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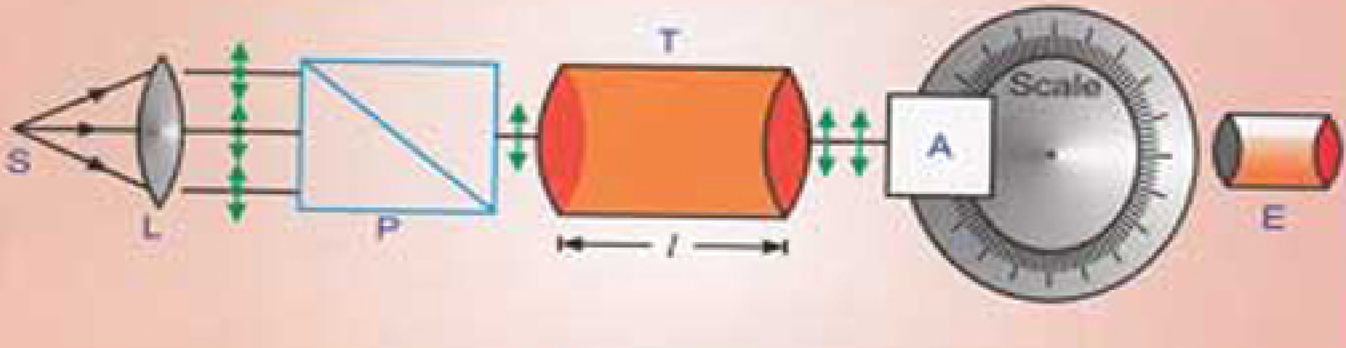
OF SOLAPUR UNIVERSITY, SOLAPUR

OPTICS

B. Sc. PART-II • PHYSICS • PAPER-V • SEMESTER-IV

Dr. R. N. MULIK
S. D. CHAVAN
Dr. S. G. HOLIKATTI
Dr. B. T. RAUT
Dr. S. G. PAWAR



Polarimeter

NIRALI PRAKASHAN
ADVANCEMENT OF KNOWLEDGE

A TEXT BOOK OF

PHYSICS

Optics

(Paper - VII)

FOR

B.Sc. Part - II : Semester - IV

As Per New Revised Syllabus (CBCS Pattern) of Solapur University, Solapur, June 2017

Dr. R. N. Mulik
M.Sc., B.Ed., M.Phil., Ph.D.
Head, Department of Physics,
D.B.F. Dayanand College of
Arts and Science,
Solapur

Dr. S. G. Holikatti
M.Sc., B.Ed., Ph.D.
Department of Physics,
Walchand College of
Arts and Science,
Solapur

Dr. S. D. Chavan
M.Sc., Ph.D.
Department of Physics,
D.B.F. Dayanand College of
Arts and Science, Solapur

Dr. B. T. Raut
M.Sc., M.Phil., Ph.D.
Department of Physics,
K.B.P. Mahavidyalay,
Pandharpur.

Dr. C. V. Chanmal
M.Sc., Ph.D., SET
Department of Physics,
D.B.F. Dayanand College of
Arts and Science, Solapur.

Dr. S. G. Pawar
M.Sc., Ph.D.
Department of Physics,
D.B.F. Dayanand College of
Arts and Science, Solapur.

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Email : niralipune@pragationline.com

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Tel : (020) 24690204 Fax : (020) 24690316
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Tel : (022) 2385 6339 / 2386 9976, Fax : (022) 2386 9976
Email : niralimumbai@pragationline.com

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PREFACE

We, the authors are pleased to present this text book of Physics (Optics) for B.Sc. II, Solapur University, Solapur, for Semester IV in the market and care, therefore, has been taken, while preparing the text book, that it caters the needs not only of the students and teachers concerned, but it also creates interest and inquisitiveness about the subject in any person, who lays hand on it.

