

Bedienungsanleitung

1/05 ALF

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Demonstrations-Laseroptik-Satz U17300 /1003049
Ergänzungssatz U17301 /1003050

Die Spalte "Gerätesatz" listet den für das jeweilige Experiment benötigten Gerätesatz auf, 1003049, 1003050 oder beide.

Einleitung

Der Demonstrations-Laseroptik-Satz ermöglicht einfache und klare Versuchsaufbauten zur Darstellung der Grundlagen der geometrischen Optik sowie der Funktionsweise verschiedener optischer Geräte. Als Lichtquelle dient der Diodenlaser, 5 Strahlen U17302. In dieser Bedienungsanleitung sind zahlreiche grundlegende Versuche mit den optischen Elementen der beiden Gerätesätze U17300 und U17301 beschrieben. Jede Versuchsbeschreibung besteht aus drei Teilen:

1. Eine einfache Beschreibung des Versuchs
2. Eine grafische Darstellung des Versuchs
3. Eine Abbildung des Versuchsaufbaus

Unter dem jeweiligen Titel steht in Klammern mit welchem Gerätesatz der Versuch durchgeführt werden kann, U17300, U17301 oder U17300/U17301. Die gleiche Angabe befindet sich auch in der letzten Spalte der Inhaltsübersicht.

Ein sehr wichtiger Bestandteil der Versuchsaufbauten ist der Diodenlaser U17302. Fünf Laserdioden erzeugen fünf parallele Lichtstrahlen. Die Anzahl der austretenden Lichtstrahlen lässt sich auswählen. Dazu wird eine im Lieferumfang des Lasers enthaltene Metallplatte mit Bohrungen vor den Diodenlaser gesetzt. Beim Einsatz des Laser ist ein direkter Augenkontakt mit dem Laserstrahl zu vermeiden.

Lieferumfang

Demonstrations-Laseroptik-Satz U17300

- 1 Bikonkav Linse
- 2 Bikonvex Linse

- 3 Bikonvex Linse
- 4 Bikonvex Linse
- 5 Bikonvex Linse
- 6 Kleine plankonkave Linse
- 7 Kleine plankonvexe Linse
- 8 Große plankonvexe Linse
- 9 Spiegel, konkav
- 10 Spiegel, konvex
- 11 Planspiegel
- 12 Planparallele Platte
- 13 Prisma
- 14 Lichtleiter

Folien

- A Augenmodell
- B Kamera
- C Teleskop nach Galilei
- D Teleskop nach Kepler
- E Sphärische Aberration
- F Winkelskala 360°

Ergänzungssatz U17301

- 21 Bikonkav Luftlinse
- 22 Bikonkav Linse
- 23 Bikonvex Luftlinse
- 24 Bikonvex Linse
- 25 Luftprisma
- 26 Gleichseitiges Prisma
- 27 2 Rechtwinklige Prismen
- 28 Planparallele Platte, quadratisch
- 29 2 Planparallele Platten, rechteckig
- 11 2 Planspiegel

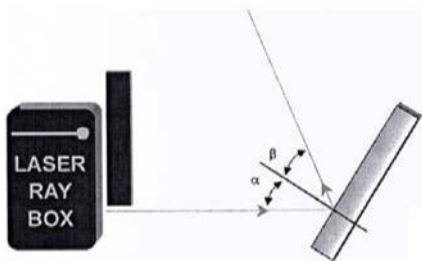
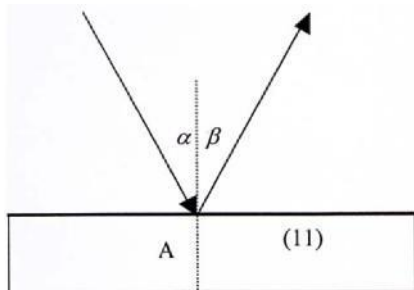
E1 Reflexion an Planspiegel

(U17300/U17301)

Darstellung des Reflexionsgesetzes. Ein Lichtstrahl, der unter dem Einfallswinkel α auf eine plane Spiegelfläche trifft, wird unter dem Winkel β reflektiert

$$\alpha = \beta$$

Beide Winkel werden zum Einfallslot hin gemessen.



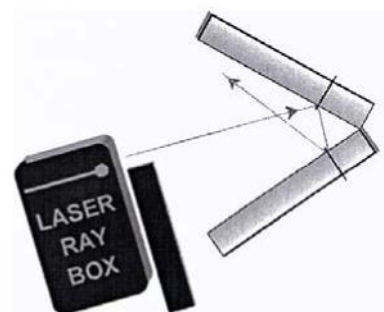
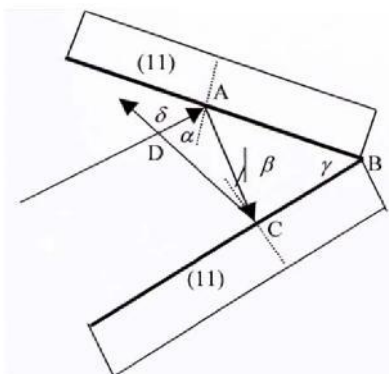
E2 Reflexion an zwei Planspiegeln

(U17301)

Demonstration der Beziehung:

$$\tau = 2 \varphi$$

wobei der Winkel τ vom einfallenden und dem reflektierten Lichtstrahl gebildet wird und φ der Winkel zwischen den Spiegelflächen ist.



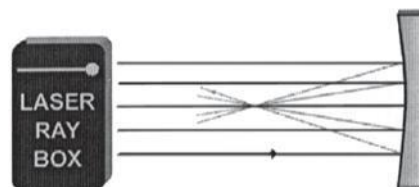
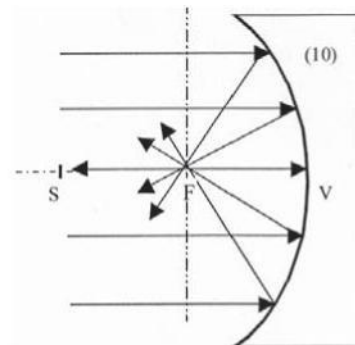
E3a Reflexion an Konkavspiegel – Lichtstrahlen parallel zur optischen Achse

(U17300)

Die Brennweite f eines Hohlspiegels wird durch die Länge der Strecke VF bestimmt. Der Krümmungsradius lässt sich mit der Formel

$$f = \frac{r}{2}$$

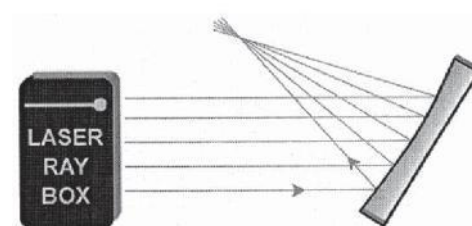
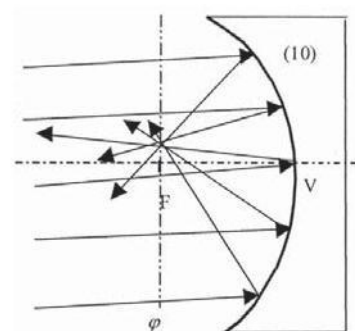
berechnen. Die Strecke VS ist doppelt so lang wie VF.



E3b Reflexion an Konkavspiegel – Lichtstrahlen nicht parallel zur optischen Achse

(U17300)

Die Achse Π steht senkrecht auf der optischen Achse und verläuft durch den Brennpunkt. Sie wird als Brennebene bezeichnet. Die einfallenden parallelen Strahlen werden reflektiert und treffen sich in einem Punkt auf der Brennebene Π . Sind die Strahlen parallel zur optischen Achse, so liegt der Punkt darauf und heißt Brennpunkt F.

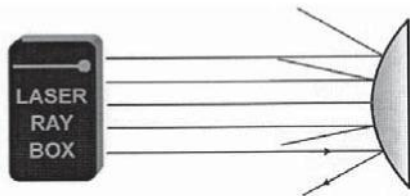
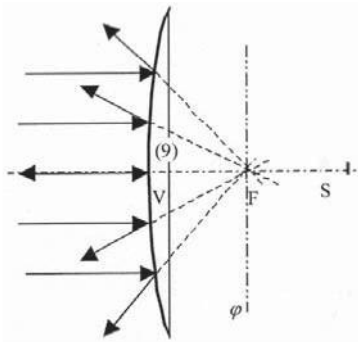


E4a Reflexion an Konkavspiegel – Lichtstrahlen parallel zur optischen Achse
(U17300)

Die reflektierten Strahlen scheinen von einem Punkt hinter dem Spiegel auszugehen. Er heißt virtueller Brennpunkt. Die Strecke VF bestimmt die Brennweite des Spiegels. Der Krümmungsradius lässt sich mit der Formel

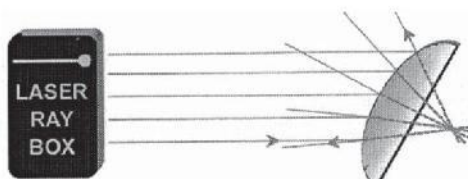
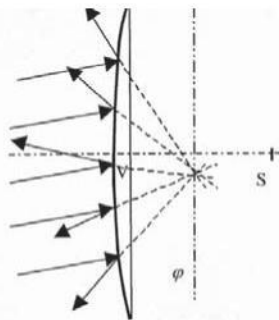
$$f = \frac{r}{2}$$

berechnen. Die Strecke VS ist doppelt so lang wie VF.



E4b Reflexion an Konkavspiegel – Lichtstrahlen nicht parallel zur optischen Achse
(U17300)

Die Achse Π steht senkrecht auf der optischen Achse und verläuft durch den Brennpunkt. Sie wird als Brennebene bezeichnet. Fallen parallele Strahlen auf den Spiegel, so werden sie so gestreut, dass sie von einem Punkt auf der Brennebene Π hinter dem Spiegel auszugehen scheinen.

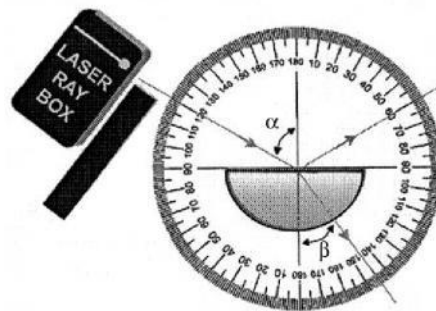
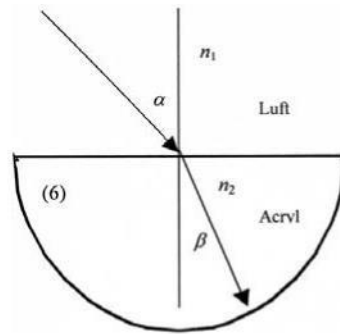


E5a Brechung eines Lichtstrahls beim Übergang von Luft in Acryl
(U17300, Folie F)

Beim Übergang eines Lichtstrahls von einem Medium mit dem Brechungsindex n_1 in ein anderes Medium mit dem Brechungsindex n_2 wird seine Richtungsänderung durch das Snelliussche Brechungsgesetz bestimmt:

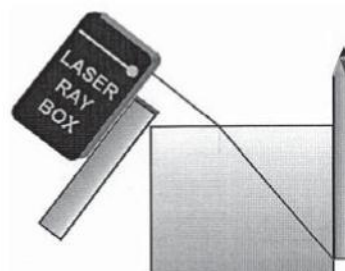
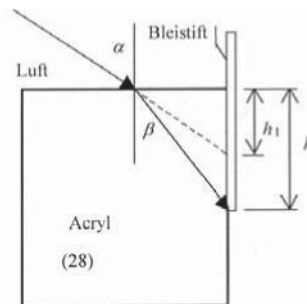
$$n_1 \sin \alpha = n_2 \sin \beta$$

α ist der Einfallswinkel in Medium n_1 und β ist der Brechungswinkel im Medium n_2 .



