普通高等教育“十二五”规划教材

光电信息科学与工程类专业规划教材

光电信息科学与工程

专业英语教程

张 彬 主编

電子工業出版社
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北京 • BEIJING

内 容 简 介

本书主要介绍光电类专业基本词汇和语法，并结合本专业有关几何光学、波动光学、信息光学及技术、激光原理及技术、光纤通信原理及技术、光电子器件、光电子技术等方面专业知识，培养学生专业文献阅读、翻译与科技论文写作的基本技能。

本书既可作为光学、光信息科学与技术、光电子技术、光电信息工程等专业本科生和硕士生的专业英语教材，也可供从事相关专业工作的工程技术人员参考。

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前　言

本书主要针对光学、光信息科学与技术、光电子技术、光电信息工程等专业本科生和硕士生开设专业英语课程而编写，旨在使学生掌握基础专业词汇、提高专业文献的阅读和翻译能力，拓展和深化学生对本学科专业基础知识和相关技术的了解和认识。

全书由 7 个主题单元组成，内容涵盖几何光学、波动光学、信息光学及技术、激光原理及技术、光纤通信原理及技术、光电子器件、光电子技术等领域。书中课文主要选自相关专业的英文原版教材、专著及专业文献。每单元后面列出了课文中新出现的专业词汇，以供学生积累专业词汇。此外，每单元最后还介绍了科技英语阅读与翻译的相关知识，以帮助学生提高科技英语的阅读和翻译能力。

在本教材的编写过程中，作者的硕、博士研究生，特别是钟哲强同学付出了辛勤的汗水，作者在此一并表示衷心的感谢！

由于编者水平所限，书中难免有些疏漏和欠妥之处，敬请读者不吝赐教。

编　者

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Part 1 Ray Optics

In this part, we treat light beams as rays that propagate along straight lines, except at interfaces between dissimilar materials, where the rays may be bent or refracted. This approach, which had been assumed to be completely accurate before the discovery of the wave nature of light, leads to a great many useful results regarding lens optics and optical instruments.

1.1 Refraction and Reflection

1.1.1 Refraction

When a light ray strikes a smooth interface between two transparent media at an angle, it is refracted. Each medium may be characterized by an index of refraction n, which is a useful parameter for describing the sharpness of the refraction at the interface. The index of refraction of air (more precisely, of free space) is arbitrarily taken to be one, n is most conveniently regarded as a parameter whose value is determined by experiment. We know now that the physical significance of n is that the ratio of the velocity of light in vacuo to that in the medium.

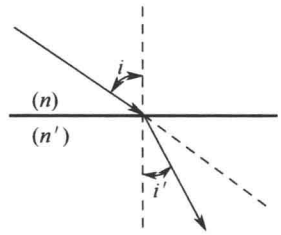

Fig.1.1 Refraction at an interface

Suppose that the ray is incident on the interface, as shown in Fig.1.1. It is refracted in such a way that

$$n\sin i = n'\sin i' \tag{1.1}$$

no matter what the inclination of the incident ray to the surface, n is the index of refraction of the first medium, n' that of the second. The angle of incidence i is the angle between the incident ray and the normal to the surface; the angle of refraction i' is the angle between the refracted ray and the normal.

1.1.2 Index of Refraction

Most common optical materials are transparent in the visible region of the spectrum, whose wavelength ranges from 400 to 700nm. They exhibit strong absorption at shorter wavelengths, usually 200nm and below.

The refractive index of a given material is not independent of wavelength, but generally increases slightly with decreasing wavelength (Near the absorption edge at 200 nm, the index of

glass increases sharply). This phenomenon is known as dispersion. Dispersion can be used to display a spectrum with a prism; it also gives rise to unwanted variations of lens properties with wavelength. Table 1.1 gives typical index of refraction of several materials.

