SPH1030

BASIC CONCEPTS IN PHYSICS II

A basic course for non-physicists assuming no prior knowledge of physics (although basic science and mathematics is required) that covers the principal ideas across the breadth of Physics, without going into the mathematical detail and worked examples that are usually associated with the subject. The second unit of this two-semester course covers Waves, Electromagnetism and Quantum Theory.

Waves

a. The wave equation. Propagation of waves
b. Sound and Light
c. Reflection and Refraction
d. Interference and Diffraction

Electromagnetism

a. Electric charge: flux, field and potential
b. Magnetic fields: the generator and dynamo effects
c. Electromagnetic waves
d. Current electricity: Ohm's and Kirchoff's Laws

Quantum Mechanics

a. Historical note: why quantum mechanics is "necessary"
b. Wave-particle duality: the uncertainty principle
c. The particle-in-a-box: confinement and tunelling
d. Applications: the Bohr atom, the photoelectric effect
e. Non-locality: the Aspect experiment: quantum entanglement

Recommended Texts:

Colletta et al, College Physics
Keller F J et al, Physics
Feynman, R, The Feynman Lectures in Physics

Further Reading:

Gribben J., In search of Schrodinger's Cat
Gribben J., Schrodinger's Kittens

WHAT ARE WAVES?

A WAVE IS AN OSCILLATORY MOTION THAT PROPAGATES THROUGH A MEDIUM.

IT IS THE VIBRATION THAT PROPAGATES, NOT THE MEDIUM.

WHY STUDY WAVES??

1. BECAUSE THEY'RE THERE

2. TECHNOLOGICAL USES
- RADIO, OPTICS, etc.

3. WAVE NATURE OF MATTER
(QUANTUM MECHANICS)

ANATOMY OF A WAVE

EACH PARTICLE VIBRATES ABOUT ITS MEAN POSITION

(LONGITUDINAL OR TRANSVERSE)

COUPLING **BETWEEN ADJACENT PARTICLES CAUSES PROPAGATION OF THE WAVE**

THE WAVE EQUATION

y - displacement of particle

x - position along direction of propagation of the wave

$$\frac{d^2 y}{dt^2} = c^2 \frac{d^2 y}{dx^2}$$

describes vibration of particle in time

describes how the vibration changes in space

speed of propagation of the wave (along x)

Plane waves

The simplest solution of the wave equation is that for a continuous plane wave:

$$y = A\cos(\omega t - kx)$$

[THE ARGUMENT OF THE COS IS IN RADIANS]

A **- THE AMPLITUDE OF THE WAVE (MAXIMUM DISPLACEMENT OF PARTICLES)**

ω **- THE ANGULAR FREQUENCY (THE MOTION REPEATS WHEN** $t = 2\pi/\omega$**)**

k **- THE WAVE NUMBER (THE MOTION REPEATS WHEN** $x = 2\pi/k$**)**

$$c = \omega / k$$

More usual definitions:

The *period* is the time for a particle to complete one oscillation.

$$T = 2\pi / \omega$$

The *frequency* is the number of cycles in unit time

$$f = 1/T = \omega / 2\pi$$

The *wavelength* is the distance over which the displacement of the particle completes one cycle

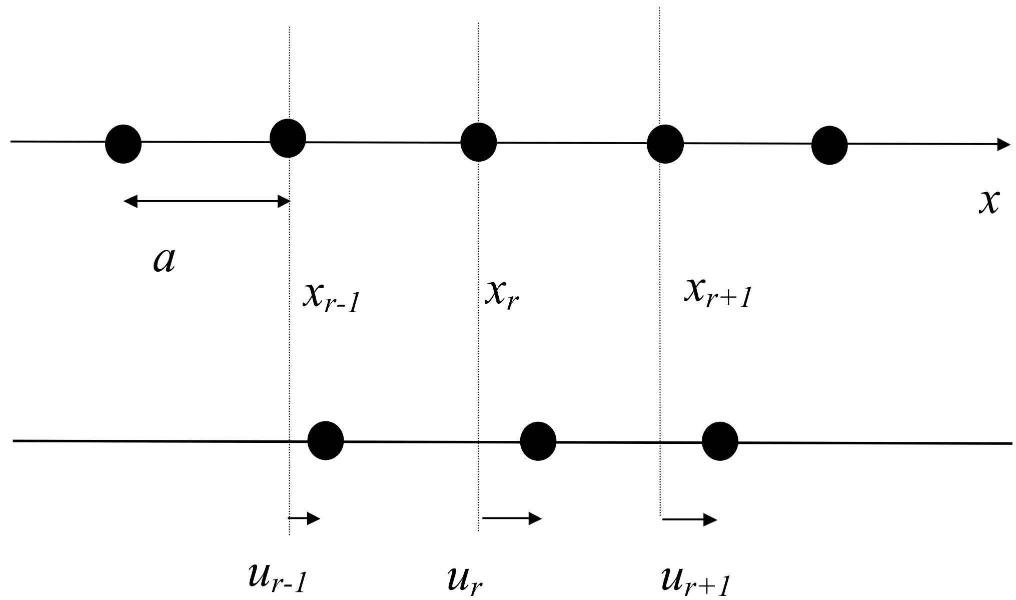
$$\lambda = 2\pi / k$$

The *velocity* of the wave is the distance the disturbance travels in unit time:

$$v = \lambda / T = f\lambda = \omega / k = c$$

Example of the wave equation:

atoms in a solid



Consider atoms of mass *m* joined together with "springs" of force constant *k*

Then the force on the r^{th} atom is:

$$F_r = k(u_{r+1} - u_r) - k (u_r - u_{r-1})$$

So, by Newton's Second Law:

$$m\frac{d^2u_r}{dt^2} = k\left[\left(u_{r+1} - u_r\right) - \left(u_r - u_{r-1}\right)\right]$$

Multiplying top and bottom by *a* gives:

$$m\frac{d^2u_r}{dt^2} = ka\left[\left(\frac{u_{r+1}-u_r}{x_{r+1}-x_r}\right) - \left(\frac{u_r-u_{r-1}}{x_r-x_{r-1}}\right)\right]$$

where the denominator is chosen so that the indices match those in the numerator (both quantities are equal to *a*)

If the limit is taken as *a* → 0, the terms in brackets are derivatives in x:

$$\frac{d^2u_r}{dt^2} = \frac{ka}{m}\left[\frac{du_{r+1}}{dx} - \frac{du_r}{dx}\right]$$

We can repeat the process:

$$\frac{d^2u_r}{dt^2} = \frac{ka^2}{m}\left[\frac{\frac{du_{r+1}}{dx} - \frac{du_r}{dx}}{x_{r+1}-x_r}\right]$$

Again, the term in brackets is a derivative, so:

$$\frac{d^2u_r}{dt^2} = \frac{ka^2}{m}\frac{d}{dx}\left(\frac{du_r}{dx}\right) = \frac{ka^2}{m}\frac{d^2u_r}{dx^2}$$

which is the wave equation.

This means that longitudinal waves can exist in the solid, and that their velocity is given by:

$$c = \sqrt{\frac{ka^2}{m}}$$

Measurements of the speed of sound in solids is in fact of great use in determining the values of the “spring constants” - the bond strengths - joining the atoms.