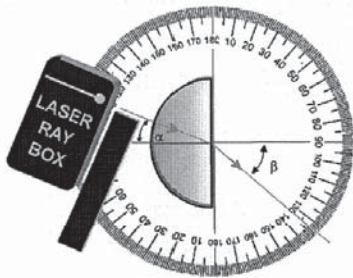
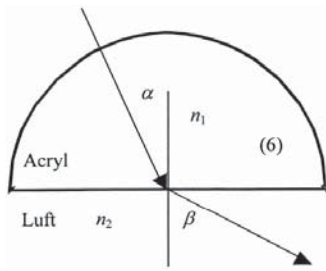
E5b Scheinbare Tiefe eines Objekts
(U17301)

Versuchsaufbau zur Beobachtung der scheinbaren Tiefe eines Objekts in Wasser oder hinter Acryl von Luft aus gesehen.



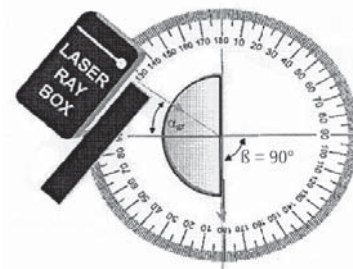
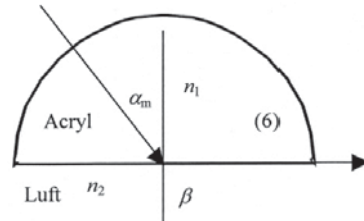
E6a Brechung eines Lichtstrahls beim Übergang von Acryl in Luft
(U17300, Folie F)

Der Brechungswinkel β ist größer als der Einfallswinkel α . Der Strahl wird vom Einfallslot weg gebrochen.



E6c Kritischer Winkel, Totalreflexion
(U17300, Folie F)

Je größer der Einfallswinkel desto größer der Brechungswinkel. Wenn $n_1 < n_2$, existiert ein kritischer Winkel α_m . Der gebrochene Strahl liegt dann an der Grenzfläche zwischen zwei Medien. Ist der Einfallswinkel größer als der kritische Winkel, dann gibt es keine Brechung mehr und das ganze Licht wird reflektiert. In diesem Fall spricht man von Totalreflexion.

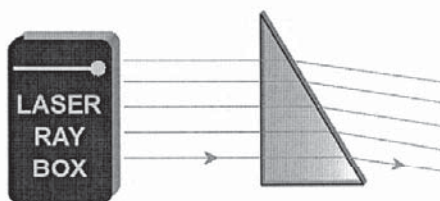
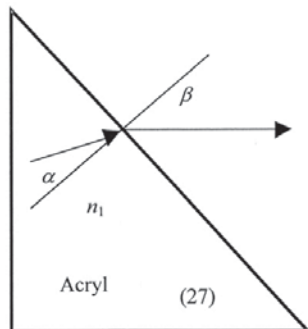


E6b Brechung an einem Acrylprisma
(U17300/U17301)

Beim Übergang eines Lichtstrahls von Acryl in Luft kann das Snelliussche Gesetz in folgender Form geschrieben werden:

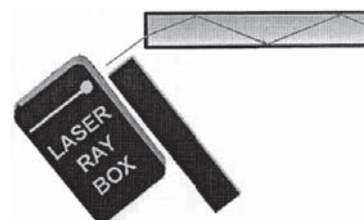
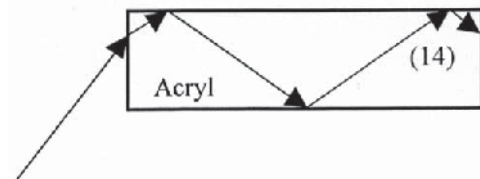
$$n_1 \sin \alpha = n_2 \sin \beta$$

Brechungsindex von Luft $n_2 = 1$.



E6d Totalreflexion – Ausbreitung von Licht in Lichtleitern
(U17300)

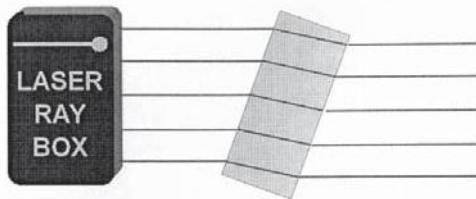
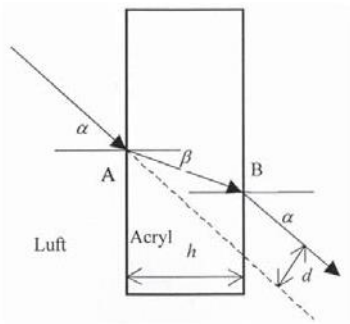
Licht breitet sich mit Hilfe der Totalreflexion in einem Lichtleiter aus. Der Parameter, numerische Apertur, bestimmt, welcher Winkel dabei nicht überschritten werden darf. Er entspricht dem Sin des maximalen Eintrittswinkels des Lichts. Auch wird der kleinste Radius, wenn der Lichtleiter gebogen wird, durch diesen Parameter bestimmt. Er darf nicht unterschritten werden, wenn der Lichtleiter installiert wird.



E7 Verschiebung eines Lichtstrahls, planparallele Acrylplatte
(U17300/U17301)

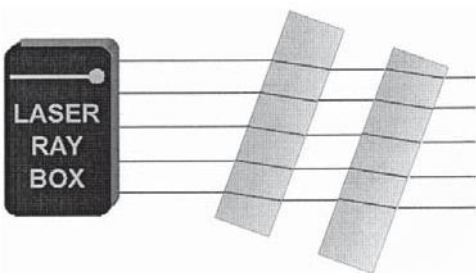
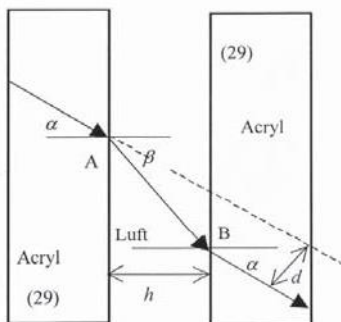
Wenn ein Lichtstrahl durch eine planparallele Platte geht, wird seine Richtung nicht verändert. Der austretende Strahl ist um den Betrag d verschoben. Bei einer Plattendicke h ergibt sich für d :

$$d = h \frac{\sin(\alpha - \beta)}{\cos \beta}$$



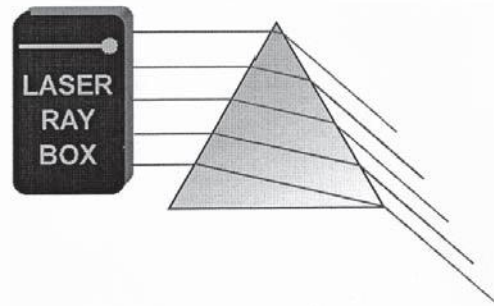
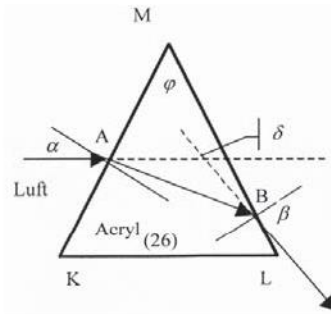
E8 Verschiebung eines Lichtstrahls, Luft zwischen zwei planparallelen Acrylplatten
(U17301)

In diesem Fall findet eine Verschiebung zwischen dem einfallenden und dem austretenden Strahl statt. Die Verschiebung geht jedoch in die umgekehrte Richtung als bei der Acrylplatte.



E9a Ablenkung eines Lichtstrahls durch ein Acrylprisma
(U17300/U17301)

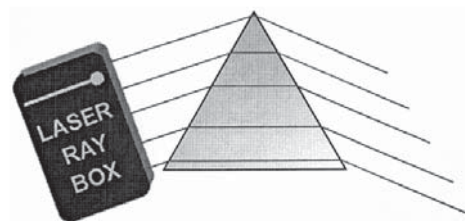
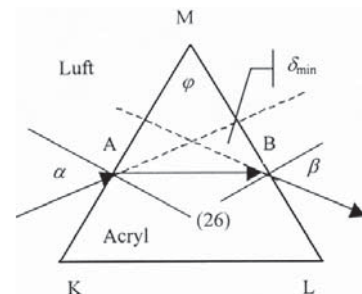
In einem Acrylprisma wird ein einfallender Lichtstrahl im Punkt A hin zum Einfallslot gebrochen. Am Austrittspunkt B findet die Brechung weg vom Einfallslot statt. Die Summe aller Brechungswinkel ist der Ablenkungswinkel δ . Es ist der Winkel zwischen dem einfallenden und austretenden Lichtstrahl.



E9b Minimale Ablenkung durch ein Acrylprisma
(U17300/U17301)

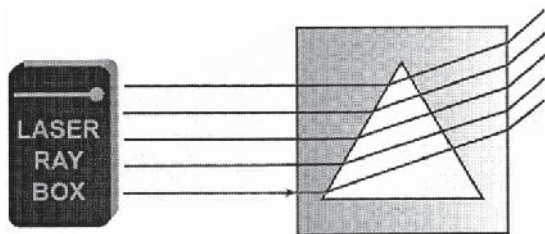
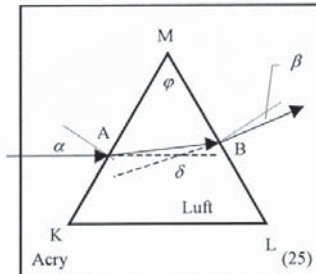
Es kann gezeigt werden, dass der Einfallswinkel α bei minimalstem Ablenkungswinkel δ_{\min} gleich dem Austrittswinkel β ist. Der gebrochene Strahl verläuft dann im Prisma parallel zu der Seite, die nicht durchgegangen wird. Für den Brechungsindex des Prismas gilt:

$$n = \frac{\sin \frac{\alpha + \beta}{2}}{\sin \frac{\phi}{2}}$$



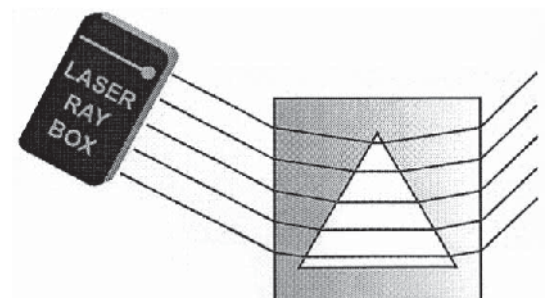
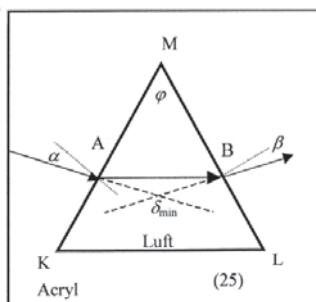
E10a Ablenkung eines Lichtstrahls durch ein Luftprisma (U17301)

Licht tritt an Punkt A durch die Grenzfläche Acryl-Luft. Der Lichtstrahl wird vom Einfallslot weg gebrochen. Am Austrittspunkt B wird er hin zum Einfallslot gebrochen. Die Summe aller Brechungswinkel ist der Ablenkungswinkel δ . Es ist der Winkel zwischen dem einfallenden und austretenden Lichtstrahl.