Tab.1.1 Index of refraction of several materials

Material	Index of refraction	Material	Index of refraction
air	1.0003	sodium chloride	1.54
water	1.33	light flint glass	1.57
magnesium fluoride	1.38	Sapphire	1.77
vitreous silica	1.46	extra-dense flint glass	1.73
Pyrex glass	1.47	carbon disulfide	1.62
Methanol	1.33	zinc sulfide (thin film)	2.3
xylene	1.50	medium flint glass	1.63
ethanol	1.36	titanium dioxide (thin film)	2.4～2.9
crown glass	1.52	heavist flint glass	1.89
benzene	1.50	Canada balsam (center)	1.53

Optical glasses are generally specified both by index n and by a quantity known as dispersion v,

$$v = \frac{n_F - n_C}{n_D - 1} \tag{1.2}$$

The subscripts F, D and C refer to the indexes at certain short, middle and long wavelengths (blue, yellow, red).

1.1.3 Reflection

Certain highly polished metal surfaces and other interfaces may reflect all or nearly all of the light falling on the surface. In addition, ordinary, transparent glasses reflect a few percent of the incident light and transmit the rest.

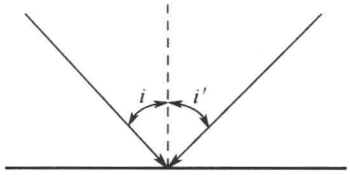

Fig.1.2 Reflection at an interface

The angle of incidence is i and the angle of reflection i'. Experiment shows that the angles of incidence and reflection are equal, except in a very few peculiar cases, as shown in Fig.1.2.

We shall later adopt the convention that i is positive; that is, if the acute angle opens counterclockwise from the normal to the ray, i is positive. The sign of i' is clearly opposite to that of i. We therefore write the law of reflection as

$$i' = -i \tag{1.3}$$

1.1.4 Total Internal Reflection

Here we consider a ray that strikes an interface from the high-index side, say, from glass to air (not air to glass). This is known as internal reflection. The law of refraction shows that the incident

ray is in this case bent away from the normal when it crosses the interface, as shown in Fig.1.3. Thus, there will be some angle of incidence for which the refracted ray will travel just parallel to the interface. In this case, $i' = 90°$, so the law of refraction becomes

$$n \sin i_c = n' \sin 90° \tag{1.4}$$

where i_c is known as the critical angle. Since $\sin 90° = 1$,

$$\sin i_c = n' / n \tag{1.5}$$

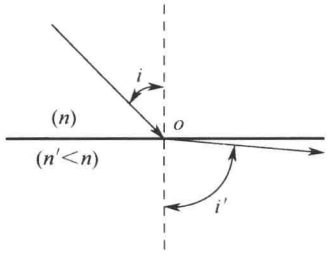

Fig.1.3 Refraction near the critical angle

If i exceeds i_c, then $n \sin i > n'$, and the law of refraction demands that $\sin i'$ exceed 1. Because this is impossible, we can conclude only that there can be no refracted ray in such cases. The light cannot simply vanish, so we are not surprised that it must be wholly reflected; this is indeed the case. The phenomenon is known as total internal reflection; it occurs whenever

$$i > \arcsin(n' / n) \tag{1.6}$$

The reflected light, of course, obeys the law of reflection.

For a typical glass-air interface, $n = 1.5$, the critical angle is about $42°$. Glass prisms that exhibit total reflection are therefore commonly used as mirrors with angles of incidence of about $45°$.

1.1.5 Reflecting Prisms

There are different types of reflecting prism. The most common are prisms whose cross sections are right isosceles triangles. One advantage of a prism over a metal-coated mirror is that its reflectance is nearly 100% if the surfaces normal to the light are antireflection coated. Further, the prism's properties do not change as the prism ages, whereas metallic mirrors are subject to oxidation and are relatively easy to scratch. A glass prism is sufficiently durable that it can withstand all but the most intense laser beams. Fig.1.4 shows a prism being used in place of a plane mirror.

