Fall Semester, 2007

재료의 전자기적 성질

Electronic Properties of Materials

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Grading

Midterm Exam 30%

Final Exam 40%

Homework & Attendance 30%

(absence more than 4 lectures = F)

Overall Contents

Part I Fundamentals

Electron Theory : Matter Waves

Chap. 1 Introduction

Chap. 2 The Wave-Particle Duality

Chap. 3 The Schördinger Equation

Chap. 4 Solution of the Schördinger Equation for Four Specific Problems

Chap. 5 Energy Bands in Crystals

Chap. 6 Electrons in a Crystal

Electromagnetic Theory : Maxwell Equations

Chap. 4 Light Waves

(Electrons in Solids, 3rd Ed., R. H. Bube)

1. Introduction

Three approaches to understand electronic properties of materials

- **Continuum theory**: consider only macroscopic quantities,
  interrelate experimental data
  ex) Ohm's law, the Maxwell equations, Newton's law,
  and the Hagen-Rubens equation

- **Classical electron theory**: postulate that free electrons in metals drift
  as a response to an external force and
  interact with certain lattice atoms
  ex) Drude equations

- **Quantum theory**: explain important experimental observations
  which could not be readily interpreted by classical means
  ex) Schrödinger Equation

1. Introduction

Basic equations

$$Newton's\ law\ : F = ma$$

$$Kinetic\ energy : E_{kin} = \frac{1}{2} m\upsilon^2$$

$$Momentum : p = m\upsilon$$

$$E_{kin} = \frac{p^2}{2m}$$

$$Speed\ \text{of light} : c = \nu\lambda$$

$$\text{Velocity of wave} : \upsilon = \nu\lambda \qquad \text{Angular frequency} : \omega = 2\pi\nu$$

$$\text{Einstein's mass-energy equivalence} : E = mc^2$$

2. The Wave-Particle Duality

- **Light : electromagnetic wave**
  light quantum (called a photon)

Energy $$E = \nu h = \omega \hbar$$

Planck constant $$\hbar = \frac{h}{2\pi}$$

1924 yr de Broglie $$\lambda p = h$$

"Wave nature of electrons" "Matter wave"

For a general wave $$\upsilon = \nu \lambda$$

"Wave number" $$k = \frac{2\pi}{\lambda} \longrightarrow \upsilon = \frac{\omega}{k}$$

2. The Wave-Particle Duality

- **Description of electron wave**

  - The simplest waveform : harmonic wave

  - A wave function (time- and space-dependent)

$$\Psi = \sin(kx - \omega t)$$

Electron wave : a combination of several wave trains

Assuming two waves,

$$\Psi_1 = \sin[kx - \omega t]$$

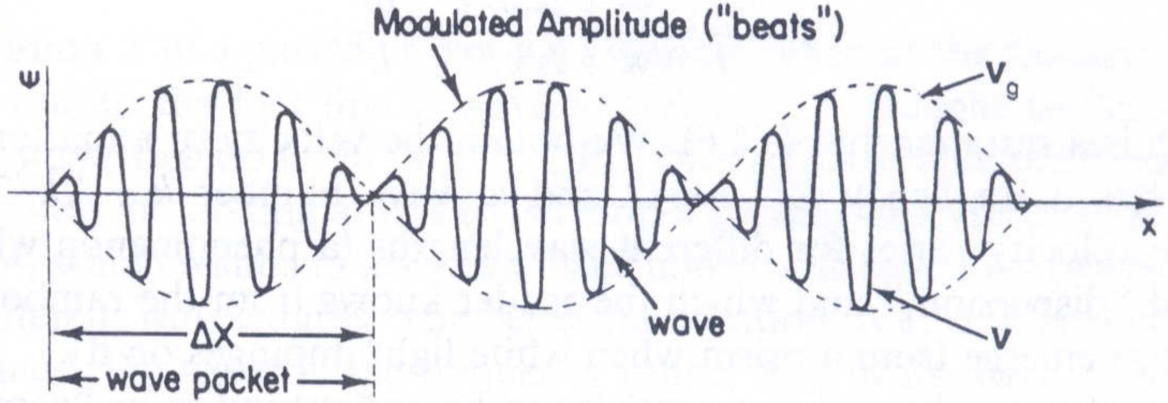
$$\Psi_2 = \sin[(k + \Delta k)x - (\omega + \Delta\omega)t]$$

2. The Wave-Particle Duality

- **Description of electron wave**

Supposition of two waves:

$$\Psi_1 + \Psi_2 = \Psi = \underbrace{2\cos(\frac{\Delta\omega}{2}t - \frac{\Delta k}{2}x)}_{\text{Modulated amplitude}} \cdot \underbrace{\sin[(k + \frac{\Delta k}{2})x - (\omega + \frac{\Delta\omega}{2})t]}_{\text{sine wave}}$$



"Wave Packet"

Figure 2.1. Combination of two waves of slightly different frequencies. ΔX is the distance over which the particle can be found.

