LECTURE # 32

Note Title 4/8/2009

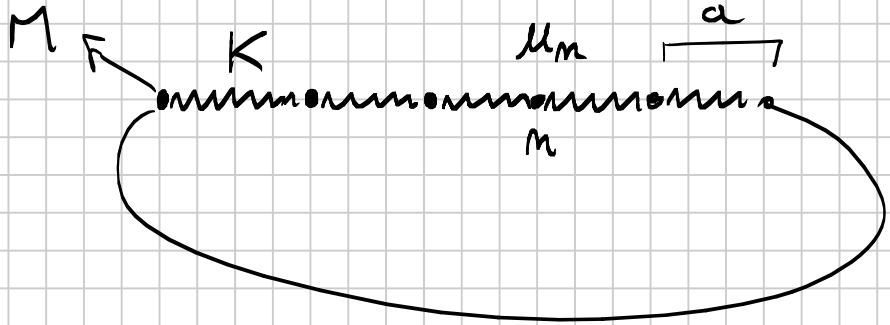
(1) ~~Quantum Hall effect~~
Graphene
(2) ~~Carbon Nanotubes~~
Excitons and exciton-polaritons
Mesoscopic physics and single electronics
Spectroscopy of quantum dots and quantum wires
(3) ~~Spintronics in metals/semiconductors~~
Neutron and electron scattering in solids
Solid state devices for quantum information processing
(5) ~~Magnetic properties~~ of solids
Superconductivity
(4) ~~FULLERENES~~

CALENDAR PRESENTATIONS

(3)	Acharyya, Rakhi	APR 27
	Bremer, Marshall T	
(5)	Deninno, Matthew Luke	APR 29
	Devi, Pampa	
	Do, Dat Thanh	MAY 1
(1)	Doan, Tri Cao	
(4)	Kittimanapun, Kritsada	MAY 8
	Latt, Kyaw Zin	
(2)	Miller, Nicholas Joel	
	Xu, Kaijie	