This book has been written strictly according to the guidelines of the revised syllabus (CBCS Pattern) of B.Sc. II Physics (Optics) prescribed by Board of Studies in Physics, Solapur University, Solapur. It is our humble belief that the text books are among the invaluable resources for successful teaching – learning process, provided they are written within the framework of the aims and objectives laid down and hence this book is really the honest efforts in that direction.

Much more attention has been paid in simplifying the topics and presenting them in a simple and scientific language. Each concept is lucidly explained and supported by self-explanatory diagrams. A few examination oriented problems have been solved in every topic and few are given for practice. The key statements, laws, principles and definitions are printed out from the rest of the matter. As per the nature of university question paper, number of multiple choice questions, short and long answer type questions are included for self testing. Every attempt has been made to make the matter easily readable and readily understandable. In fact, the book has been written out of a prolonged teaching experience.

Every care has been taken to check the mistakes and misprints, yet it is very difficult to claim perfection. Any errors, omission and suggestions for the improvement of this text book, if brought to our notice will be thankfully acknowledged and incorporated in the next edition.

Authors are very much thankful to Shri. Dineshbhai Furia of Nirali Prakashan and Shri. M. P. Munde whose inspiration and constant prompting are responsible for producing this text book in short period. Authors are also very much thankful to Shri. Jignesh Furia who have contributed quite a lot for this publication. We reserve special thanks to Shri. Prabhakar D. Nandkile and Kiran Velankar for active help throughout this work. In fact entire staff of Nirali Prakashan especially Mr. Santosh Bare and Mrs. Prachi Sawant has put in a lot of efforts for the publication of this book. Authors are thankful to all those who have contributed and helped during compilation of this book.

We hope this book will receive spontaneous response from teachers and students.

Authors

NATURE OF THEORY QUESTION PAPER FOR NEW CBCS SEMESTER PATTERN
(With effect from June 2017)

Time : 2 hrs 30 min. **Total Marks : 70**

Q. No. 1 Choose and write a correct answer from given four alternatives : (14)

1. ....
   (a) .... (b) .... (c) .... (d) ....
2. …do…
3. …do…
4. …do…
5. …do…
6. …do…
7. …do…
8. …do…
9. …do…
10. …do…
11. …do…
12. …do…
13. …do…
14. …do…

Q. No. 2 Answer any seven of the following : (14)

(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)

Q. No. 3 (A) Attempt any two of the following : (10)

(1)
(2)
(3)

(B) Solve an example/short answer question : (04)

Q. No. 4 Solve any two of the following : (14)

(1)
(2)
(3)

Q. No. 5 (A) Answer any one of the following long answer questions :

(1) Long answer question/question of derivation **(10)**
Example on the above long answer question **(04)**
(2) Long answer question/question of derivation **(10)**
Example on the above long answer question **(04)**

N.B. :

1. Two numericals based sub-questions in question number one.
2. At least one mathematical example of 2 marks in question number two.
3. One mathematical example of 5 marks in both question number 3A.
4. One mathematical example of 7 marks may be in question number 4.

●●●

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❑❑❑

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CHAPTER

CARDINAL POINTS

INTRODUCTION

Optics is a branch of physics which deals with the study of light energy and various phenomena associated with the light energy such as reflection, refraction, interference etc.

Optics is divided into three branches :

(i) **Geometrical optics :** The geometrical optics which deals with the image formation by mirrors, lenses and prism.

(ii) **Physical optics :** The physical optics which deals with the study of nature of light. We study the phenomena like reflection, refraction etc.

(iii) **Quantum optics :** The quantum optics deals with the study of light with atomic and nuclear particles.

1.1 LAGRANGE'S EQUATION

Consider a spherical surface separating the two media of refractive indices μ_1 and μ_2. Let C be the centre of curvature of the spherical surface LM and P be the pole on the surface LM. The points F_1 and F_2 are two principal focii on the line OPC. The line OPC is the principal axis of the given spherical surface LM as shown in Fig. 1.1.

