SECOND EDITION

ENGINEERING PHYSICS-II

(Strictly as per the Latest syllabus prescribed by Gautam Buddh Technical University, Lucknow)

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Dr. A.K. Katiyar
Narinder Kumar

ENGINEERING PHYSICS - II

For

B.E./B.Tech.

STRICTLY AS PER THE LATEST SYLLABUS PRESCRIBED BY U.P. TECHNICAL UNIVERSITY, LUCKNOW

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Contents

Preface to the Second Edition

This second edition of Engineering Physics-II book is designed strictly as per the new syllabus of UP Technical University. This book not only covers entire UPTU syllabus, but also gives complete information about the subject. The matter of the book is presented in such a simple and logistic manner that even a student belongs to poor background of subject can understand the subject easily. Authors feel that by reading this book, particularly engineering students, for whom this book is prepared can make themselves perfect in the field covered in the book.

The chapters of this book cover the subject matters of Wave Mechanics, X-ray Diffraction, Dielectrics, Magnetic Properties of Materials, Electromagnetic, Superconductivity and Nano-technology. Each chapter starts with basic knowledge and covers all information to be provided to readers. Topics are explained with knowledgeable examples and relevant numerical problems for better understanding. Looking the present pattern of question paper of the University, a large number of multiple choice questions with answers are given at the end of each chapter. This may also be treated by the students as a strong self evaluation exercise for examination point of view. A large number of solved and unsolved problems are backbone of the book.

Though we made every effort for the excellent presentation and error free book, even then some misprint/errors might be crept in. We shall be thankful for pointing out them and giving suggestions for further improvement.

—Authors

Preface to the First Edition

This book is prepared as per new course introduced in second semester for engineering students of UP Technical University. It will intend to satisfy the entire requirements of the students preparing for engineering physics-II. Some emerging topics like superconductivity and nanotechnology provide basic informative knowledge to readers. This book is the result of a long teaching experience of authors in this field. Hence presentation of the matter is thoroughly lucid and comprehensive. Way of expression is so simple that a student poor in background of the subject can also be benefited.

The salient features of the book are as under:

- The subject matter of each and every topic is quite rich in content.
- The accuracy of the subject matter as well as the accuracy of printing matter has been assured completely.
- A large number of multiple choice questions have been provided. This may be treated by the students as a strong self evaluation exercise for examination point of view.
- A large number of solved and unsolved problems are backbone of the book.

Although every effort has been made for the excellent presentation of the work, even we are open to suggestions for future incorporation.

—Authors

SYLLABUS

ENGINEERING PHYSICS - II

EAS-202

Unit-1 : Wave Mechanics and X-ray Diffraction

Wave-particle duality, de-Broglie matter waves, Phase and Group velocities, Davisson-Germer experiment, Heisenberg uncertainty principle and its applications. Wave function and its significance, Schrödinger's wave equation — particle in one dimensional box.

Diffraction of X-rays by crystal planes, Bragg's spectrometer, Compton's effect.

10 Hrs.

Unit-II : Dielectric and Magnetic Properties of Materials

Dielectric constant and Polarization of dielectric materials, Types of Polarization (Polarizability). Equation of internal fields in liquid and solid (One-Dimensional), Claussius-Mossotti Equation, Ferro and Piezo electricity (Qualitative), Frequency dependence of dielectric constant, Dielectric Losses, Important applications of dielectric material, Langevin's theory for dia and paramagnetic material, Phenomena of hysteresis and its applications.

Ultrasonic: Generation, detection and application of ultrasonics. **08 Hrs.**

Unit-III : Electromagnetics

Displacement Current, Maxwell's Equations (Integral and Differential Forms). Equation of continuity, EM-Wave equation and its propagation characteristics in free space and in conducting media, Poynting theorem and Poynting vectors. **06 Hrs.**

Unit-IV : Superconductivity and Science and Technology of Nanomaterials

Temperature dependence of resistivity in superconducting materials, Effect of magnetic field (Meissner effect), Type I and Type II superconductors, Temperature dependence of critical field, BCS theory (Qualitative), High temperature superconductors. Characteristics of superconductors in superconducting state, Applications of Superconductors.