PAPER FORMAT: DOUBLE SPACE 12 pt

LIMIT 5 PAGES INCLUDING FIGS & REFS

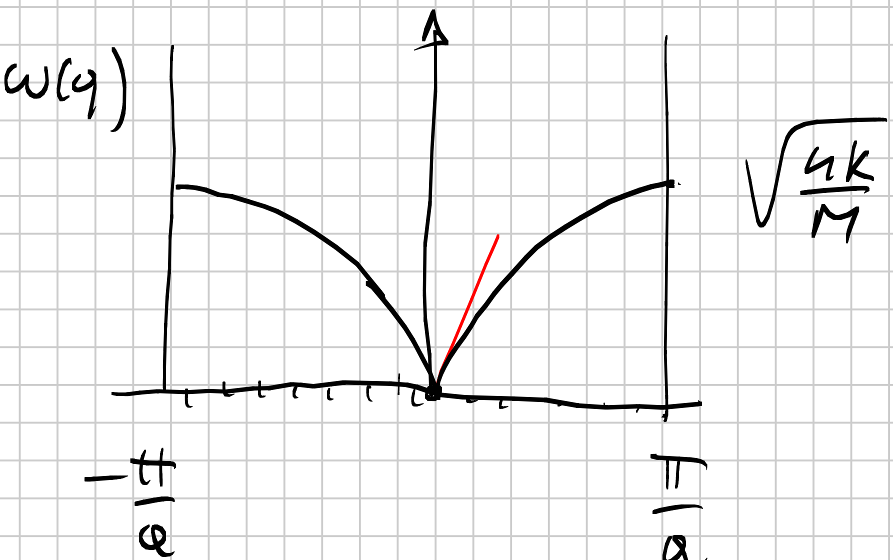


FIND THE NORMAL MODES OF OSCILLATIONS LABELED BY q IN

THE FIRST BRILLOUIN ZON

$$u_n(q) = e^{i(qna - \omega(q)t)} \qquad \lambda = \frac{2\pi}{q}$$

WE FOUND $\omega(q) = \sqrt{\frac{4K}{M}} \left| \sin \frac{qa}{2} \right|$

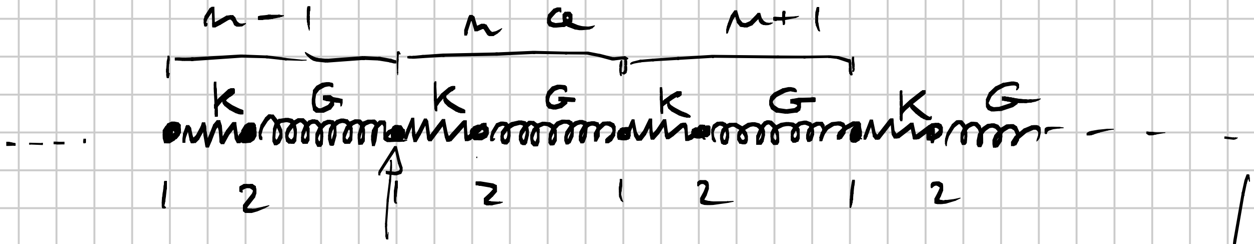


SMALL q $\lambda \gg a$

$$\omega(q) \sim v_s q$$

$$\left(\hbar\omega(q) = \hbar v_s q \right)$$

ACOUSTIC MODES



ASSUME SAME MASS M

u_{1m} u_{2m}

$$\begin{cases} M\ddot{u}_{1m} = -K(u_{1m} - u_{2m}) - G(u_{1m} - u_{2m-1}) \\ M\ddot{u}_{2m} = -G(u_{2m} - u_{1m+1}) - K(u_{2m} - u_{1m}) \end{cases}$$

$$u_{1m}(q) = \varepsilon_1 e^{i(qma - \omega t)}$$

$$u_{2m}(q) = \varepsilon_2 e^{i(qma - \omega t)}$$

$$u_{2m-1} = e^{-iqa} u_{2m}$$

\# UNIT CELLS N

$\# q = N$

$2N$ ATOMS

$\Rightarrow$ $2N$ NORMAL MODES

$\Rightarrow$ 2 DIFFERENT MODES FOR EACH q

$$\begin{cases} \left[M\omega^2 - (K+G)\right]\varepsilon_1 + \left(K + G e^{-iqa}\right)\varepsilon_2 = 0 \\ \left(K + G e^{+iqa}\right)\varepsilon_1 + \left[M\omega^2 - (K+G)\right]\varepsilon_2 = 0 \end{cases}$$

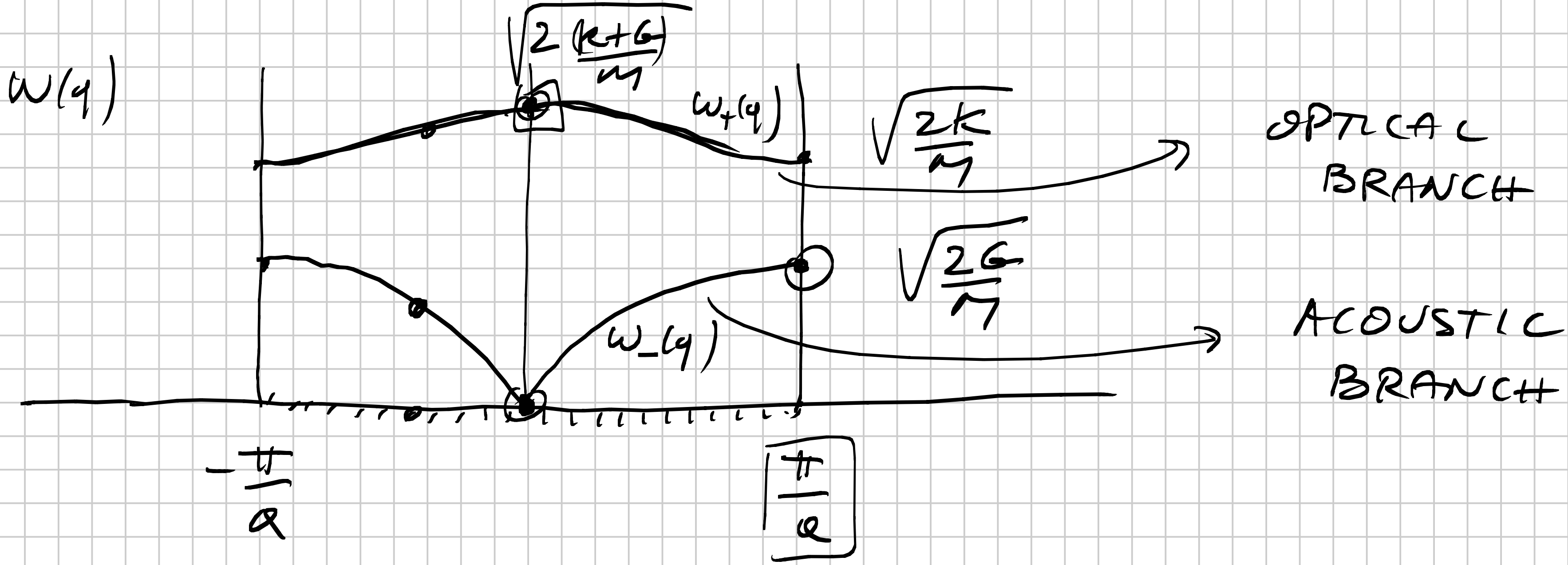
$$M \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \end{pmatrix} = 0$$