Let OO' in a small object having size y_1 is placed perpendicular to the axis be the medium of refractive index μ.

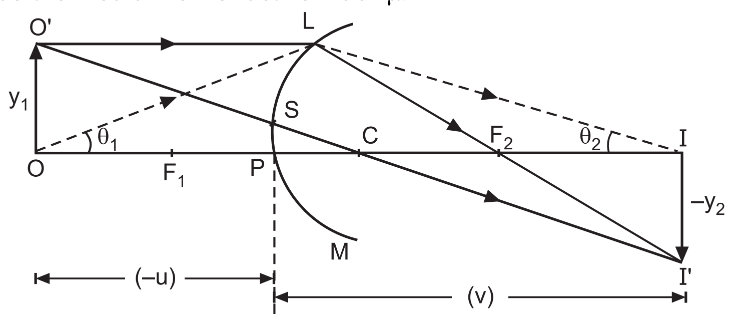


Fig. 1.1

Consider the incident ray OL, after refraction it travels in a medium of refractive index μ_2 along LI. I is the image of the object O on the principal axis. Let O'L be the incident ray parallel to the principal axis which after refraction passes through F_2. LF_2 represents the corresponding refracted ray.

Consider another incident ray O'S directed towards the centre of curvature i.e. point C, it passes without suffering any refraction and intersect at point I'. Hence II' represents the image of OO'. The lateral magnification is given by

Lateral magnification,

$$m = \frac{\text{Size of a image}}{\text{Size of an object}}$$

$$= \frac{II'}{OO'} = \frac{-y_2}{y_1} \qquad \ldots (1.1)$$

From the theory of refraction at the spherical surface and the geometry of Fig. 1.1, it can be shown that

$$\text{Lateral magnification} = \frac{\mu_1}{\mu_2} \times \frac{v}{u}$$

As $u = -u$

$$\therefore \quad m = \frac{\mu_1}{\mu_2} \times \frac{v}{(-u)} \qquad \ldots (1.2)$$

Consider the refraction of ray OL. If θ_1 and θ_2 are angles made by OL and LI with the principal axis then angular magnification is given by

$$\text{Angular magnification } (\alpha) = \frac{\tan \theta_2}{\tan \theta_1} \qquad \ldots (1.3)$$

We assume that the size of object is very small i.e. the point L is near the axis.

$$\therefore \quad \tan \theta_1 = \frac{PL}{PO} \qquad \ldots (1.4)$$

$$\text{and} \quad \tan(-\theta_2) = \frac{PL}{PI} \qquad \ldots (1.5)$$

Since θ_2 is clockwise, hence taken as –ve.

By using equations (1.4) and (1.5) in equation (1.3), we get

$$\text{Angular magnification } \alpha = \frac{-\left(\frac{PL}{PI}\right)}{\left(\frac{PL}{PO}\right)} = \frac{-PO}{PI} = \frac{-(-u)}{(v)} = \frac{u}{v}$$

$$\therefore \qquad \alpha = \frac{\tan \theta_2}{\tan \theta_1} = \frac{u}{v} \qquad \ldots (1.6)$$

Substituting equation (1.6) in equation (1.2), we get

Lateral magnification,

$$m = \frac{\mu_1}{\mu_2} \times \frac{(-\tan \theta_1)}{\tan \theta_2}$$

$$\therefore \qquad \frac{-y_2}{y_1} = \frac{\mu_1}{\mu_2} \times \frac{(-\tan \theta_1)}{\tan \theta_2}$$

$$\therefore \qquad \frac{y_2}{y_1} = \frac{\mu_1}{\mu_2}\left(\frac{\tan \theta_1}{\tan \theta_2}\right)$$

$$\text{Hence,} \qquad \mu_1 y_1 \tan \theta_1 = \mu_2 y_2 \tan \theta_2 \qquad \ldots (1.7)$$

This equation is known as Lagrange's equation or Lagrange's law.