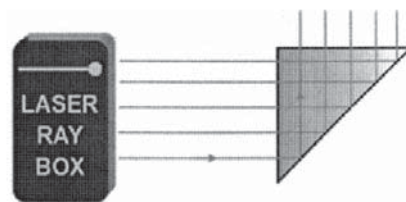
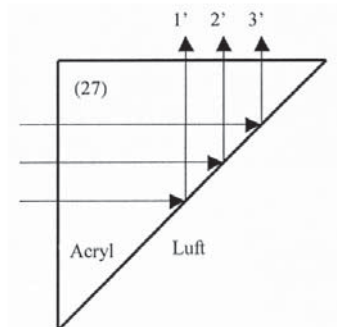
E10b Minimale Ablenkung durch ein Luftprisma (U17301)

Im Fall der minimalsten Ablenkung δ_{\min} ist der Einfallswinkel α gleich dem Austrittswinkel β . Der gebrochene Strahl verläuft dann im Prisma parallel zu der Seite, die nicht durchgegangen wird. Für den Brechungsindex des Prismas gilt: (siehe E9b). Die Richtung der Ablenkung ist umgekehrt der in einem Acrylprisma.



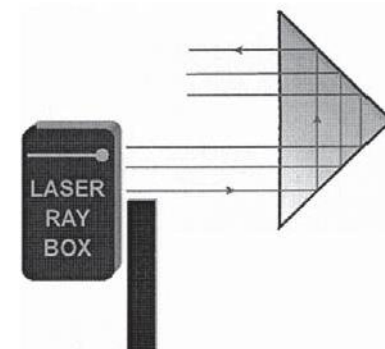
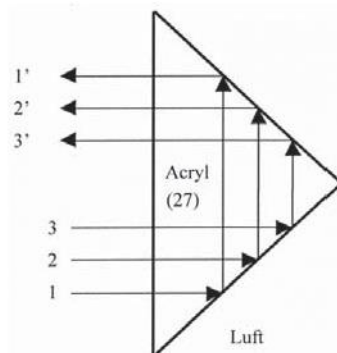
E11a Reflexion an einer Kante eines Acrylprismas (U17301)

Wenn die Lichtstrahlen auf die Kante treffen, werden sie total reflektiert. Bei leichtem Drehen des Prismas kann sowohl Brechung als auch Reflexion beobachtet werden.



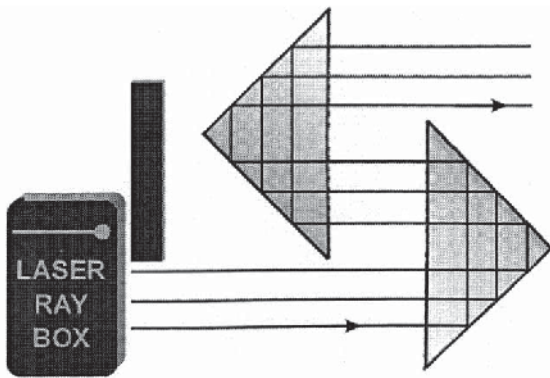
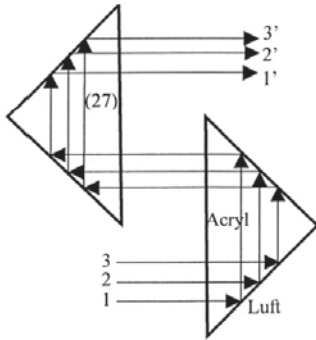
E11b Reflexion an zwei Kanten eines Acrylprismas (U17301)

In diesem Fall sind die Bedingungen für Totalreflexion an beiden Kanten des Prismas erfüllt. Wird der oberste einfallende Strahl ausgeblendet, so verschwindet der unterste austretende Strahl. Das Bild ist um 180° gedreht.



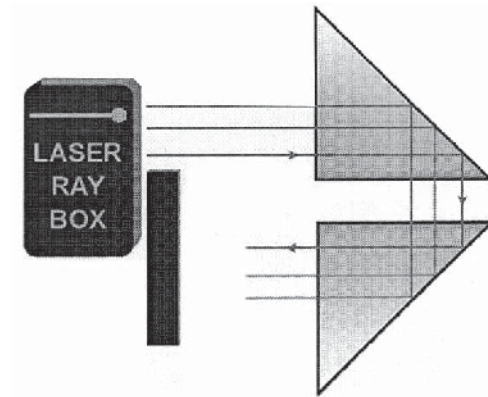
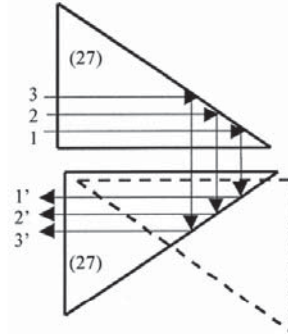
E11c Reflexion an zwei Acrylprismen
(U17301)

Die Bedingungen für Totalreflexion sind an allen Kanten der Prismen erfüllt.



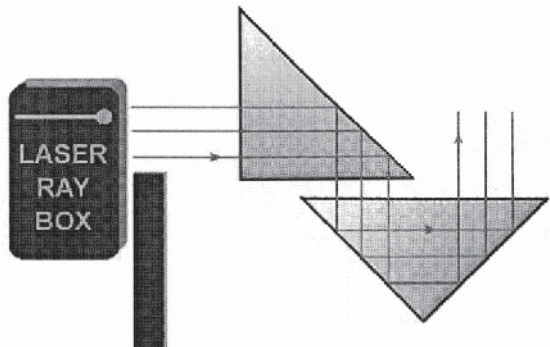
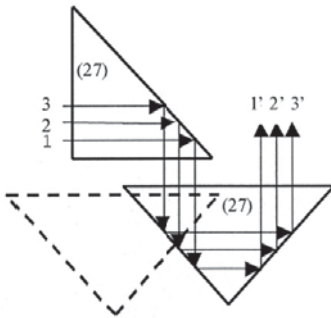
E11e Reflexion an zwei Acrylprismen
(U17301)

Die Bedingungen für Totalreflexion sind an allen Kanten der Prismen erfüllt.



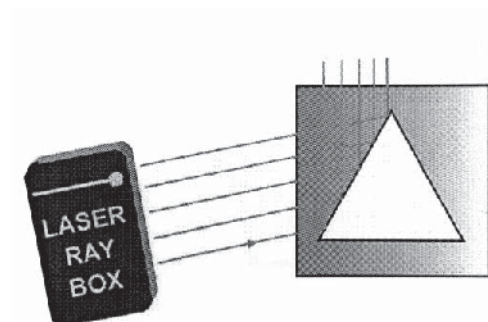
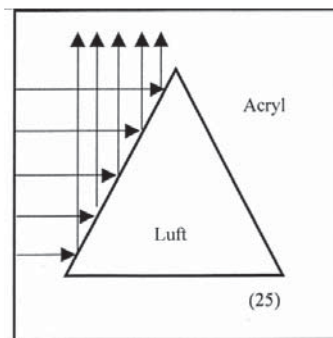
E11d Reflexion an zwei Acrylprismen
(U17301)

Die Bedingungen für Totalreflexion sind an allen Kanten der Prismen erfüllt.



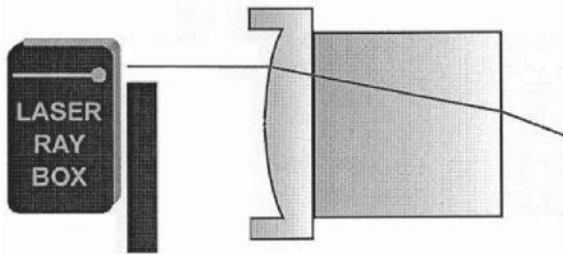
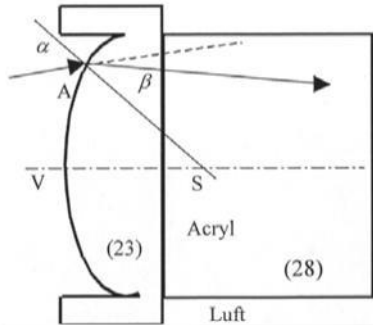
E12 Reflexion an einem Luftprisma
(U17301)

Wenn der Einfallswinkel der Lichtstrahlen kleiner ist als der kritische Winkel (42°), werden die Lichtstrahlen ins Acryl hin reflektiert. Ist der Winkel größer, geht ein Teil des Lichts durch das Luftprisma.



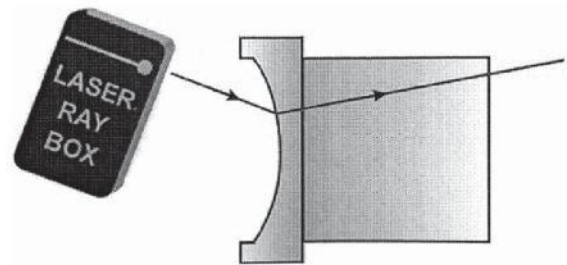
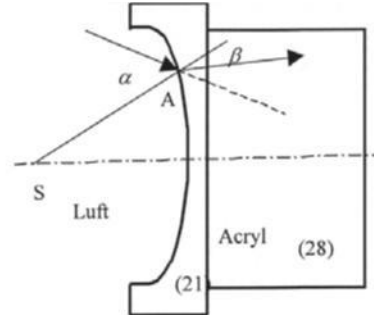
E13a Durchgang eines Lichtstrahls durch eine konvexe Grenzfläche Luft-Acryl
(U17301)

Wenn ein Lichtstrahl an Punkt A durch die Grenzfläche Luft-Acryl tritt, wird er hin zum Einfallslot gebrochen. Das Einfallslot ist die Gerade von Punkt A zum Krümmungsmittelpunkt S.



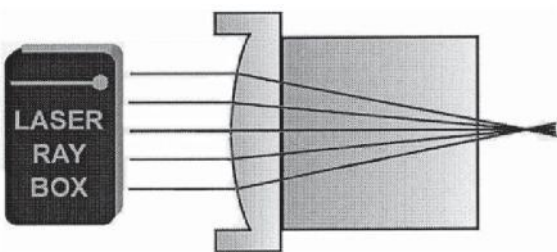
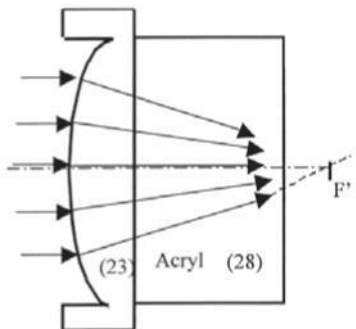
E14a Durchgang eines Lichtstrahls durch eine konkave Grenzfläche Luft-Acryl
(U17301)

Wenn der Lichtstrahl durch Punkt A auf der Grenzfläche tritt, ist eine Brechung hin zum Einfallslot zu beobachten. Das Einfallslot ist die Gerade von Punkt A zum Krümmungsmittelpunkt S.