Introduction to Nanomaterials—Basic principle of nanoscience and technology, creation and use of buckyballs, structure, properties and uses of Carbon nanotubes, Applications of nanotechnology. **06 Hrs.**

UNIT I

WAVE MECHANICS & X-RAY DIFFRACTION

This unit contains the following chapters:

1. Wave Mechanics
2. X-rays

1

Wave Mechanics

1.01 WAVE-PARTICLE DUALITY

(*i*) **Dual Nature of Radiation**

Different theories have been put forward at different times regarding the real nature of radiation and light. A successful theory would make the least possible assumptions, explain the existing facts and should be able to explain various other phenomena which are discovered later. On this test, no theory of light is really complete and successful.

(*a*) **Corpuscular theory.** Historically speaking, in the later half of the seventeenth century, Newton gave the '*corpuscular theory*' of light, according to which, light consists of tiny particles or corpuscles which are shot out by the luminous body. This theory quite satisfactorily explained rectilinear propagation, reflection, refraction etc. But it did not tackle the question as to how and why a candle light and a powerful arc light should send the same corpuscles of the same energy with the same velocity.

Further, on refraction, this theory suggests that light should travel faster in the denser medium, and slower in the rarer medium. This later on proved to be just the reverse. We now know that light travels *slower* in the denser medium than in a rarer medium. And again reflection was explained on the basis of repulsion of a light corpuscle by the reflecting surface while refraction was explained as due to attraction by the refracting medium. Thus, a medium could either attract or repel the corpuscle of light. But we all know that glass partially reflects and partially refracts light. How could glass then attract as well as repel the light corpuscle simultaneously ? To add to this confusion, Newton himself discovered that a thin oil film on water shows various colours. This phenomenon could not be explained on this theory. To cap it all, new phenomena of interference, diffraction, polarisation etc., could never be explained on the basis of corpuscular theory. So, Newton's corpuscular theory was discarded. After this, light began to be regarded as a wave phenomenon.

(*b*) **Huygens' theory.** A new theory by Christian Huygens was put forward. This was called the *wave theory*. An illuminated body sends out a disturbance in the form of a wave in the space. Huygens assumed the existence of a hypothetical medium ether, through which waves could pass. Later on, Maxwell modified the concept by stating that light consists of *electromagnetic waves* requiring no material medium. All the same, Maxwell's theory of light could explain rectilinear propagation, reflection, refraction etc., in addition to phenomena like interference, diffraction, polarisation etc.

(*c*) **Photon picture of light.** The wave theory held a firm ground till spectroscopy and photoelectricity came into picture. Lines of the spectrum are possible only when an electron jumps from a higher energy level to a lower energy level, releasing the difference of energy in the form of radiation of a definite frequency in 'packets' or discrete units called *quanta* (Its singular is quantum.).

Likewise a definite quantum of light radiation, called photon, is falling on a surface to release an electron. Thus, these and similar phenomena could *never* be explained on the basis of wave theory. The only way we can explain these phenomena is by assuming that light really consists of packets of energy called 'photons' having a definite frequency. So, we revert to the particle (corpuscle or quantum) aspect of the nature of radiation or light. This caused a lot of confusion, whether radiation has a particle nature or a wave nature.

(*d*) **Dual nature of light.** The confusion is resolved by the assumption that light has in fact *a dual nature*. In certain experiments, it behaves *only* as particles and in certain others, it behaves *only* as waves. One thing is certain that no experiment has ever been found in which light simultaneously behaves like both particles and waves. It is *either* this *or* that; and never this *and* that aspect. This is known as the Bohr's law of complimentarity of radiation.

At present, we reconcile ourselves to this dual aspect by asserting that when the radiation is emitted, it is in quanta. When it is transmitted, it is in waves; and finally when it is absorbed, it is again in quanta.

- ***In the later part of the 19th century and in the beginning of 20th century, it was realised that black body radiation and the photoelectric effect can be understood only on the basis of particle model of light.***
- ***Some experiments require light to be a wave while others require light to be a particle. This led to the acceptance of dual (particle and wave) nature of light.***

(*ii*) **Dual Nature of Matter/Matter Waves**

It is an established fact that radiation has a dual aspect behaving either as waves or as particles under suitable circumstances. A particle having a finite mass has been supposed to be associated with a definite amount of energy, given by Einstein in his mass-energy relationship, $E = mc^2$, where E is the energy associated with a particle of mass m, c being the velocity of light. On this basis, a wave has a particle aspect.