If θ_1 and θ_2 are smaller then $\tan \theta \approx \theta$.

$$\therefore \qquad \mu_1 y_1 \theta_1 = \mu_2 y_2 \theta_2$$

1.2 CARDINAL POINTS OF AN OPTICAL SYSTEM

In the derivation of various lens formulae, the lens is assumed to be thin, but in case of a thick lens or a system of lenses (two or three in contact), the assumption is no more true and hence the lens formulae cannot be used.

The scientists Gauss and Listing in 1841 solved this difficulty and proved that thick lens can be treated as a single unit and same formulae of a thin lens can be applied by introducing a three pairs of points and these are :

(i) the pair of principal focii and focal planes,

(ii) the pair of principal points and principal planes,

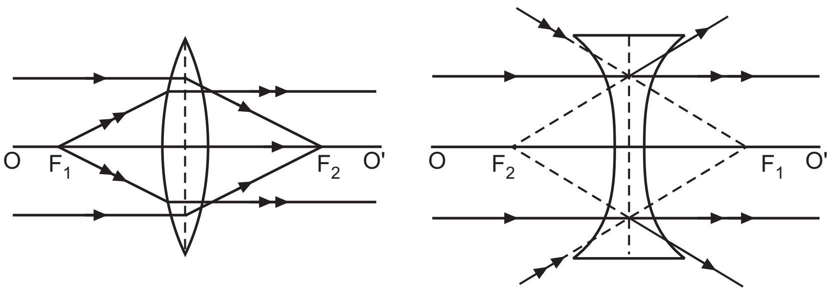
(iii) the pair of Nodal points and Nodal planes.

Thus there are six such fixed points known as cardinal points of an optical system.

(i) Principal focii and focal planes :

Let us consider an optical system consisting of a thick lens or a number of co-axial lenses either in contact or separated by some distance having its axis OO'.

A set of rays incident on the system parallel to the axis, on refraction through the system converges to (for a converging system) or appears to diverge from (for a diverging system) an axial point F_2 on the axis. This point F_2 is called the second principal focus.



(a) Converging system **(b) Diverging system**

Fig. 1.2

In a similar way, if the rays starting from (for a converging system) or directed towards (for a diverging system) an axial point F_1, after refraction through the system become parallel to the axis OO' then such a point F_1 is called first principal focus.

The two points F_1 and F_2 are called the principal focii or focal points and the planes passing through the principal focii and perpendicular to the axis are called focal planes.

(ii) Principal points and principal planes :

Consider a thick lens having its principal focii F_1 and F_2. The ray AB is incident at B parallel to the principal axis OO', after refraction emerges along BC and the ray passes to the second principal focus F_2. The incident and emergent ray when produced backward intersect at H_2.

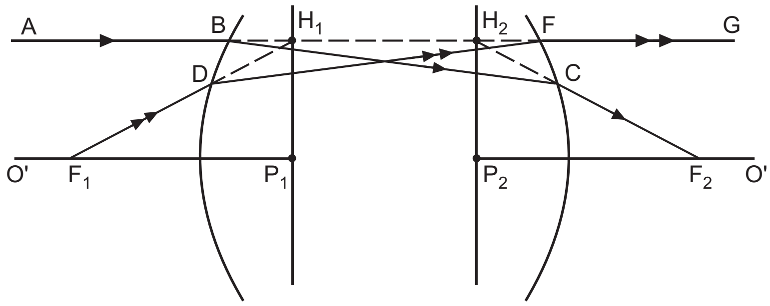


Fig. 1.3

The plane passing through H_2 and perpendicular to the principal axis OO' is termed as second principal plane of a lens. The point of intersection of this plane with the axis at P_2 is called second principal point (P_2).