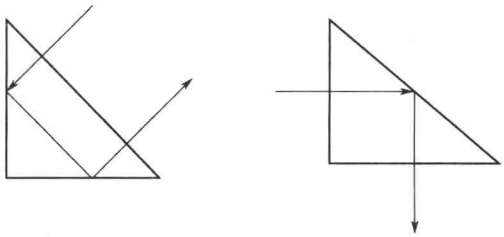
Fig.1.4 Reflecting prisms

In imaging-forming systems, these prisms must be used in collimated light beams to avoid introducing defects into the optical image.

1.2 Imaging

1.2.1 Spherical Surfaces

Because a simple lens consists of a piece of glass with, in general, two spherical surfaces, we will find it necessary to examine some of the properties of a single, spherical refracting surface. We will for brevity call such a surface, as shown in Fig.1.5, a "len". Two of these form a lens. To avoid

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confusion, we will always place "len" in quotes.

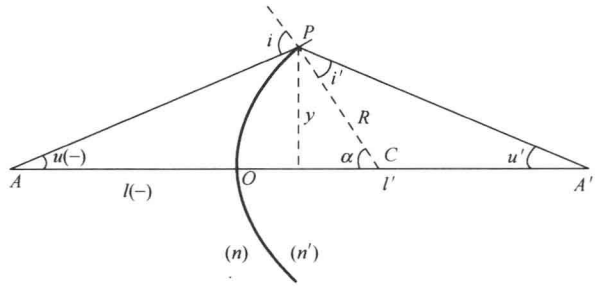

Fig.1.5 Spherical refracting surface

We are interested in the imaging property of the 'len". We consider a bright point A and define the axis along the line AC, where C is the center of the spherical surface. We examine a particular ray AP that strikes the "len" at P. We shall be interested in the point A' where this ray intersects the axis.

Before proceeding any further, we must adopt a sign convention. The choice of convention is, of course, arbitrary, but once we choose a convention, we shall have to stick with it. The convention we adopt appears, at first, quite complicated. We choose it at least in part because it is universally applicable; with it we will not need to derive a special convention for spherical mirrors.

To begin, imagine a set of Cartesian coordinate axes centered at O. Distances are measured from O. Distances measured from O to the right are positive; those measured from O to the left are negative. Thus, for example, OA' and OC are positive, whereas OA is negative. Similarly, distances measured above the axis are positive; those below are negative. This is our first sign convention.

We now adopt a convention for the signs of angles such as OAP or $OA'P$. We determine their signs by trigonometry. For example, the tangent of angle OAP is approximately

$$\tan OAP \approx y/OA \tag{1.7}$$

where y is the distance indicated between P and the axis. Our previous convention shows that y is positive, and OA, negative. Thus, tan OAP is negative and so is OAP itself. Similarly, $OA'P$ and OCP are positive.

This is our second sign convention. An equivalent statement is that angle $OA'P$ (for example) is positive if it opens clockwise from the axis, or negative otherwise. It is probably simplest, however, merely to remember that angle OAP is negative as drawn in Fig.1.5.

Finally, we deal with angles of incidence and refraction, such as angle CPA'. It is most convenient to define CPA' to be positive as shown in Fig.1.5. The angle of incidence or refraction is positive if it opens counterclockwise from the normal (which is, in this case, the radius of the spherical surface）.

Unfortunately, when the last convention is expressed in this way, the statement differs from that which refers to angles (such as OAP) formed by a ray crossing the axis. It is best to learn the sign convention by remembering the signs of all of the important angles in Fig.1.5. Only angle OAP is negative.

Let us now assign symbols to the more important quantities in Fig.1.5. The point A' is located

a distance l' to the right of O, and the ray intersects the axis at A' with angle u'. The radius R through the point P makes angle α with the axis. The angles of incidence and refraction are i and i', respectively.