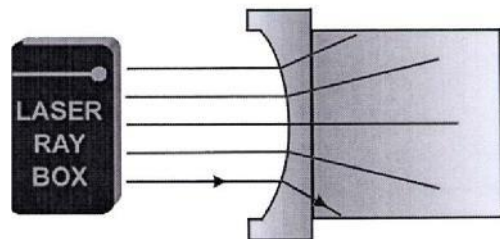
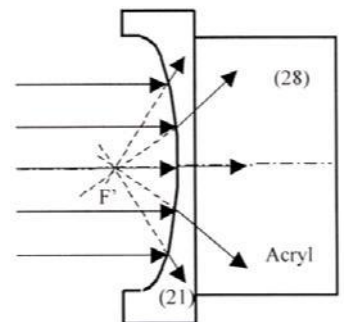
E13b Durchgang von Lichtstrahlen durch eine konvexe Grenzfläche Luft-Acryl
(U17301)

Die einfallenden Lichtstrahlen werden zweimal gebrochen und treffen sich im Punkt F auf der optischen Achse, dem Brennpunkt.



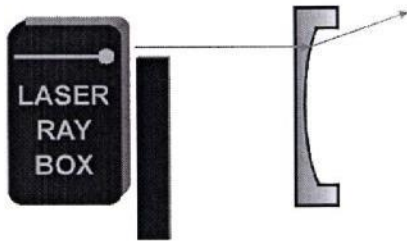
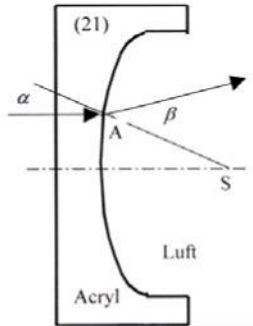
E14b Durchgang von Lichtstrahlen durch eine konkave Grenzfläche Luft-Acryl
(U17301)

Nach Durchgang durch die Grenzfläche Acryl-Luft wird das Strahlenbündel divergent gebrochen. Werden die gebrochenen Strahlen nach hinten verlängert, so treffen sie sich in einem Punkt auf der optischen Achse. Dieser Punkt heißt virtueller Brennpunkt F'.



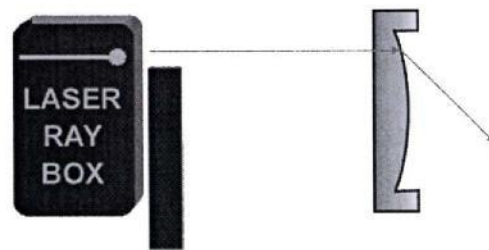
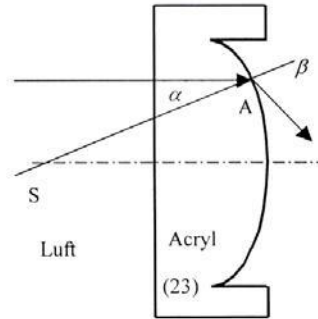
E15a Durchgang eines Lichtstrahls durch eine konvexe Grenzfläche Acryl-Luft (U17301)

Nach Durchgang des Lichtstrahls durch Punkt A wird er vom Einfallslot weg gebrochen. Das Einfallslot ist die Gerade von Punkt A zum Krümmungsmittelpunkt S.



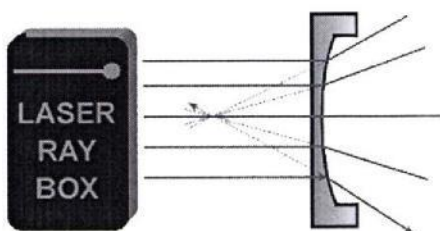
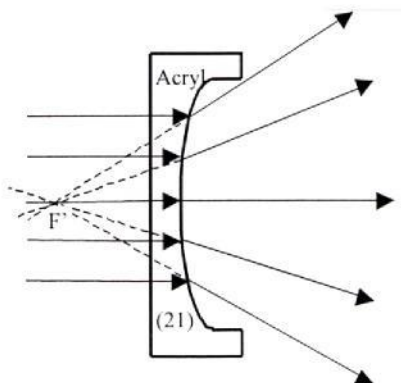
E16a Durchgang eines Lichtstrahls durch eine konkave Grenzfläche Acryl-Luft (U17301)

Nach Durchgang des Lichtstrahls durch Punkt A wird er vom Einfallslot weg gebrochen. Das Einfallslot ist die Gerade von Punkt A zum Krümmungsmittelpunkt S.



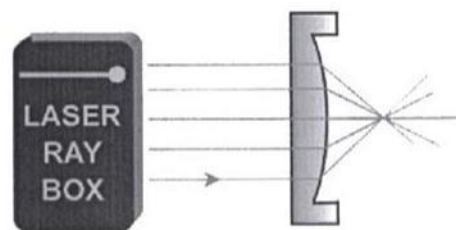
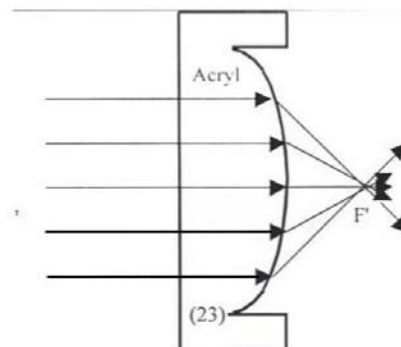
E15b Durchgang von Lichtstrahlen durch eine konvexe Grenzfläche Acryl-Luft (U17301)

Nach Durchgang durch die Grenzfläche Acryl-Luft wird das Strahlenbündel divergent gebrochen. Verlängert man die gebrochenen Strahlen nach hinten, so treffen sie sich in einem Punkt auf der optischen Achse. Dieser Punkt heißt virtueller Brennpunkt F'.



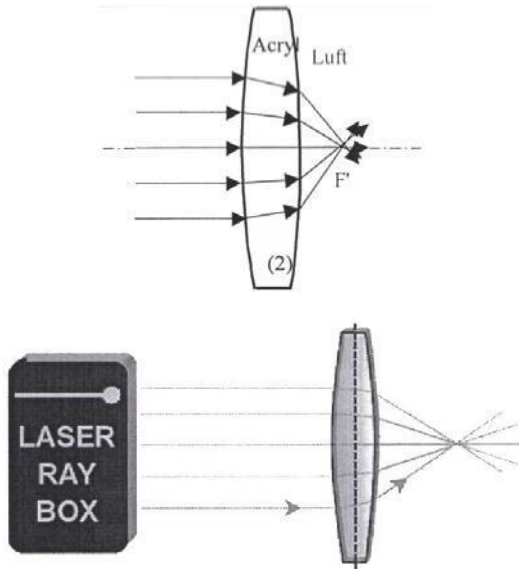
E16b Durchgang von Lichtstrahlen durch eine konkave Grenzfläche Acryl-Luft (U17301)

Nach Durchgang durch die Grenzfläche ist das Strahlenbündel konvergent. Parallele Strahlen treffen sich in einem Punkt auf der optischen Achse, dem Brennpunkt F.



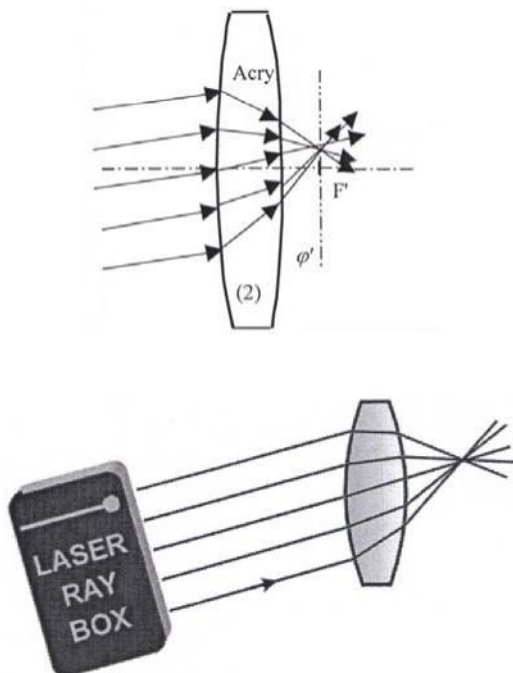
E17a Durchgang von Lichtstrahlen durch eine konvexe Acryllinse – Lichtstrahlen parallel zur optischen Achse
(U17300/U17301)

Eine konvexe Acryllinse ist eine Sammellinse und die Lichtstrahlen treffen sich nach Durchgang durch die Linse im Brennpunkt F' .



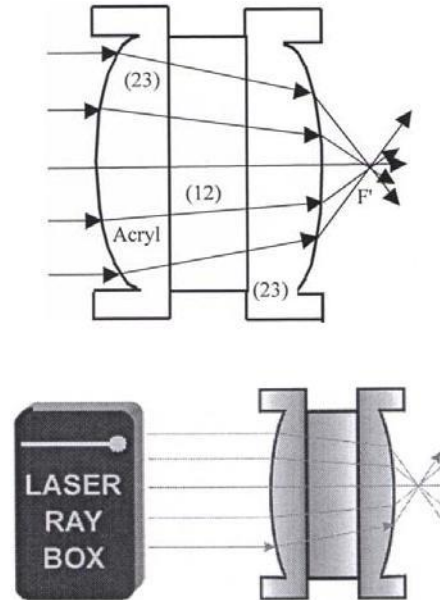
E17b Durchgang von Lichtstrahlen durch eine konvexe Acryllinse - Lichtstrahlen nicht parallel zur optischen Achse
(U17300/U17301)

Die Achse $\Pi\Pi'$ steht senkrecht auf der optischen Achse und verläuft durch den Brennpunkt F' . Sie wird als Brennpunktebene bezeichnet. Die einfallenden Strahlen werden gebrochen und treffen sich in einem Punkt auf der Achse $\Pi\Pi'$.



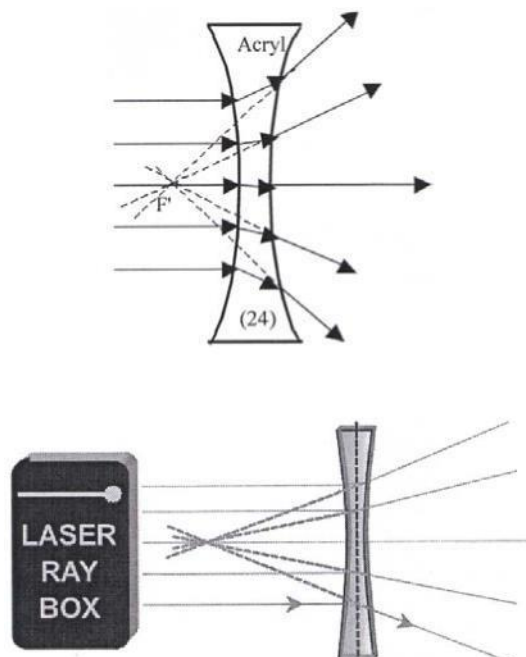
E17c Durchgang von Lichtstrahlen durch eine dicke konvexe Acryllinse
(U17301)

Durch Platzieren einer planparallelen Platte zwischen zwei Linsen (23) kann das Modell einer dicken Linse verwirklicht werden. Mit Veränderung der Dicke d der Linse verändert sich auch die Brennweite, je dicker die Linse desto kleiner die Brennweite. Ab einer kritischen Dicke wird aus der Sammellinse eine Zerstreuungslinse.