2. The Wave-Particle Duality

The extreme conditions

(a) No variation in angular frequency and wave number : monochromatic wave

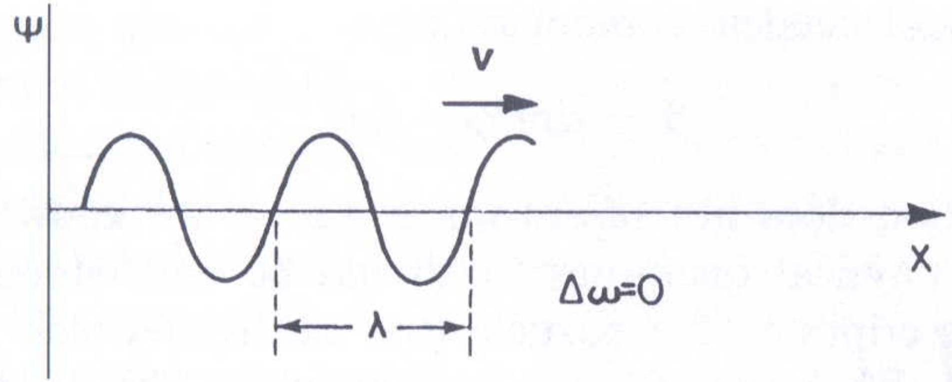


Figure 2.2. Monochromatic matter wave ($\Delta\omega$ and $\Delta k = 0$). The wave has constant amplitude. The matter wave travels with the phase velocity, v.

2. The Wave-Particle Duality

The extreme conditions

(b) Very large variation in angular frequency and wave number

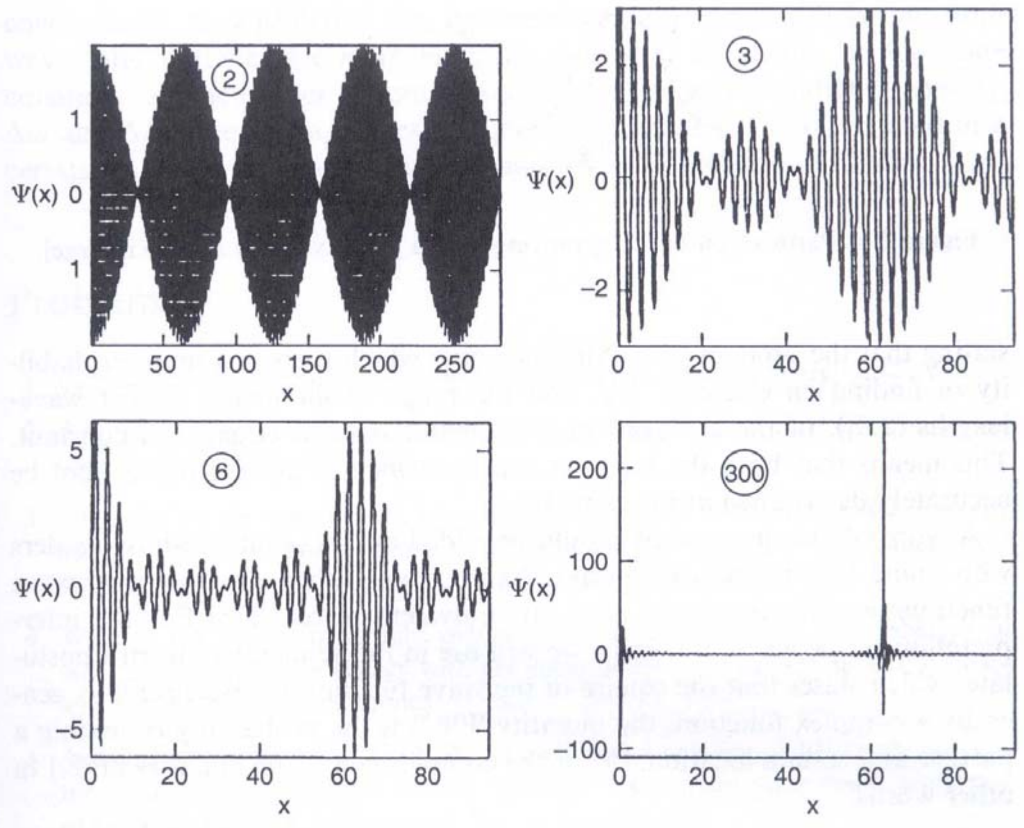


Figure 2.3. Superposition of Ψ-waves. The number of Ψ-waves is given in the graphs. (See also Fig. 2.1 and Problem 2.8.)

Phase velocity :

velocity of a matter wave

$$\upsilon = \frac{x}{t} = \frac{\omega + \Delta\omega/2}{k + \Delta k/2} = \frac{\omega'}{k'}$$

Group velocity:

velocity of a pulse wave

(i.e., a moving particle)

$$\upsilon_g = \frac{x}{t} = \frac{\Delta\omega}{\Delta k} = \frac{d\omega}{dk}$$

2. The Wave-Particle Duality

The extreme conditions

(b) Very large variation in angular frequency and wave number

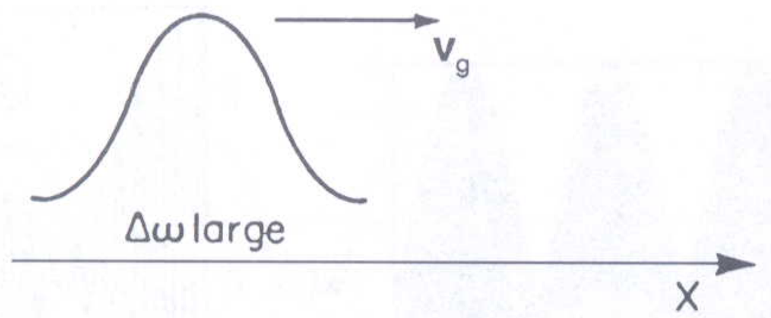


Figure 2.4. Particle (pulse wave) moving with a group velocity v_g ($\Delta\omega$ is large).

Heisenberg's Uncertainty principle $\Delta p \cdot \Delta X \geq h$

Probability of finding a particle at a certain location

$$\Psi\Psi^* dxdydz = \Psi\Psi^* d\tau$$