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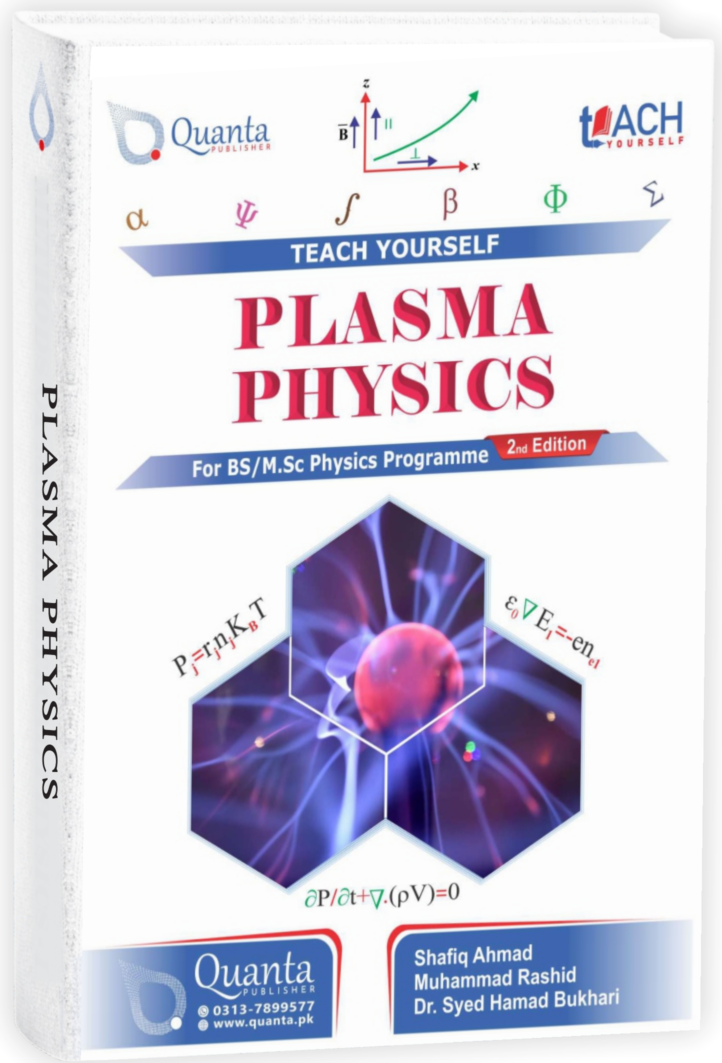

TEACH YOURSELF

PLASMA PHYSICS

2nd Edition

For **BS/M.Sc Physics** students of all Pakistani Universities.

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Chapter 1

Introduction to Plasma

Introduction

1. It is estimated that 99% of the matter in observable universe is in the plasma state. We live in 1% of the universe in which plasma do not occur naturally.
2. Unlike gases, liquid and solid, plasma does not contain molecules instead it is a gas that is composed of ions (see Fig (1.1)).
3. Plasma is the fourth state of matter which is not purely in solid form, not in gas form.
4. Plasma exists at very high temperature.
5. Ionization is used to form plasma. Ions and electrons formed in plasma by ionization process by giving external energy to the medium then electron start to move freely.
6. Plasma consists of heavy ions and lighter electrons which move fastly because there mass is less than the mass of ions.
7. Plasma is highly conducting due to free electrons.
8. Due to movement electric field produced. Due to electric field, it respond to the magnetic field of earth due to which path of conduction changes.
9. High temperature generates the plasma. Plasma changes due to temperature.
10. When the temperature of gas and plasma increased up to the level of ionization, hot plasma is produced.
11. If only the small fraction of gas molecules are ionized and electricity is used as energy source of the ionization then cold plasma is produced.

Chapter 2

Single Particle Motion

2.1 Motion of Charge Particles in Static Uniform Magnetic Field

Once current if flowing through a coil, a uniform magnetic field will exist all along inside the coil. We study the motion of single particle in electric field E and and magnetic field B. Plasma behave like a fluid or gas, but because of charged particles present in plasma it responds to, and generates electromagnetic force as well as collection of individual particles.