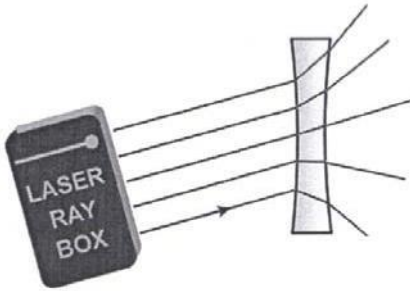
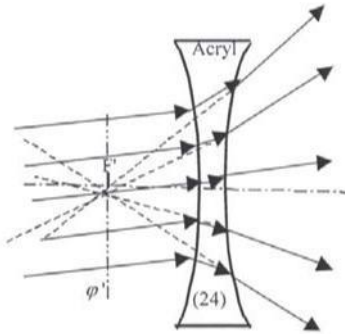
E18a Durchgang von Lichtstrahlen durch eine konkave Acryllinse – Lichtstrahlen parallel zur optischen Achse
(U17300/U17301)

Die Lichtstrahlen sind divergent nach Durchgang durch die Linse. Sie bildet kein Objekt ab. Nach hinten verlängert, treffen sich die Strahlen im virtuellen Brennpunkt F' .



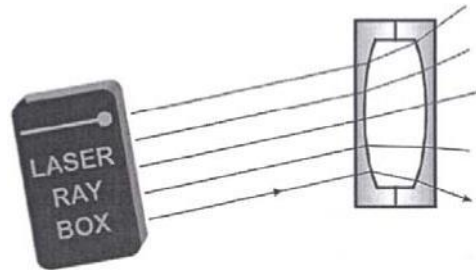
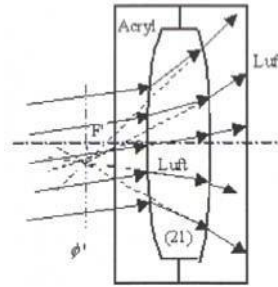
E18b Durchgang von Lichtstrahlen durch eine konkave Acryllinse – Lichtstrahlen nicht parallel zur optischen Achse
(U17300/U17301)

Die Achse Π' steht senkrecht auf der optischen Achse und verläuft durch den virtuellen Brennpunkt F' . Sie wird als Brennpunktebene bezeichnet. Die Verlängerung der gebrochenen Strahlen treffen sich in einem Punkt auf der Achse Π' .



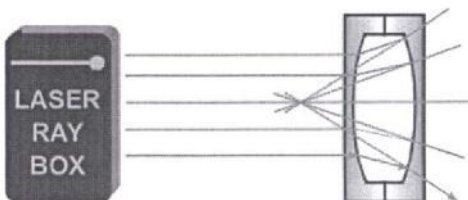
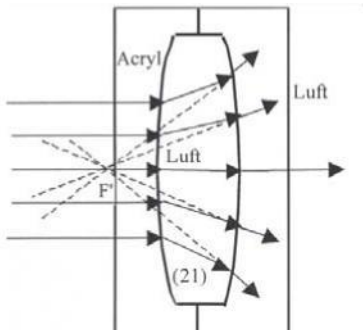
E19b Durchgang von Lichtstrahlen durch eine konvexe Luftlinse – Lichtstrahlen nicht parallel zur optischen Achse
(U17301)

Die Achse Π' steht senkrecht auf der optischen Achse und verläuft durch den virtuellen Brennpunkt F' . Sie wird als Brennpunktebene bezeichnet. Die Verlängerung der gebrochenen Strahlen treffen sich in einem Punkt auf der Achse Π' .



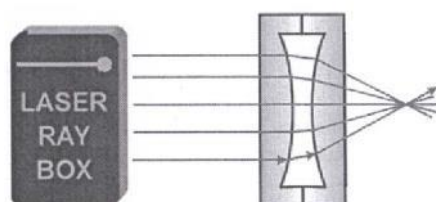
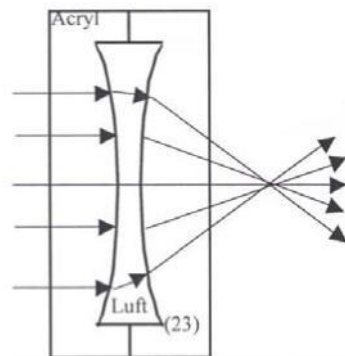
E19a Durchgang von Lichtstrahlen durch eine konvexe Luftlinse – Lichtstrahlen parallel zur optischen Achse
(U17301)

Die Lichtstrahlen sind divergent nach Durchgang durch die Linse. Sie bildet kein Objekt ab. Nach hinten verlängert, treffen sich die Strahlen im virtuellen Brennpunkt F' .



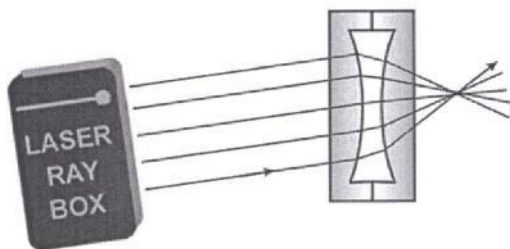
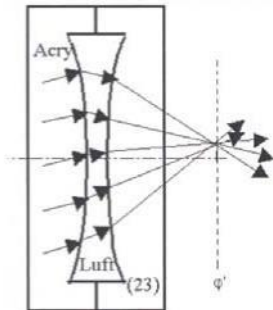
E20a Durchgang von Lichtstrahlen durch eine konkave Luftlinse – Lichtstrahlen parallel zur optischen Achse
(U17301)

Ein konkave Luftlinse verhält sich wie eine Sammellinse und die gebrochenen Strahlen treffen sich im Brennpunkt F' nach Durchgang durch die Linse.



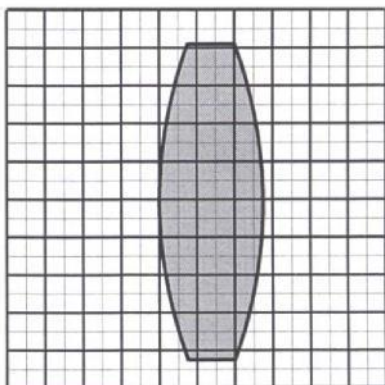
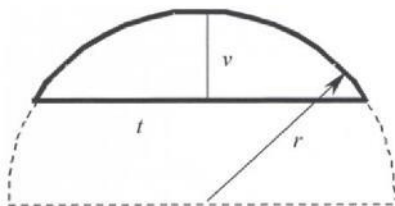
E20b Durchgang von Lichtstrahlen durch eine konkave Luftlinse – Lichtstrahlen parallel zur optischen Achse
(U17301)

Die Achse Π' steht senkrecht auf der optischen Achse und verläuft durch den Brennpunkt F' . Sie wird als Brennpunktebene bezeichnet. Die gebrochenen Strahlen treffen sich in einem Punkt auf der Achse Π' .



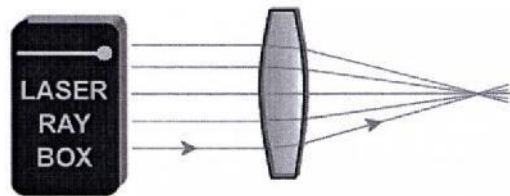
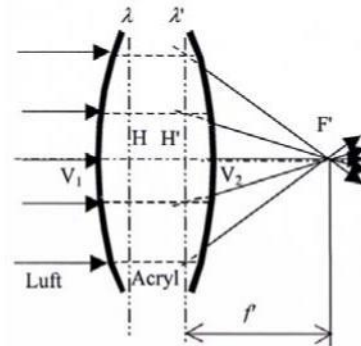
E21a Parameter von dicken Linsen – Bestimmung des Krümmungsradius
(U17300/U17301)

Die Linsen im Laseroptik-Satz besitzen eine zylindrische Brechungsfläche auf kreisförmiger Grundfläche mit gleichen Krümmungsradien. Mit Hilfe von Millimeterpapier lassen sich diese Radien bestimmen.



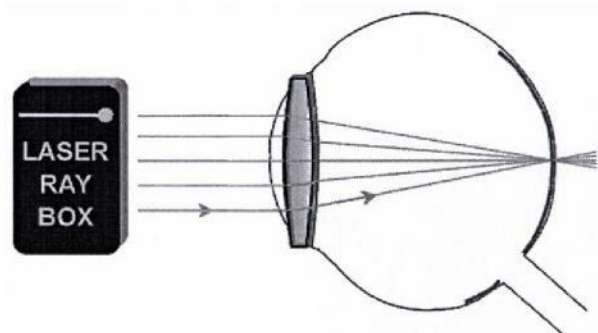
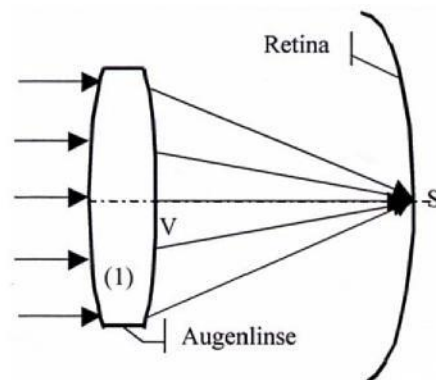
E21b Parameter von dicken Linsen – Brennweite
(U17300/U17301)

Dicke Linsen sind Linsen, bei denen die Dicke nicht vernachlässigbar ist. Bei der Definition der Brennweite muss der Abstand zwischen den beiden Hauptebenen H and H' berücksichtigt werden.



E22a Augenmodell
(U17300, Folie A)

Lichtstrahlen parallel zur optischen Achse werden durch die Augenlinse gebrochen und treffen sich in einem Punkt auf der Netzhaut. Augenlinse (1) direkt hinter der Linie O_2 platzieren.

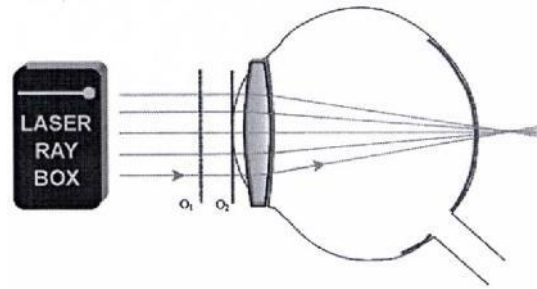
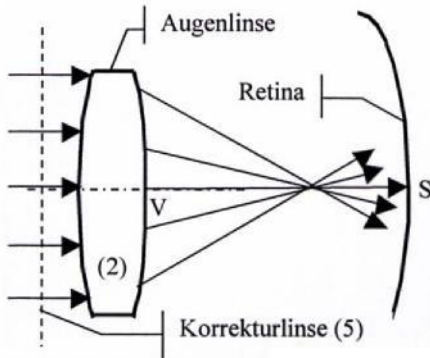


E22b Augenmodell, Kurzsichtigkeit

(U17300, Folie A)

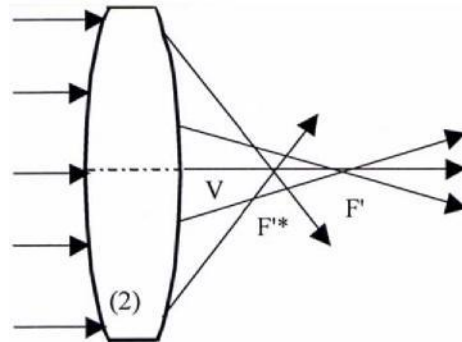
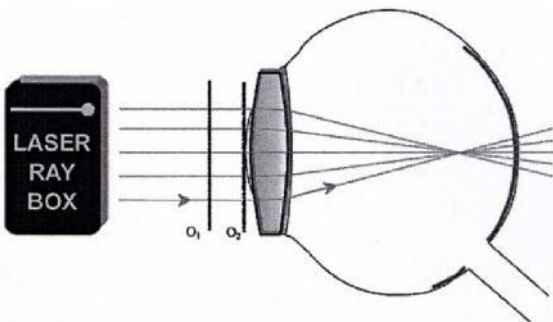
Lichtstrahlen parallel zur optischen Achse werden durch die Augenlinse gebrochen und treffen sich in einem Punkt vor der Netzhaut.

