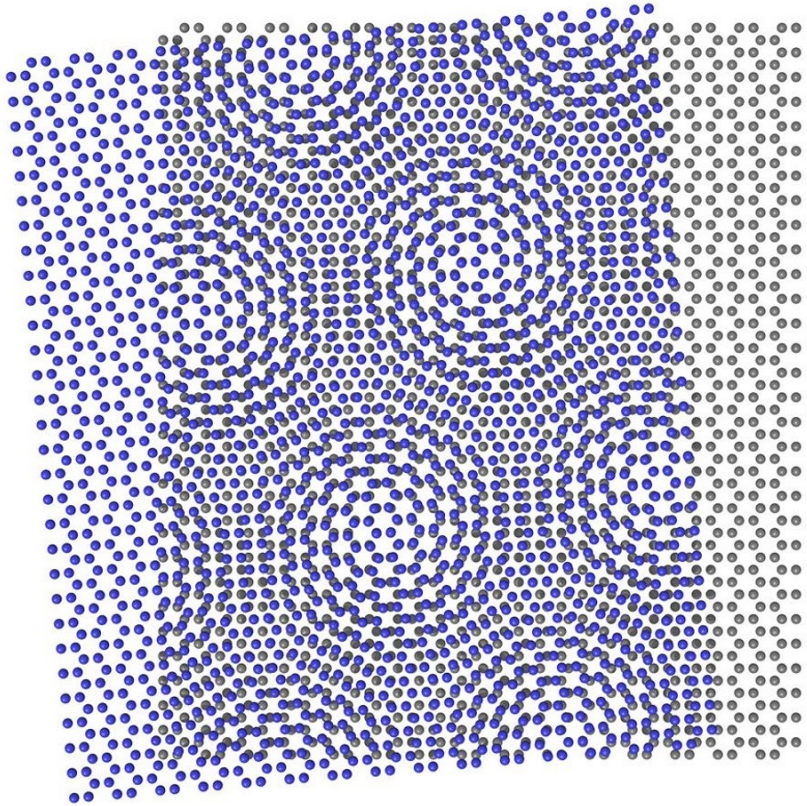
# Moiré Patterns Activity: Twist Angle

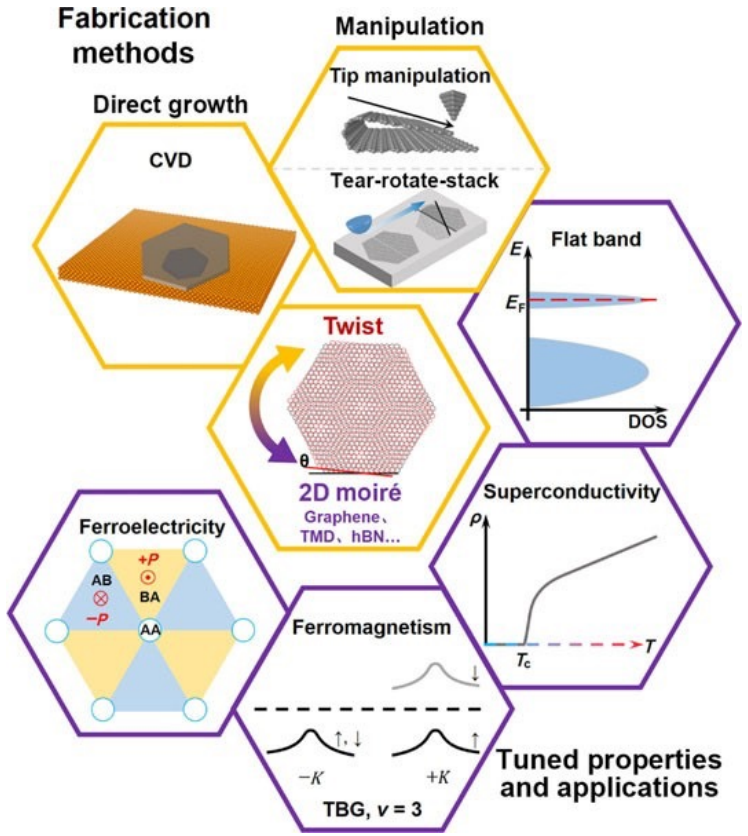



$$\lambda_{\text{moiré}} = \frac{\lambda}{2\sin(\theta/2)}$$

# Modern Research: Twistronics

- Twistronics is an emerging field in materials physics that uses moiré patterns to manipulate electrical properties in materials as a function of twist angle

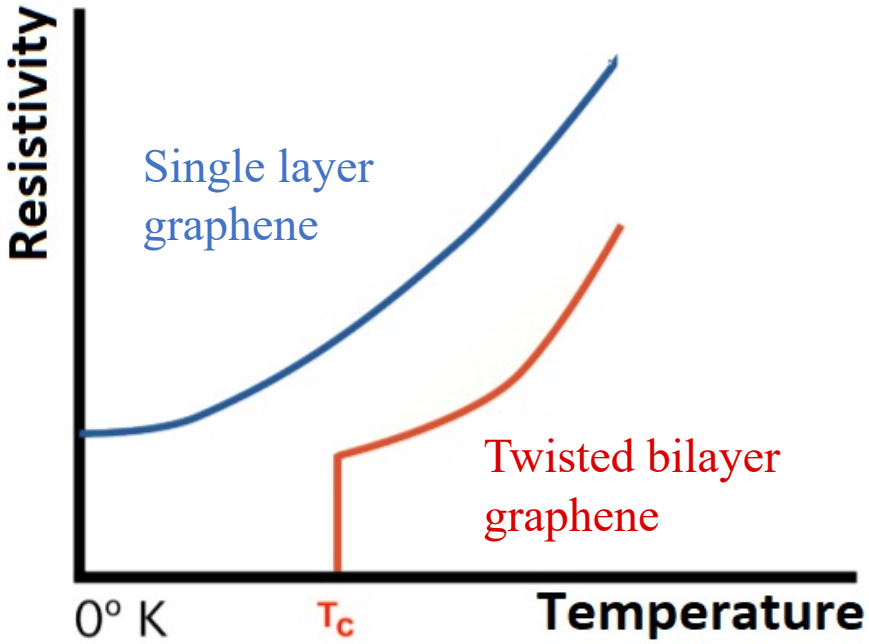




# Twistronics and Superconductivity

- An example of a moiré material is *twisted bilayer graphene*

- This synthetic material exhibits superconductivity, which is unobserved in a single layer of graphene




**Unconventional superconductivity in magic-angle graphene superlattices**

Yuan Cao[1], Valla Fatemi[1], Shiang Fang[2], Kenji Watanabe[3], Takashi Taniguchi[3], Efthimios Kaxiras[2,4] & Pablo Jarillo-Herrero[1]

Activity kits and sheets containing detailed instructions will be made available for you all.

Thanks for listening!