- ***In analogy with the behaviour of light, de Broglie proposed that all material particles should also show dual behaviour. The particle character of matter, e.g., electron, had been established from a number of experiments and its wave character was confirmed by diffraction and interference experiments. Many modern instruments like electron microscope are based on the wave nature of electrons. Neutrons, protons, hydrogen atoms and even C_{60} fullerene molecules have also been shown to possess wave character.***
- ***We have seen that light and other electromagnetic radiations have a dual nature i.e., wave and particle nature. Both these characters are instrumental in explaining the characteristics of these radiations. Inspired by this, Louis de Broglie, a French physicist in 1924 advanced a new idea by stating that all moving material particles (microscopic as well as macroscopic) have dual nature i.e., wave and particle nature. However, the wave associated with matter is known as matter wave with characteristics different from the electromagnetic wave. He co-related the two characters in the form of an equation known as de-Broglie Equation after his name.***

$$\lambda = \frac{h}{mv}$$

Here λ denotes the wave nature of the moving material object while mv (momentum) represents its particle nature.

In 1924, it was argued by the French physicist Louis de Broglie that if radiation has a dual aspect, why not think of particles of matter also as having this dual aspect ? Nature loves symmetry and if mass-energy symmetry is present for waves, then the same symmetry should be available for material particles. In simple words, what we know as material particles (like electrons, protons, neutrons etc.) should also behave like waves of a definite λ, under suitable conditions. Thus, particles may also behave as waves. This is *the dual nature of matter*. The waves which are associated with matter are called **matter waves** or **de-Broglie waves** after the name of the French scientist who gave us this idea. Experiments performed later on actually proved the duality of matter. We know that electrons are particles having a discrete mass and moving with a definite velocity. Sometimes, these behave like waves and produce diffraction patterns as was shown by Davisson and Germer; as also by Thomson. Thus, the concept of de-Broglie waves is not merely the flight of fancy of a scientist but actually in existence ! So we accept this duality of matter, as we accept the duality of radiation. It has to be noted that *Bohr's law of complimentarity* holds good here. This means that in no experiment, matter exists *both* as a particle and as a wave simultaneously. It is either one or the other aspect and not this and that aspect together ! The two aspects (wave and particle) are complimentary to each other.

1.02 De-BROGLIE WAVE EQUATION

According to Einstein relation of mass-energy equivalence, E = mc^2, where m is the mass of the particle and c is the velocity of light. Further, according to Planck's quantum theory, E = $h\nu$, where ν is the frequency of radiation and 'h' is Planck's constant. Combining the two, we get

$$E = h\nu = mc^2$$

But $c = \nu\lambda$ for waves. Thus, for a quantum of light (photon), we get

$$E = h \cdot \frac{c}{\lambda} = mc^2; \text{ giving us } \lambda = \frac{h}{mc}$$

The product of mass and velocity is the momentum p.

$$\therefore \qquad \boxed{\lambda = \frac{h}{p}}$$

Thus, a quantum (particle) having a momentum p is associated with a wavelength λ.

This relation was for a photon and it proved true experimentally. It now occurred to de Broglie that what is true for a photon, may also be true for a material particle of mass m moving with velocity v (not c).

$$\therefore \qquad \boxed{\lambda = \frac{h}{mv}} \qquad (\because \quad p = mv)$$

This means that a material particle of mass m moving with a velocity v, can be considered as a wave of length λ, given by the above relation. This is *de Broglie wave equation*. It firmly establishes the aspect of unity of matter ; since the momentum p can be associated only with a particle, while λ is associated only with a wave.

Discussion

(i) $\lambda \propto \frac{1}{v}$ *i.e.*, if $v = 0$, $\lambda = \infty$.

Thus, the matter waves are associated with material particles only if they are in motion. Moreover, the wavelength of a particle should decrease as its velocity increases.

(ii) $\lambda \propto \frac{1}{m}$. Smaller the mass of the particle, higher is the wavelength associated with it.

For a given velocity, heavier particles should have shorter wavelength than lighter particles. In the case of macroscopic objects such as a bullet or a ball, the de Broglie wavelength is so small that it cannot be measured directly by any known means.

(iii) $\lambda \propto \frac{1}{p}$. Larger the momentum of the particle, shorter is the wavelength.

(iv) Wavelength associated with a material particle is independent of the charge of the particle.