Augenlinse (2) direkt hinter der Linie O_2 und die Korrekturlinse (5) zwischen die Linien O_1 und O_2 platzieren.



E23a Korrektur der sphärischen Aberration durch Verringerung des Durchmessers des Strahlenbündels (U17300/U17301)

Sphärische Aberration einer Linse kann durch Verringerung des Durchmessers des Strahlenbündels, das durch die Linse geht, reduziert werden. Dazu die äußersten Strahlen ausblenden.



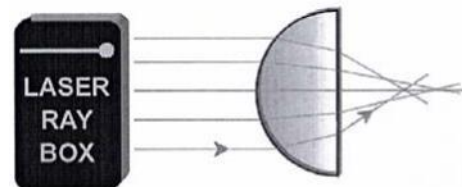
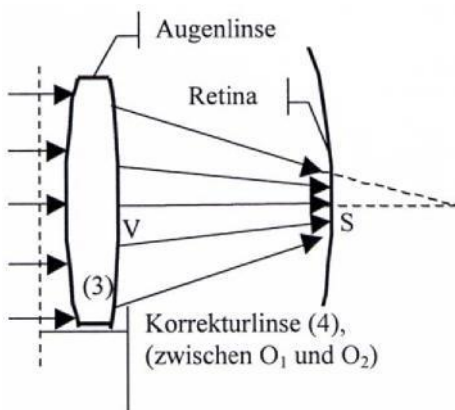
E22c Augenmodell, Weitsichtigkeit

(U17300, Folie A)

Lichtstrahlen parallel zur optischen Achse werden durch die Augenlinse gebrochen und treffen sich in einem Punkt hinter der Netzhaut. Die Korrekturlinse ist eine Sammellinse. Für die Brennweite f des Linsensystems gilt:

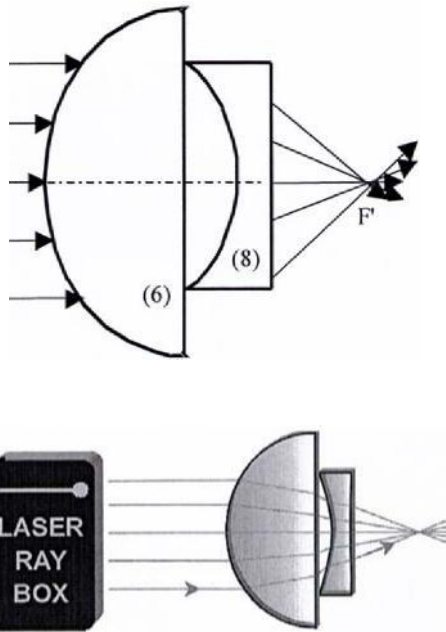
$$f = \frac{f_1 f_2}{f_1 + f_2}$$

wobei f_1 die Brennweite der Augenlinse und f_2 die der Korrekturlinse ist.



E23b Korrektur der sphärischen Aberration durch eine Linsenkombination (U17300, Folie E)

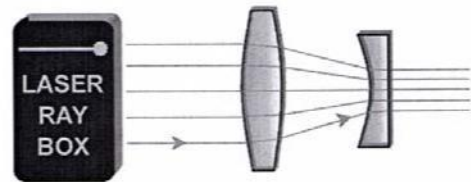
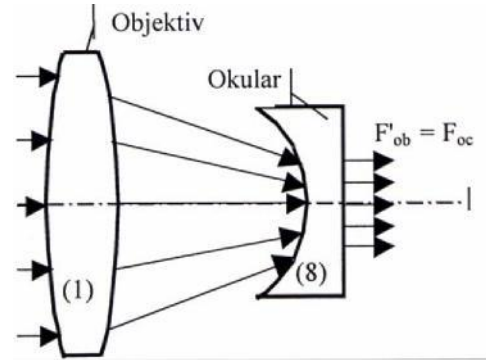
Sphärische Aberration von Sammellinsen haben einen umgekehrten Effekt. Durch eine Kombination von Linsen lässt sich der Fehler korrigieren. Die Aberration $\Delta f = f_1 - f_2$ ist definiert als die Differenz zwischen der Brennweite f_1 der äußeren und f_2 der inneren Strahlen. Bei Sammellinsen hat die Aberration ein positives bei Zerstreuungslinsen ein negatives Vorzeichen.



E24b Teleskop nach Galilei

(U17300, Folie C)

Beim Galilei-Fernrohr treffen die vom Objektiv kommenden Strahlen auf eine Zerstreuungslinse bevor sie den Brennpunkt erreichen. Die Strahlen gelangen als parallele Strahlen ins Auge. Die Abbildung des Objekts ist vergrößert, aufrecht und seitenrichtig.



E24a Teleskop nach Kepler

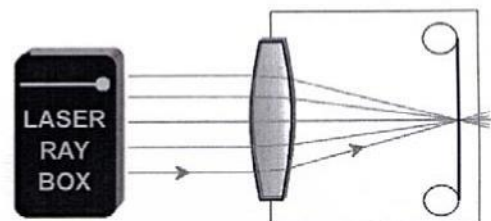
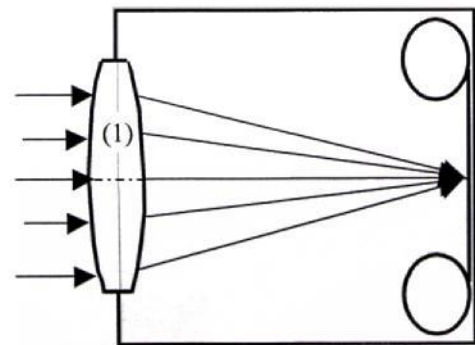
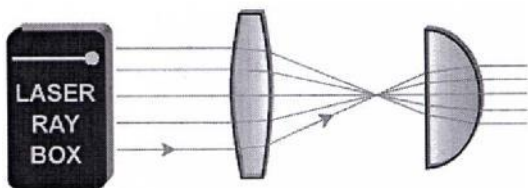
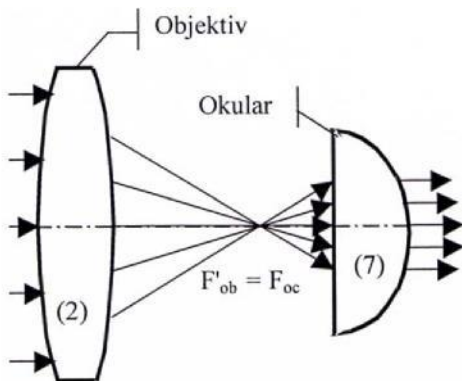
(U17300, Folie D)

Das Objektiv in Keplers Teleskop erzeugt ein verkleinertes reelles Bild des betrachteten Objekts, das vom Okular wie durch eine Lupe vergrößert wird. Es entsteht eine umgekehrte (oben und unten sowie rechts und links sind vertauscht), stark vergrößerte Abbildung. Zur Demonstration dieses Sachverhalts einen der äußeren Lichtstrahlen ausblenden. Wird der oberste einfallende Strahl ausgeblendet, so verschwindet der unterste ausgehende Strahl.

E25 Kamera

(U17300, Folie B)

Die Linse der Kamera ist eine Sammellinse. Sie bildet ein Objekt in einem reellen Bild auf dem Kopf stehend auf dem an der Rückseite der Kamera befindlichen Film ab.



1003049 / U17300 Laser Optics Demonstration Set and 1003050 / U17300 Laser Optics Supplement Set

Instruction sheet

1/05 ALF

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Laser Optics Demonstration Set U17300 / 1003049

Laser Optics Supplement Set U17301 / 1003050

The column "SET TO USE" informs you which set is appropriate for which experiment (either 1003049, or 1003050, or both).

Introduction

The demonstration set U17300 was designed for easy and clear demonstration of basic optical effects and devices. Using diode laser as a light source for experiments enables both teacher and student to understand the principle of simple and more complicated optical systems. In this guide book you can find many basic experiments and demonstrations using U17300 and U17301, which is an additional set of optical elements containing air lenses, air prisms etc. Every experiment in this book has three parts:

1. A simple description of the experiment
2. A geometric diagram of the experiment
3. A diagram showing what the experiment looks like when it is set up.

Shown in brackets under the title of the experiment is whether it can be demonstrated with the U17300 or U17301 set, or both. The same note can be found also in the table of contents in the last row. It is clear now, that some experiments cannot be done with U17300 and some of them with U17301.

A very important constituent of the experiments is the LASER RAY BOX which consists of five laser diodes. Be careful to avoid direct eye contact with the laser beam! If you have basic set U17300 and you are interested in realizing experiments for additional set U17301, please, contact your distributor of didactic aids.

- 2 Biconvex lens
- 3 Biconvex lens
- 4 Biconvex lens
- 5 Biconvex lens
- 6 Small planeconcave lens
- 7 Large planeconvex lens
- 8 Small planeconvex lens
- 9 Concave mirror
- 10 Convex mirror
- 11 Planar mirror
- 12 Planparallel plate
- 13 Prism
- 14 Optical fibre

Working sheets

- A Human Eye Model
- B Camera
- C Galileian Telescope
- D Keplerian Telescope
- E Correction of Spherical Aberration
- F Hartle's circle

U17301, Additional Set

- 21 Biconcave air lens
- 22 Biconcave glass lens
- 23 Biconvex air lens
- 24 Biconvex glass lens
- 25 Optical air prism
- 26 Equilateral optical glass prism
- 27 Rectangular optical glass prism (2 pc)
- 28 Square glass planparallel plate
- 29 Rectangular glass planparallel plate (2 pc)
- 11 Planar mirror (2 pc)

Table of set elements

U17300 Basic Set

1 Biconcave lens

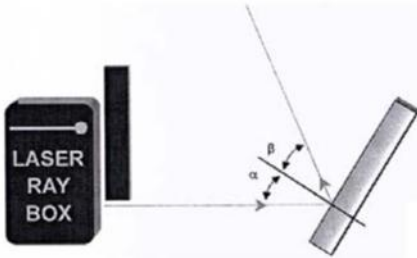
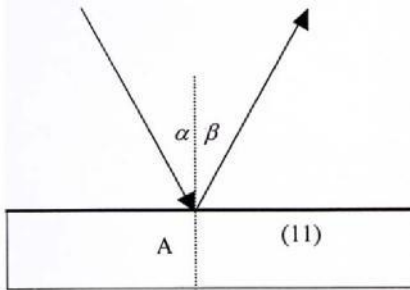
E1 Refraction on planar mirror

(U17300/U17301)

The law of reflection is demonstrated. When a light ray impinges a plane mirror under an angle α it is re-flected under the same angle β

$$\alpha = \beta$$

Both angles are measured from the perpendicular line to the mirror plane.



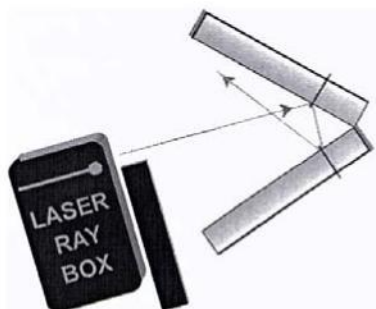
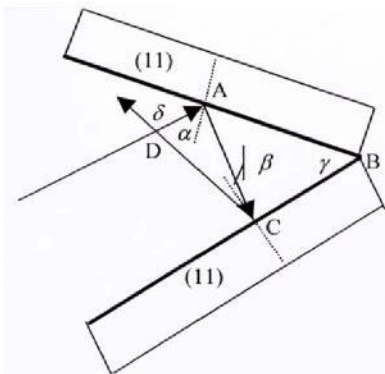
E2 Reflection on two planar mirrors

(U17301)

An interesting relation can be shown:

$$\theta = 2 \phi$$

where θ is the angle between the incident and the reflected ray and ϕ is the angle between the mirrors' planes.