We must be careful of the signs of OA and angle OAP, both of which are negative according to our sign convention. This is indicated in Fig.1.5 with parenthetical minus signs. We shall later find it necessary, after a derivation based on geometry alone, to go through our formulas and change the signs of all quantities that are algebraically negative. This is so because our sign convention is not used in ordinary geometry. To make our formulas both algebraically and numerically correct, we must introduce our sign convention, which we do as indicated, by changing signs appropriately.

1.2.2 Object-Image Relationship

We now attempt to find a relationship between the quantities l and l' for a given geometry. First, we relate angle u and i to angle α. The three angles in triangle PAC are u, α and $\pi-i$. Because the sum of these angles must be π, we have

$$u+\alpha+(\pi-i)=\pi \tag{1.8}$$

or

$$i=\alpha+u \tag{1.9}$$

Similarly

$$i'=\alpha-u' \tag{1.10}$$

At this point, it is convenient to make the paraxial approximation, namely, the approximation that the ray AP remains sufficiently close to the axis that angles u, u', i and i' are so small that their sines or tangents can be replaced by their arguments; that is

$$\sin\theta=\tan\theta=\theta \tag{1.11}$$

where θ is measured in radians.

It is difficult to draw rays that nearly coincide with the axis, so we redraw Fig.1.5 by expanding the vertical axis a great amount, leaving the horizontal axis intact. The vertical axis has been stretched so much that the surface looks like a plane. In addition, because only one axis has been expanded, all angles are greatly distorted and can be discussed only in terms of their tangents. Thus, for example,

$$u=y/l \tag{1.12}$$

and

$$u'=y/l' \tag{1.13}$$

in paraxial approximation. Note also that large angles are distorted. Although the radius is normal to the surface, it does not look normal in the paraxial approximation.

To return to the problem at hand, the law of refraction is

$$ni=n'i' \tag{1.14}$$

in paraxial approximation, from which we write

$$n(\alpha+u)=n'(\alpha-u') \tag{1.15}$$

Because $OC=R$, we write α as

$$\alpha=y/R \tag{1.16}$$

The last equation therefore becomes

$$n(\frac{y}{R}+\frac{y}{l})=n'(\frac{y}{R}-\frac{y}{l'}) \tag{1.17}$$

A factor of y is common to every term and therefore cancels. We rewrite this relation as

$$\frac{n'}{l'}+\frac{n}{l}=\frac{n'-n}{R} \tag{1.18}$$

At this point, we have made no mention of the sign convention. We derived the proceeding equation on the basis of geometry alone. According to our sign convention, all of the terms in the equation are positive, except l, which is negative. To make the equation algebraically correct, we must, therefore, change the sign of the term containing l. This change alters the equation to

$$\frac{n'}{l'}-\frac{n}{l}=\frac{n'-n}{R} \tag{1.19}$$

which we refer to as the "len" equation.

There is no dependence on y in the "len" equation. Thus, in paraxial approximation, every ray leaving A (and striking the surface) crosses the axis at A'. We therefore refer to A' as the image of A. A and A' are called conjugate points, and the object distance l and image distance l' are called conjugates.

Had we not made the paraxial approximation, the y dependence of the image point would not have vanished. Rays that struck the lens at large values of y would not cross the axis precisely at A'. The dependence on y is relatively small, so we would still refer to A' as the image point. We say that the image suffers from aberrations if all of the geometrical rays do not cross the axis within a specified distance of A'.

1.2.3 Use of the Sign Conventions

A word of warning with regard to the signs in algebraic expression: Because of the sign convention adopted here, derivations based solely on geometry will not necessarily result in the correct sign for a given term. There are two ways to correct this defect. The first, to carry a minus sign before the symbol of each negative quantity, is too cumbersome and confusing for general use. Thus, we adopt the second, which is to go through the final formula and change the sign of each negative quantity. This procedure has already been adopted in connection with the "len" equation and is necessary, as noted, to make the formula algebraically correct. It is important, though, not to change the signs until the final step, lest some signs be altered twice.