KNOWLEDGE PLUS

- $$\lambda \propto \frac{1}{p} \quad \text{or} \quad \text{Wave nature} \propto \frac{1}{\text{Particle nature}}$$

  Thus, we conclude that the wave and particle nature of the moving material objects are inversely proportional to each other.
- The experimental confirmation of the de-Broglie relation was obtained when Davisson and Germer observed that a beam of electrons is diffracted. The wavelengths of the electrons determined by the diffraction experiments were found to be in agreement with the values predicted by de Broglie relation.

Louis de-Broglie (1892-1987)

De Broglie, a French physicist, studied history as an undergraduate in the early 1910's. His interest turned to science as a result of his assignment to radio communications in World War I. He received his Dr. Sc. from the University of Paris in 1924. He was professor of theoretical physics at the University of Paris from 1932 until his retirement in 1962. He was awarded the Nobel Prize in Physics in 1929.

1.03 SIGNIFICANCE OF De-BROGLIE RELATIONSHIP

Although the dual nature of matter is applicable to all material objects but it is significant for microscopic bodies only. For large bodies, the wavelengths of the associated waves are very small and cannot be measured by any of the available methods. Therefore, practically these bodies are said to have no wavelengths. Thus, any material body in motion can have wavelength but it is measurable or significant only for microscopic bodies such as electron, proton, atom or molecule. This may be illustrated as follows :

The wavelength of an electron with mass 9.11×10^{-31} kg and moving with the velocity of 10^6 m s^{-1} is 7.28×10^{-10} m as shown below :

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{(9.11 \times 10^{-31} \text{ kg}) \times (10^6 \text{ m s}^{-1})}$$

$$= 7.28 \times 10^{-10} \text{ m} \qquad [\text{J} = \text{kg m}^2 \text{ s}^{-2}]$$

This wavelength associated with the moving electron is of the same order of magnitude as of X-rays which can be easily measured.

On the other hand, the wavelength associated with a ball, for example, weighing 10 g and moving with the same velocity as that of electron (10^6 m s^{-1}) is only 6.63×10^{-38} Å as shown below :

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}}{(10 \times 10^{-3} \text{ kg}) \times (10^6 \text{ m s}^{-1})} = 6.63 \times 10^{-38} \text{ m}$$

This wavelength is shorter than any electromagnetic radiation and cannot be measured by any known method. Therefore, it is difficult to grasp the idea of waves associated with the moving ball. In other words, we can say that the ball does not have waves associated with it. Similarly, the other large bodies are said to be associated with waves but their wavelengths are too small to be measured by any conceivable method.

1.04 LIMITATION OF De-BROGLIE EQUATION

It has been stated earlier that the de-Broglie equation or relationship must cover every moving object but in actual practice it is true only for microscopic particles such as electrons, protons, neutrons, atoms, ions etc. It has no relevance for moving semimicro and macro objects where particle character is very large and the wave character is negligible. In order to clarify this view point, let us apply this relation to a moving microparticle (say electron) and a moving macroparticle (say a ball weighing 100 g or 0.1 kg) both travelling with the same speed *e.g.* 10^5 m s^{-1}. Let us calculate the wavelength in both the cases.

For electron :

$$\lambda = \frac{h}{mv} = \frac{(6.626 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1})}{(9.11 \times 10^{-31} \text{ kg}) \times (10^5 \text{ m s}^{-1})}$$

$$= 7.27 \times 10^{-9} \text{ m}$$

For ball :

$$\lambda = \frac{h}{mv} = \frac{(6.626 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1})}{(0.1 \text{ kg}) \times (10^5 \text{ m s}^{-1})}$$

$$= 6.626 \times 10^{-38} \text{ m}$$

The wavelength of the electron wave is within the range of the electromagnetic waves and can be measured. However, the wavelength of the wave associated with the ball is very small as compared to any of the known electromagnetic waves. Therefore, it is not possible to measure the same. Thus, practically an electron has a wave character while no such character is associated with a ball which signifies a moving macroscopic or macro particle. The same is also true for the moving semimicro particles although their mass is small as compared to the macro particles.