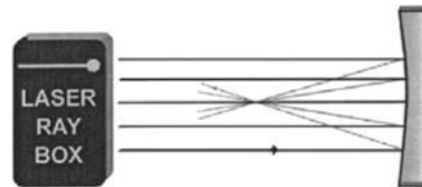
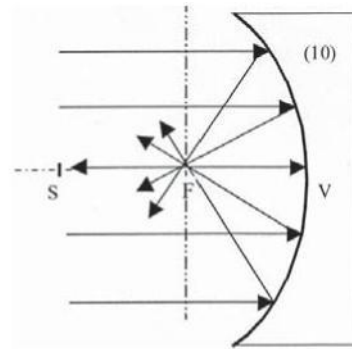
E3a Reflection of light rays on concave mirror – rays are parallel to optical axis

(U17300)

The focal length f of the concave mirror is determined by the length of the line VF. The curvature radius can be obtained using the known formula:

$$f = \frac{r}{2}$$

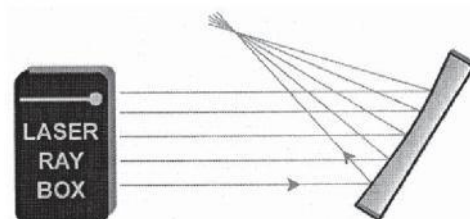
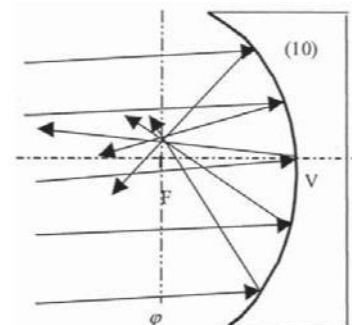
The distance of the centre of curvature S is twice as long as the distance of the focus F.



E3b Reflection of light rays on concave mirror – rays are non-parallel to optical axis

(U17300)

The axis Π which is perpendicular to the optical axis and passes through the focus is referred as the focal plane of the concave mirror. If the parallel rays impinging the mirror, they meet at one point of the axis Π after the reflection. In the case of the rays parallel to the optical axis, the point belongs to the axis and is called the focus (F).

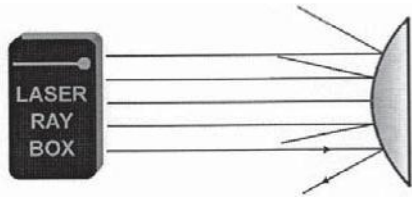
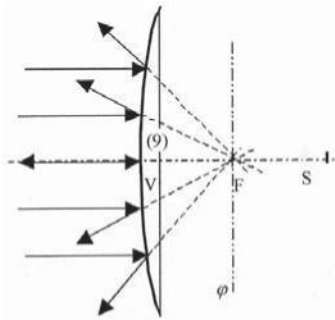


E4a Reflection of light rays on convex mirror – rays are parallel to optical axis
(U17300)

The reflected rays, parallel to the optical axis, appear to start from one point on the right side behind the mirror. This point is referred to as the figure focus. The length of line VF determines the focal length f of the mirror. The radius of curvature can be obtained from the next formula.

$$f = \frac{r}{2}$$

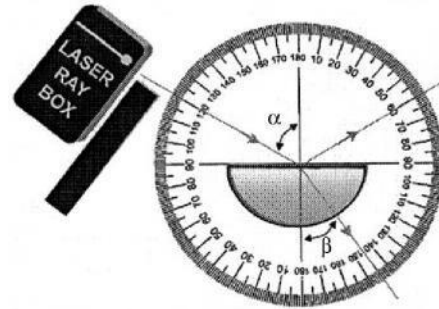
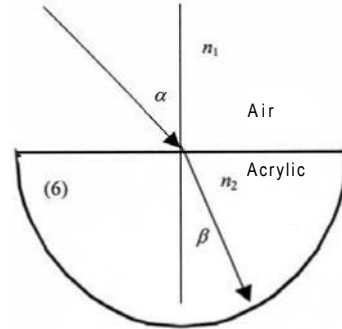
The distance of the centre of curvature S is two times longer than the distance of the focus F.



E5a Refraction of light passing air-glass boundary
(U17300, transparency F)

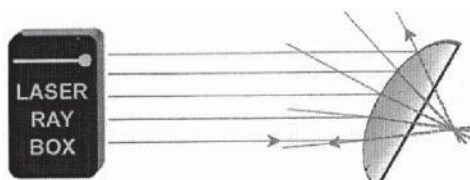
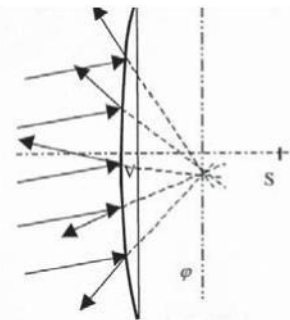
If light passes through one optical medium characterized by refraction index n_1 into the other with refraction index n_2 its direction is changed by Snell's law: $n_1 \sin \alpha = n_2 \sin \beta$

where α is an incidence angle in the medium n_1 and β is an angle of refraction in the medium n_2 . The angles are measured from the normal to the planar boundary.



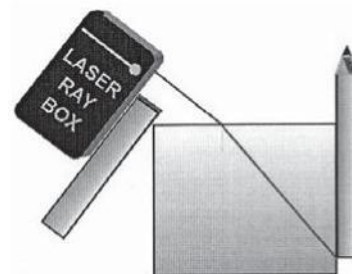
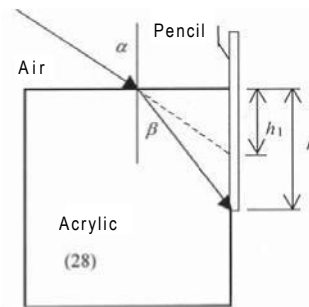
E4b Reflection of light rays on convex mirror – rays are non-parallel to optical axis
(U17300)

The axis Π which is perpendicular to the optical axis and passes through the focus is referred to as the focal plane of the convex mirror. If parallel rays impinge the mirror, they are scattered in such a way that they appear to start from one point of the plane Π . In the case of incidence rays parallel to the optical axis this point belongs to the axis.



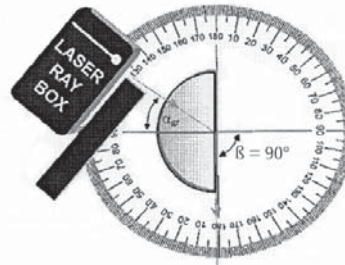
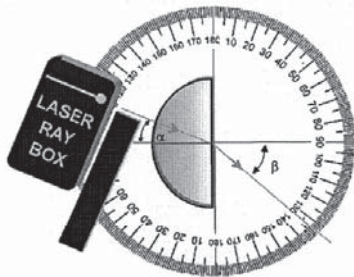
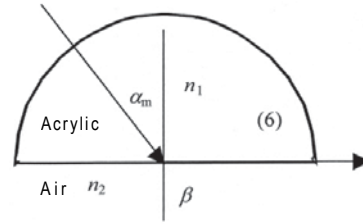
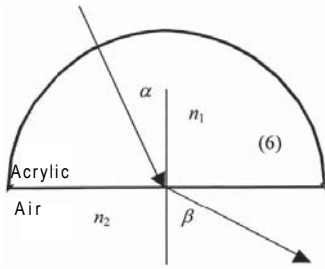
E5b Apparent depth of objects
(U17301)

You can build up the model of observing the depth of objects in water or glass from air.



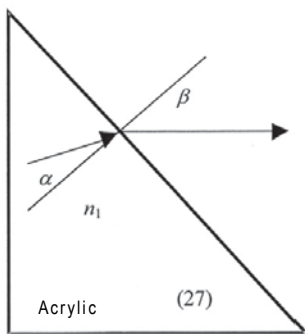
E6a Refraction of light passing glass-air boundary
(U17300, transparency F)

The ray is refracted with the refraction angle β , which is larger than α . The ray is bent away from the normal.



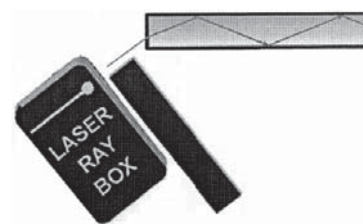
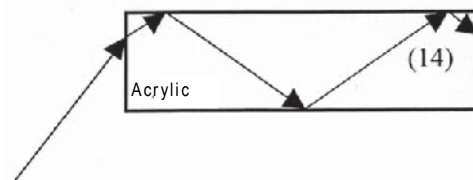
E6b Refraction on glass prism edge
(U17300/U17301)

When light passes through glass to air, Snell's law can be written in the next form: $n_1 \sin \alpha = \sin \beta$
Refractive index of air $n_2 = 1$.



E6d Total reflection – propagating of light in optical fibres
(U17300)

If light enters the optical fibre under some angles it propagates in it using the total reflection on the borders of the fibre. An important parameter determines what angle should not be overcome. This parameter is called the numerical aperture. It is SIN of the maximum entrance angle of the light. Also the minimal radius of the fibre bent is set by this parameter. It cannot be smaller, when the fibre is installed.



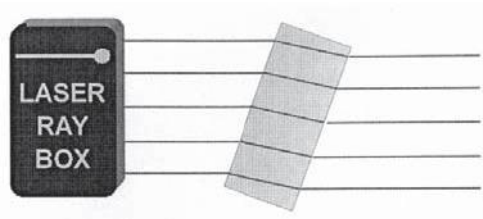
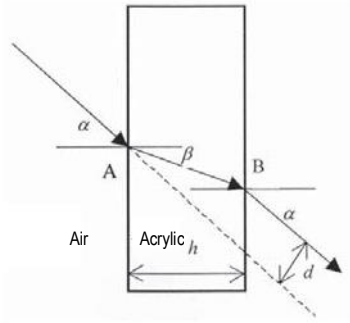
E6c Critical angle, total reflection
(U17300, transparency F)

The larger the incidence angle the larger the refraction angle. If $n_1 < n_2$ a critical angle α_c exists. In other words, the refracted ray lies on the border of two mediums. When the incidence angle is larger than the critical angle, there is no more refracted light and all light energy is reflected, this is called total reflection.