1.2.4 Lens Equation

A thin lens consists merely of two successive spherical refracting surfaces with a very small separation between them. Fig.1.6 shows a thin lens in air. The index of the lens is n. The two refracting surfaces have radii R_1 and R_2, both of which are drawn positive.

We can derive an equation that relates the object distance l and the image distance l' by considering the behavior of the two surfaces separately. The first surface alone would project an image of point A to a point A_1'. If A_1' is located at a distance l_1' to the right of the first surface, the

"len" equation shows that, in paraxial approximation,

$$\frac{n}{l_1'}-\frac{1}{l}=\frac{n-1}{R_1} \tag{1.20}$$

because n is the index of the glass (second medium) and 1, the index of the air.

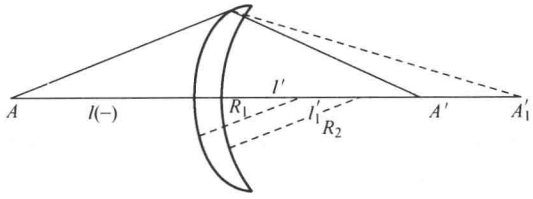

Fig.1.6 Thin lens

The ray does not ever reach A_1', because it is intercepted by the second surface. The second surface, however, behaves as if an object were located at A_1'. The object distance is l_1', if we neglect the thickness of the lens. In applying the "len" equation to the second surface, we must realize that the ray travels across the interface from glass to air. Thus n is the index of the first medium and 1, that of the second. The final image point A' is also the image projected by the lens as a whole. If we call the corresponding image distance l', then the "len" equation yields

$$\frac{1}{l'}-\frac{n}{l_1'}=\frac{1-n}{R_2} \tag{1.21}$$

for the second surface.

If we add the last two equations algebraically, we find that

$$\frac{1}{l'}-\frac{1}{l}=(n-1)(\frac{1}{R_1}-\frac{1}{R_2}) \tag{1.22}$$

which is known as the lens-maker's formula. The lens-maker's formula was derived from the "len" equation by algebra alone. There are no signs to change because that step was included in the derivation of the "len" equation.

We may define a quantity f' whose reciprocal is equal to the right-hand side of the lens-maker's formula,

$$\frac{1}{f'}=(n-1)(\frac{1}{R_1}-\frac{1}{R_2}) \tag{1.23}$$

The lens-maker's formula may then be written as

$$\frac{1}{l'}-\frac{1}{l}=\frac{1}{f'} \tag{1.24}$$

where f' is the focal length of the lens. We call this equation the lens equation.

We may see the significance of f' in the following way. If the object is infinitely distant from the lens, then $l=-\infty$. The lens equation then shows that the image distance is equal to f'. If the object is located along the axis of the lens, the image also falls on the axis. We call the image point in this case the secondary focal point F'. Note that any ray that travels parallel to the axis is directed by the lens through F', an observation that we will later find particularly useful.

We define the primary focal point F in a similar way. The primary focal length f is the object distance for which $l'=\infty$. Thus, the lens equation shows that

$$f' = -f \tag{1.25}$$

the primary and secondary focal lengths have equal magnitudes. Any ray that passes through F will be directed by the lens parallel to the axis.

Finally, we note that, in the general case, a lens may have different media on opposite sides. In this case, the lens equation may be shown to be

$$\frac{n'}{l'} - \frac{n}{l} = \frac{n'}{f'} = -\frac{n}{f} \tag{1.26}$$

where n and n' are the indices in the first and second media, respectively. The primary and secondary focal lengths are not equal, but are related by

$$\frac{f'}{f} = -\frac{n'}{n} \tag{1.27}$$

1.2.5 Classification of Lenses and Images

A positive lens is a lens that will cause a bundle of parallel rays to converge to a point. Its secondary focal point lies to the right of the lens and f' is therefore positive. It may be regarded as a lens that is capable of projecting an image of a relatively distant object on a screen. An image that can be projected on a screen is called a real image. In general, a positive lens projects a real, inverted image of any object located to the left of its primary focal point F. When an object is located at F, the image is projected to ∞. The lens is not strong enough to project an image when the object is inside F. In that case, an erect image appears to lie behind the lens and is known as a virtual image.