> ***Practically, de-Broglie relation can be applied only to the moving microscopic particles including electrons, protons, atoms, small molecules etc. while it has no relevance for the moving semimicro or macroparticles.***

1.05 DERIVATION OF BOHR'S POSTULATE OF QUANTISATION OF ANGULAR MOMENTUM FROM De-BROGLIE RELATION

This postulate gives the quantum condition that only such orbits are permitted in which the angular momentum of the electron is an integral multiple of $h/2\pi$. In mathematical language, for a permitted stationary orbit, the condition

$$mvr = \frac{nh}{2\pi}$$

must be satisfied. Here, n is an integer known as the principal quantum number. De Broglie gave the theory that such permitted orbits can exist only when the orbit's circumference equals an integral multiple of the wavelength of the electron. There is a stationary wave system for the de Broglie waves for an electron in that orbit and the orbit must contain a whole number of electron waves (Fig. 1.1). Thus, in the diagram, we have a permitted stationary orbit for an electron where $n = 3$. The whole circumference of the orbit is equal to three complete waves of wavelength λ given by the de Broglie relation. Thus in a permitted orbit, we must have

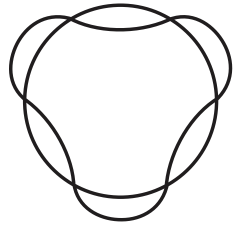

Fig. 1.1

$$2\pi r = n\lambda$$

de-Broglie wavelength, $$\lambda = \frac{h}{mv}$$

Equating $$2\pi r = n\frac{h}{mv} \quad \text{or} \quad m\,vr = n\,\frac{h}{2\pi}$$

This is the same condition as given by Bohr's quantum postulate. So, we note that the concept of de Broglie waves is fully reconciled with the observed quantum conditions of the Bohr's model of hydrogen atom. Later experiments by Thomson and also by Davisson and Germer have conclusively established the truth of the existence of de Broglie waves in nature.

Niels Bohr, a Danish physicist received his Ph.D. from the University of Copenhagen in 1911. He then spent a year with J.J. Thomson and Ernest Rutherford in England. In 1913, he returned to Copenhagen where he remained for the rest of his life. In 1920 he was named Director of the Institute of theoretical Physics. After first World War, Bohr worked energetically for peaceful uses of atomic energy. He received the first Atoms for Peace award in 1957. Bohr was awarded the Nobel Prize in Physics in 1922.

Niels Bohr (1885-1962)

1.06 De-BROGLIE WAVELENGTH IN TERMS OF ABSOLUTE TEMPERATURE

We know that $$\lambda = \frac{h}{mv}$$

or $$\lambda = \frac{h}{p}$$

Now $$E_k = \frac{1}{2}mv^2 = \frac{m^2v^2}{2m} = \frac{p^2}{2m}$$

or $$p = \sqrt{2m\,E_k}$$

$\therefore$ $$\lambda = \frac{h}{\sqrt{2m\,E_k}}$$

In thermal equilibrium state, at temperature T, the kinetic energy associated with a particle is of the order of $\frac{3}{2}k_B T$, where k_B is Boltzmann's constant.

$\therefore$ $$\lambda = \frac{h}{\sqrt{2m\frac{3}{2}k_B T}} \quad \text{or} \quad \lambda = \frac{h}{\sqrt{3m\,k_B T}}$$

1.07 De-BROGLIE WAVELENGTH OF AN ELECTRON WAVE (NON-RELATIVISTIC CASE)

Consider an electron accelerated through a potential difference of V volt. According to work-energy principle, work done (eV joule) on the electron must be equal to the gain of kinetic energy $\left(\frac{1}{2}mv^2\right)$ of the electron.

$\therefore$ $$eV = \frac{1}{2}mv^2 \quad \text{or} \quad v = \sqrt{\frac{2eV}{m}}$$

Now, de-Broglie wavelength associated with moving electron is given by :

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{h}{\sqrt{2meV}}$$

Putting $h = 6.62 \times 10^{-34}$ Js, $m = 9.1 \times 10^{-31}$ kg and $e = 1.6 \times 10^{-19}$ C, we get

$$\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times V}}\ \text{m}$$

or $$\lambda = \frac{12.27 \times 10^{-10}}{\sqrt{V}}\ \text{m} \quad \text{or} \quad \lambda = \frac{12.27}{\sqrt{V}}\ \text{Å}$$

1.08 DISTINCTION BETWEEN WAVE AND PARTICLE

A particle always occupies a well-defined and specific position in space which cannot be simultaneously occupied by another particle. If there are more than one particles in a given region of space, then their sum is equal to the number of individual particles. The sum can neither be more nor less.

On the other hand, a wave is spread out or delocalised in space. Unlike particles, two or more waves can co-exist in the same region. Two or more waves can even superimpose to form a resultant wave. The resultant wave can be larger or smaller than the individual waves.