Case-I

When we supply electric field to charged particles, then there is an electric force $F = qE$. Lorentz force is the combination of both electric field E and and magnetic field B, then

$$F = q\left(E + \left(V \times B\right)\right)$$

If $B = 0$ then,

$$F = qE \tag{2.1}$$

Also,

$$F = m\,a \quad \Rightarrow \quad F = m\frac{dV}{dt} \tag{2.2}$$

By comparing Eq.(2.1) and Eq.(2.2),

Chapter 3

Plasma as Fluid

3.1 Plasma Response to Field and Fluid Model

When phase velocity of a wave excited in a plasma is larger then thermal velocity, the main body of plasma particles are out of resonance with wave and the number of resonant (abnormal large vibration is produced) particles which exchange the energy with the wave is small, in this case treated as fluid.
We study plasma as a whole system e.g. fluid, then we check the response of electric field and magnetic field by the fluid model.

Fields

Two fields, electric field (E.F) and magnetic field (M.F). It is also includes external, internal, self generated fields. Now we check how the plasma response to all these fields.

Set of Equations and Formula

Fluid model mainly consist of four set of equations.

1. Equation of motion/Momentum conservation equation.
2. Continuity equation.
3. Momentum loss via collision.
4. Equation of states

Single particle → Collisionless motion.
Whole system → Collision occur and momentum loss.

Chapter 4

Plasma in Waves

4.1 Representation of Waves

Any periodic motion of fluid can be decomposed by Fourier analysis into two components

1. Superposition of sinusoidal oscillation with different frequencies ω.
2. Wavelength λ.

Here we consider the sinusoidal oscillations. When the oscillation amplitude is small, the waveform is generally sinusoidal and there is only one component. Let any sinusoidal oscillating quantity, the density n can be represented as follows,

$$n = \bar{n}\exp[i(k - r - \omega t)] = n\,e^{i(k.r-\omega t)}$$

Where $\bar{n}$ = amplitude of wave and k = propagation constant. Where in cartesian coordinates.

$$\begin{aligned} k\,.\,r &= k_x x + k_y y + k_z z \quad (\text{in } 3-D) \\ n &= n\,e^{i(k_x x + k_y y + k_z z - \omega t)} \\ k\,.\,r &= k_x x \qquad\qquad\qquad (\text{in } 1-D) \end{aligned}$$

Where n is amplitude of wave and k is propagation constant. If the wave propagation on x-direction $n = n\,e^{i(kx-\omega t)}$, the exponential term can be written as,

$$n = \overline{n}[\cos(kx - \omega t) + i\sin(kx - \omega t)]$$

Chapter 5

Plasma Confinement

5.1 Introduction to Controlled Fusion

Extremely high temperatures are required for a nuclear fusion reaction to occur. The temperature inside the sun and the stars is $10^8 - 10^9$ K. Hence the atoms are completely ionized and matter exists in the plasma state. When nuclei moving with very high velocities collide, they combine with the release of a large amount of energy. Fusion reactions taking place at such high temperatures are called thermonuclear fusions.
The Sun is known to be mainly made of hydrogen and helium (90%) in about equal proportions. If by some suitable series of nuclear reactions, four hydrogen nuclei combine to produce one helium nucleus, then the energy release for each such fusion will be

$$E = 4M_H - M_{He} = 4 \times 1.007825 - 4.002603$$

$$= 0.028697\, U = 26.73\, MeV = 4.28 \times 10^{-12}\, J$$

Since each kilogram of hydrogen contains 6×10^{26} protons, the energy content of such a source will be about 2.4×10^{15} J/kg, which could liberate energy at the rate of 2×10^{-4} J/kg for 10^{12} Y. So the nuclear reactions leading to the fusion of four hydrogen nuclei to produce one helium nucleus could be adequate for the energy production in the sun.
R. Atkinson and F. Houtermans (1928) were the first to suggest that the successive capture of four protons by some light nuclei to produce an alpha particle might be the processes which would release energy at reasonable rates for the sun to continue burning


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