Consider another ray F_1D through the first principal focus F_1 incident at D, after refraction, it emerges along EG parallel to the axis OO'. The rays F_1D and EG when produced intersect at H_1. The plane perpendicular to the principal axis OO' passing through H_1 is called the first principal plane of a lens. The point of intersection of this plane with the axis at P_1 is called first principal point (P_1).

From Fig. 1.3, we see that any incident ray (AB or F_1D) directed towards H_1 appears to come from H_2 after refraction. Therefore, H_2 is the image of H_1. Hence H_1 and H_2 are the conjugate points and the planes H_1P_1 and H_2P_2 are pairs of conjugate planes.

$$\therefore \qquad H_1P_1 = H_2P_2$$

$$\text{Hence the lateral magnification} = \frac{\text{Height of the image}}{\text{Height of the object}} = \frac{H_2P_2}{H_1P_2} = +1$$

Thus the principal plane have lateral magnification = + 1.

Properties :

(1) They are two conjugate planes of unit positive lateral magnification.

(2) The distance P_1F_1 represents the first principal focal length denoted by F_1 and the distance P_2F_2 represents the second principal focal length denoted by F_2.

(iii) Nodal points and Nodal planes :

Nodal points are defined as a pair of conjugate points on the axis having a unit positive angular magnification. It means that a ray of light directed towards one of these points, after refraction through the optical system appears to proceed at the second point in a parallel direction as shown in Fig. 1.4.

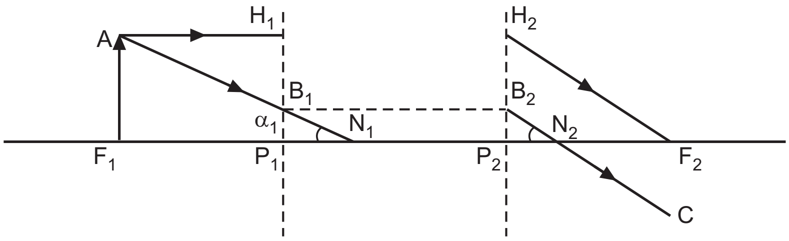


Fig. 1.4

Consider a point in a first focal plane of an optical system. One ray AH_1 is parallel to the axis. Its conjugate ray emerges along H_2F_2 such that

$$H_1P_1 = H_2P_2$$

Another ray AB_1 is parallel to H_2F_2, its conjugate ray B_2C originates from B_2 such that $B_1P_1 = B_2P_2$. B_2N_2 is parallel to H_2F_2. The point of intersection of incident AB_1 and its conjugate emergent ray B_2C with the axis are called the nodal points N_1 and N_2. The planes passing through nodal points perpendicular to the axis are called nodal planes.

Consider $\angle B_1N_1P_1$ and $\angle B_2N_2P_2$.

$$\angle B_1P_1N_1 = \angle B_2P_2N_2 = 90°$$

$$B_1P_1 = B_2P_2 \text{ and } \angle B_1N_1P_1 = \angle B_2N_2P_2$$

$$\therefore \quad P_1N_1 = P_2N_2$$

Add N_1P_2.

$$\therefore \quad P_1N_1 + N_1P_2 = P_2N_2 + N_1P_2$$

$$\therefore \quad P_1P_2 = N_1N_2$$

Thus the distance between the principal points P_1P_2 is equal to the distance between the nodal points N_1N_2.

Again consider $\Delta\, AF_1N_1$ and $\Delta\, H_2P_2F_2$.

$$AF_1 = H_2P_2$$

$$\angle AN_1F_1 = \angle H_2F_2P_2 \text{ and } \angle AF_1N_1 = \angle H_2P_2F_2$$

$\therefore$ $F_1N_1 = P_2F_2$

But $F_1N_1 = F_1P_1 + P_1N_1$

$\therefore$ $F_1P_1 + P_1N_1 = P_2F_2$

$\therefore$ $P_1N_1 = F_2P_2 - F_1P_1 = P_2N_2$

As $P_1N_1 = P_2N_2$

But $P_2F_2 = F_2$ and $P_1F_1 = -F_1$

where F_1 and F_2 are first and second focal lengths.