DET $M = 0$ $\Rightarrow$ GIVES NON TRIVIAL SOLUTIONS

$$\Downarrow$$

$$\begin{cases} \omega^2_{\pm}(q) = \left(\dfrac{K+G}{M}\right) \pm \dfrac{1}{M}\sqrt{K^2 + G^2 + 2KG\cos qa} \\ \dfrac{\varepsilon_2}{\varepsilon_1} = \mp \dfrac{K + G e^{iqa}}{\left|K + G e^{iqa}\right|} \end{cases}$$

NORMAL MODES



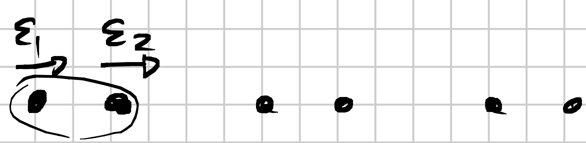
NORMAL MODES AT $\boxed{q = 0}$

ACOUSTIC MODE

$\omega_-(q) \qquad q \to 0$

$$\frac{\varepsilon_2}{\varepsilon_1} = \frac{K + G e^{iqa}}{|K + G e^{iqa}|} \to 1$$

$\Rightarrow$ ε_1 PARALLEL TO ε_2

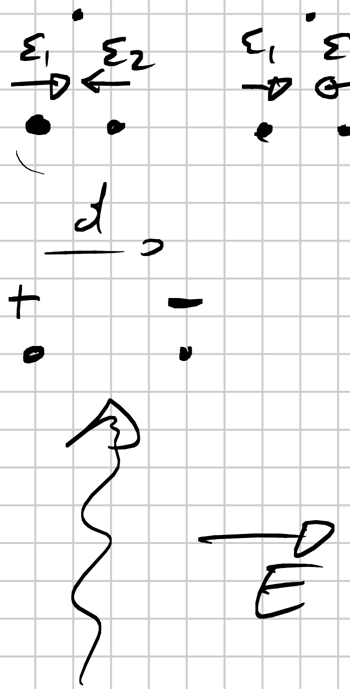


FOR ACOUSTIC MODE

1 & 2 ARE "IN PHASE"

OPTICAL MODE AT $q = 0$

$$\omega_+(q) \rightarrow \sqrt{\frac{2(G+K)}{m}} \qquad \frac{\varepsilon_2}{\varepsilon_1} \rightarrow -1$$



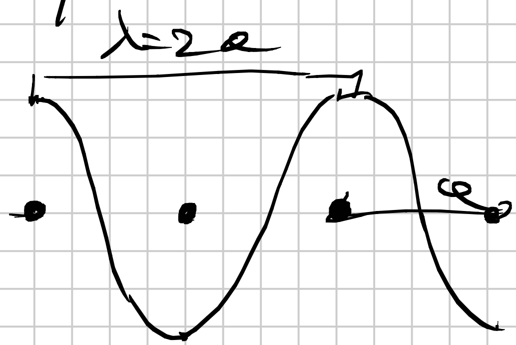
OPTICAL MODE OF OSCILLATION

THE OSCILLATING EM FIELD CAN EXCITE THE DIPOLE OSCILLATION

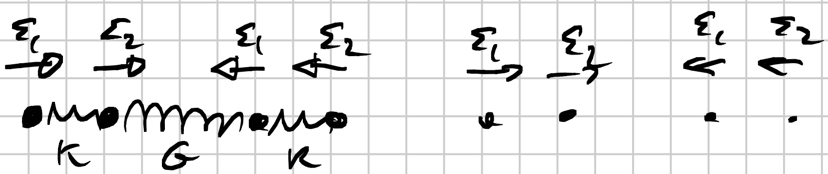
NORMAL MODES AT THE ZONE BOUNDARY

BOUNDARY $q = \frac{\pi}{a}$

$$\lambda = \frac{2\pi}{q} \Rightarrow \lambda = 2a$$



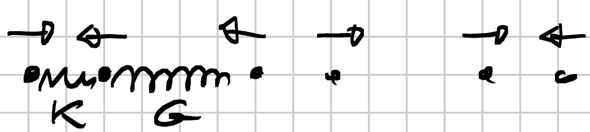
ACOUSTIC MODE AT $q = \frac{\pi}{a}$ $\omega_-\left(\frac{\pi}{a}\right)$