A positive lens need not have two convex surfaces. It may have the meniscus shape of Fig.1.6. If the lens is thickest in the middle, the lens-maker's formula will show it to be a positive lens.

A negative lens has its secondary focal point located to the left. Its secondary focal length f' is negative, and it cannot project a real image of a real object. Rather, it displays an erect, virtual image of such an object. In only one instance can a negative lens display a real image. This is the case when a positive lens projects a real image that is intercepted by a negative lens located to the left of the image plane. Because the rays are cut off by the negative lens, the real image never appears, but behaves as a virtual object projected by the negative lens.

Like a positive lens, a negative lens need not be concave on both surfaces, but may be a meniscus. If the lens is thinnest in the center, f' will prove to be negative and the lens, also negative.

1.2.6 Spherical Mirrors

Our formalism allows mirror optics to be developed as a special case of lens optics. We notice first that the law of reflection $i' = -i$ can also be written

$$(-1)\sin i' = 1 \sin i \tag{1.28}$$

which is precisely analogous to the law of refraction, with $n' = -1$. We may therefore regard a

mirror as a single refracting surface, across which the index changes from +1 to −1. It is left as a problem to apply the "len" equation to this case. We find that the focal length of a mirror is

$$f' = R/2 \tag{1.29}$$

where R is the radius of curvature. In addition, the focal points F and F' coincide. The formula that relates the conjugates for a curved-mirror system is

$$\frac{1}{l'} + \frac{1}{l} = \frac{2}{R} \tag{1.30}$$

Mirrors are usually classified as concave and convex. A concave mirror usually projects a real, inverted image, whereas a convex mirror forms an erect, virtual image.

1.2.7 Aberrations

The aberrations of simple, single-element lenses can be quite severe when the lens is comparatively large (with respect to image or object distance) or when the object is located far from the lens axis. When a simple lens is incapable of performing a certain task, it will be necessary to employ a lens, such as a camera lens, whose aberrations have been largely corrected. For specially demanding functions, special lenses may have to be designed and built.

All real lenses made from spherical surfaces may display spherical aberration. Additionally, if the object point is distant from the axis of the lens, or off-axis, the image may display other aberrations, such as astigmatism, coma, distortion, and field curvature. Furthermore, the index of refraction of the lens is a function of wavelength, so its focal length varies slightly with wavelength; the resulting aberration is called chromatic aberration.

Spherical aberration appears both on the axis and off the axis, and does not depend on the distance off-axis. Astigmatism occurs because an off-axis bundle of rays strikes the lens asymmetrically. This asymmetry causes a pair of line images to appear: one behind the plane of best focus and the other in front of it. Coma gives rise to a cometlike image; the head of the comet is the paraxial image point, and the aberration manifests itself as the tail. The tail points away from the axis of the lens and is 3 times longer than its wide. The length of the comatic image, from the paraxial image point to the end of the tail, increases in proportion to the square of the lens diameter and to the distance of the image point from the axis of the lens. The image projected by a lens does not truly lie on a plane but rather on a curved surface, even if other aberrations are zero. This aberration is called field curvature. If the magnification is function of the distance of an image point from the axis, then the image will not be rectilinear. The resulting aberration is called distortion.

Aberrations may be reduced by adjust the radii of the curvature of lens elements so that, for example, angles of incidence are minimized; this process is sometimes called bending the lens. Astigmatism, however, is only weakly influenced by bending the elements. Similarly, one aberration can sometimes be balanced against another. For example, spherical aberration can be partially compensated by moving the image plane from the paraxial image plane to the waist, that is, by compensating spherical aberration by defocusing. Similarly, coma, distortion, and astigmatism can be reduced by adjusting the axis position of the aperture stop.

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