$\therefore$ $P_1N_1 = P_2N_2 = F_1 + F_2$

If the medium on the two sides of the system is same then $F_2 = -F_1$ or $F_1 + F_2 = 0$.

Hence, $P_1N_1 = P_2N_2 = 0$

Thus if the medium on the two sides of an optical system is same then principal points coincide with the nodal points.

1.3 AND 1.4 GRAPHICAL CONSTRUCTION OF IMAGE AND NEWTON'S FORMULA

The cardinal points are only sufficient for the construction of the image corresponding to an object. They are not sufficient to know the position and curvature of the refracting surface.

Consider the optical system and is represented by two principal focii F_1 and F_2, two principal points P_1 and P_2 and two nodal points N_1 and N_2. Let AB be an object of height h_1. Fig. 1.5 gives the graphical construction of the image using the properties of cardinal points.

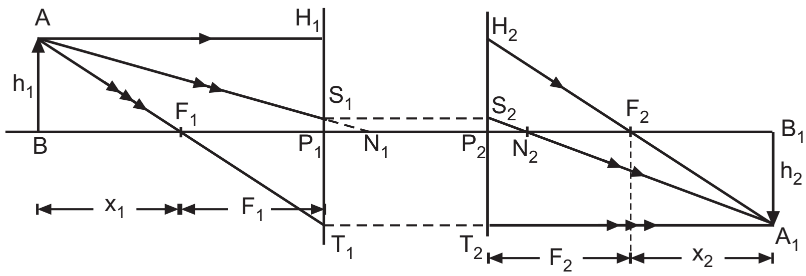


Fig. 1.5 : Graphical construction of image

(1) Draw a ray AH_1 parallel to the axis meeting the first principal plane P_1H_1 at H_1.

$\therefore$ $AB = P_1H_1 = h_1$.

Its conjugate ray will proceed from point H_2 in second principal plane at height h_1 and will pass through the second principal focus F_2 at A_1.

(2) Draw another ray AS_1N_1 directed towards the first nodal point N_1, it intersects the first principal plane in S_1. Its conjugate ray proceeds from S_2 and pass through second nodal point N_2 to meet at A_1.

(3) Draw a third ray AF_1 through the first principal focus F_1. It intersects the first principal plane in T_1, its conjugate ray proceeds from the point T_2 such that $P_1T_1 = P_2T_2$ and it goes parallel to the axis and meet at A_1. Thus A_1 is the image of the object A.

Hence $AB = h_1$ = height of the object and $A_1B_1 = h_2$ = height of the image. As $P_1F_1 = F_1$ = first focal length and $P_2F_2 = F_2$ = second focal length.

Proof of Newton's formula :

Let $BF_1 = x_1$ and $B_1F_1 = x_2$

$\Delta\ ABF_1$ and $\Delta\ T_1P_1F_1$ are similar.

$$\therefore \quad \frac{AB}{T_1P_1} = \frac{BF_1}{P_1F_1}$$

$$\frac{h_1}{h_2} = \frac{x_1}{F_1} \qquad \dots (1.8)$$

Similarly, $\Delta\ A_1B_1F_2$ and $\Delta\ H_2P_2F_2$ are similar.

$$\therefore \quad \frac{H_2P_2}{A_1B_1} = \frac{P_2F_2}{B_1F_2}$$

$$\therefore \quad \frac{h_1}{h_2} = \frac{F_2}{x_2} \qquad \dots (1.9)$$

From equations (1.8) and (1.9), we get

$$\frac{x_1}{F_1} = \frac{F_2}{x_2}$$

$$\therefore \quad x_1x_2 = F_1F_2$$

This is the Newton's formula.

If the medium on both sides of the system is same then $F_1 = F_2 = F$.

$$\therefore \quad x_1x_2 = F^2$$