$$\omega_- \propto \sqrt{\frac{G}{M}}$$

OPTICAL MODE AT $q = \frac{\pi}{a}$ $\omega_+\left(\frac{\pi}{a}\right)$

$$\frac{\varepsilon_2}{\varepsilon_1} \to -1$$



$$\omega_+\left(\frac{\pi}{a}\right) \sim \sqrt{\frac{K}{m}}$$

3D $\quad \vec{\mu} \parallel \vec{q}$ LONGITUDINAL

$\vec{\mu} \perp \vec{q}$ 2 TRANSVERSAL MODES

$\langle E \rangle$? ENERGY

$$\langle E \rangle = \langle T \rangle + \langle V \rangle$$

$$\langle T \rangle = \frac{K_B T}{2} \cdot 3 \quad (3D)$$

$$\langle V \rangle = ?$$

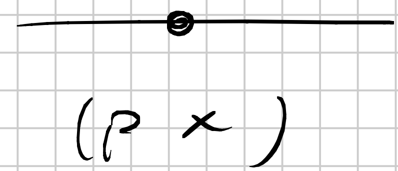
VIRIAL THEOREM CLASSICAL MECHANICS

$$V \sim (r_i - r_j)^\lambda$$

$\langle V \rangle$ IS PROP TO $\langle T \rangle$ ACCORDING TO

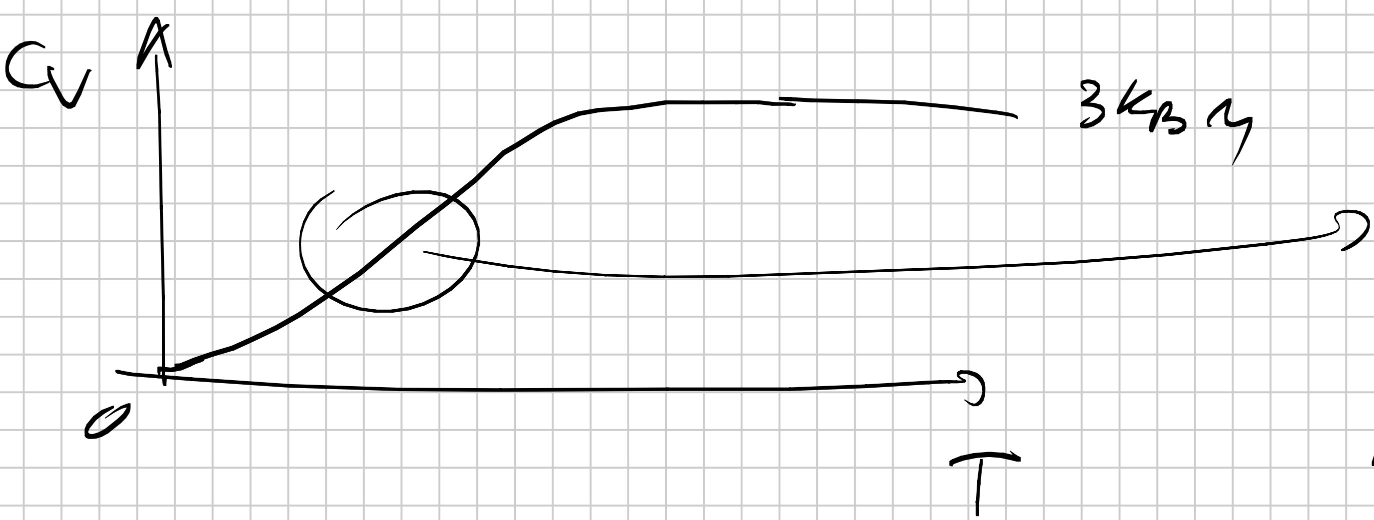
$$2\langle T\rangle = \lambda\langle V\rangle \qquad \lambda = 2 \text{ FOR SPRINGS}$$

$$\Rightarrow \langle V\rangle = \langle T\rangle$$



$$\langle E\rangle = \frac{3}{2}k_B T + \frac{3}{2}k_B T \rightarrow 3k_B T N$$

$$C_V = \frac{1}{V}\frac{\partial\langle E\rangle}{\partial T} = 3k_B\frac{N}{V} = 3k_B n$$



NEEDS QUANTUM MECHANICS