E7 Light ray shift by glass planparallel plate
(U17300/U17301)

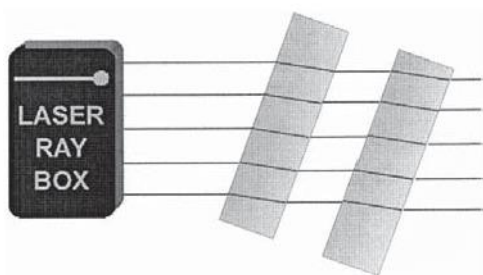
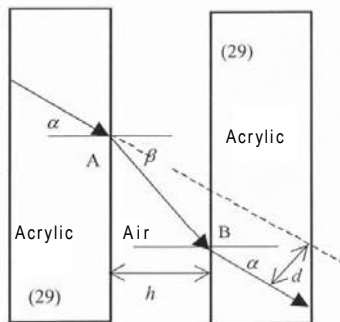
If a light ray passes through a planparallel plate its direction is not changed. The outgoing ray is shifted in accordance with the incoming one. The shift d can be estimated with respect to the thickness h of the plate using the formula:

$$d = h \frac{\sin^2 I}{\cos I}$$



E8 Light ray shift by air planparallel plate
(U17301)

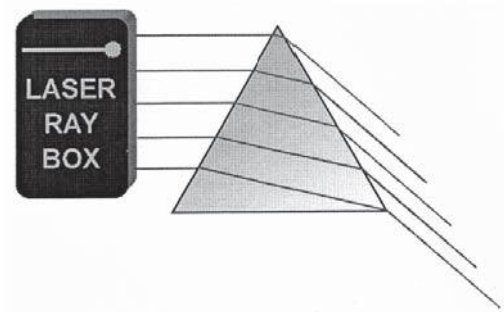
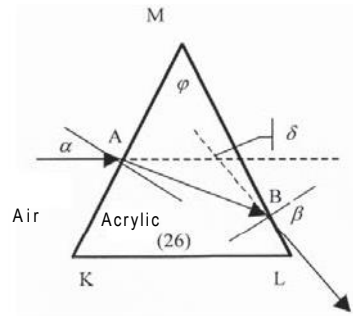
In this case, a shift between the incoming and the outgoing ray can be observed. This shift has an opposite direction than in the case of the glass plate.



E9a Glass prism deviation of light ray
(U17300/U17301)

If the prism is glass, after the light impinges the point A, it is bent toward the normal and refracts to point B. At this point it is bent into the air away from the normal. The sum of all refraction angles is the deviation

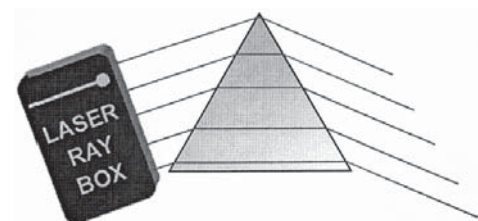
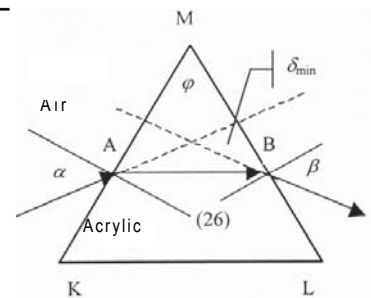
angle δ . It is the angle between the incidence and the outgoing ray.



E9b Glass prism minimal deviation
(U17300/U17301)

It can be seen that in the case of minimal deviation δ_{min} the incidence angle α is equal to the angle of the outgoing ray β . The direction of the refraction of light in the prism is parallel to the edge the ray does not pass through. The refractive index of the prism obeys the formula:

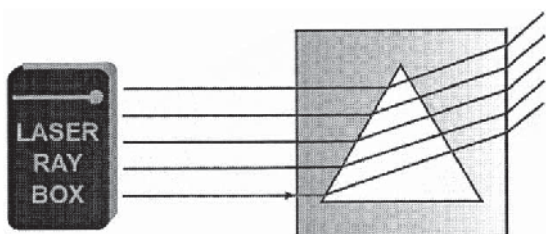
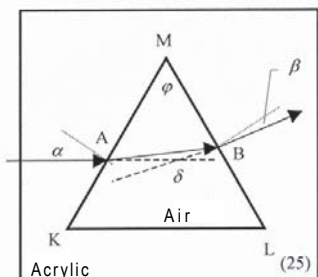
$$n = \frac{\sin \frac{\alpha + \beta + \phi}{2}}{\sin \frac{\phi}{2}}$$



E10a Air prism deviation of light

(U17301)

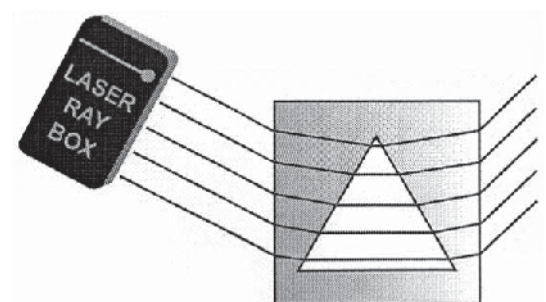
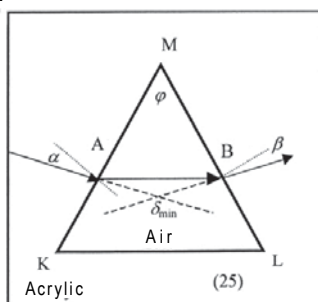
Light passes through the glass-air border at point A. Then it is directed away from the normal axis and after light passes through point B, it is then directed toward the normal. The sum of the refraction angles is referred as the deviation angle δ . It is the angle between the incidence and the outgoing ray.



E10b Air prism minimal deviation

(U17301)

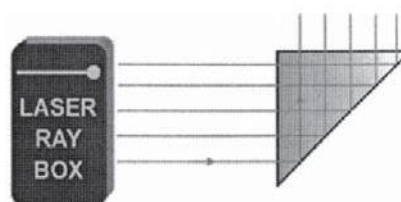
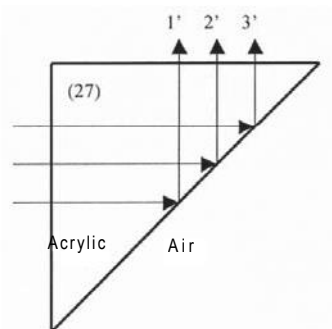
In the case of minimal deviation δ_{min} , the incidence angle α is equal to the angle of the outgoing ray β . The direction of the refracted light in the prism is parallel to the edge the ray does not pass through. The refractive index of the prism obey formula (see E9b). The deviation has an opposite direction as in the case of a glass prism.



E11a Reflection of light on one edge of glass prism

(U17301)

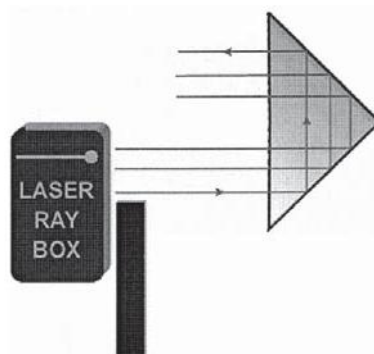
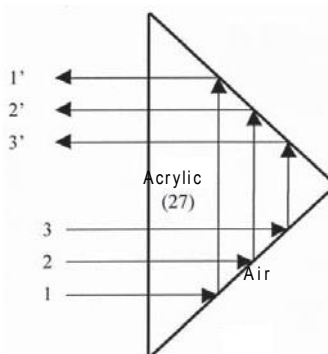
When the rays impinge the edge, they are totally reflected. If the prism is slightly adjusted reflection and refraction can be observed.



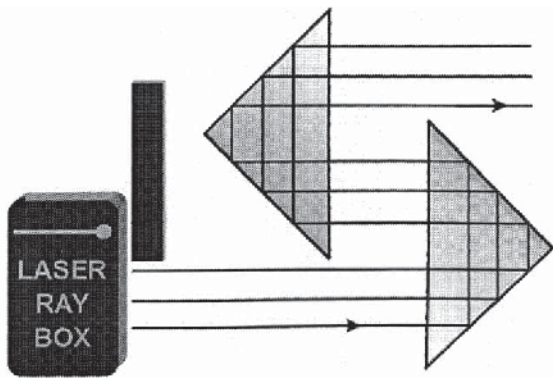
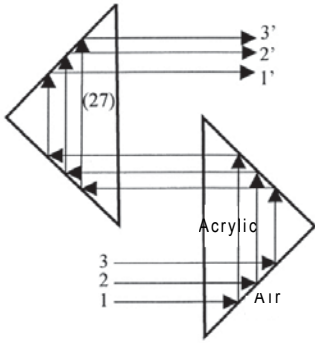
E11b Reflection of light on two edges of glass prism

(U17301)

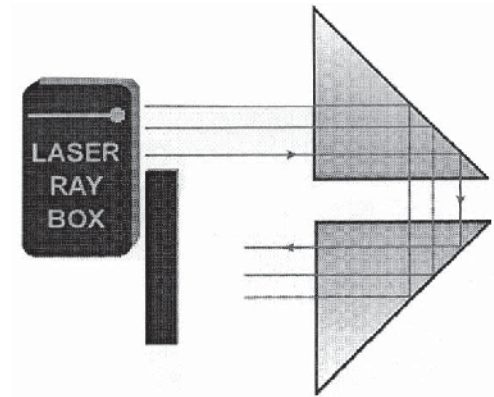
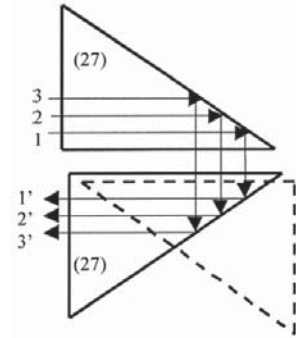
The conditions for total reflections are fulfilled on both edges of the prism. If the top ray of the incidence light is eliminated, the bottom ray of the outgoing light disappears. The picture is 180° rotated.



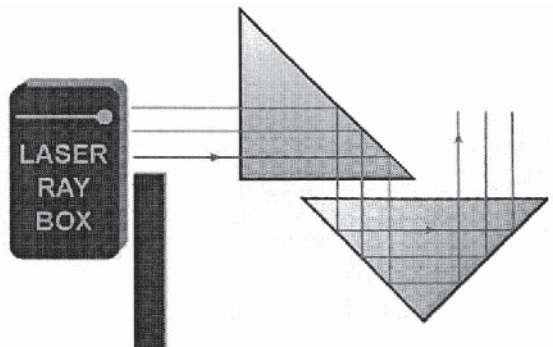
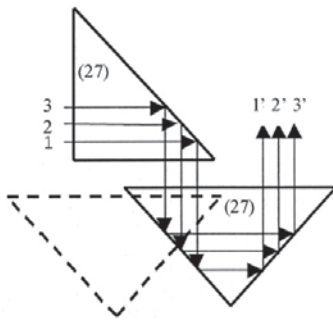
E11c Reflection of light on two glass prisms
(U17301)
Conditions for total reflection are fulfilled on every edge.



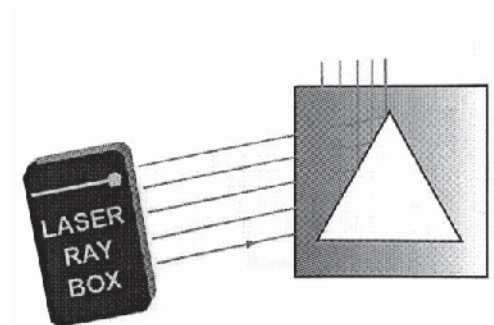
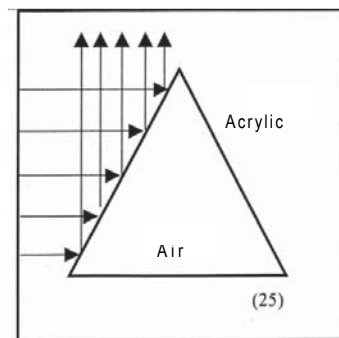
E11e Reflection of light on two glass prisms
(U17301)
Conditions necessary for total reflection are fulfilled on every edge.



E11d Reflection of light on two glass prisms
(U17301)
Conditions necessary for total reflection are fulfilled on every edge.

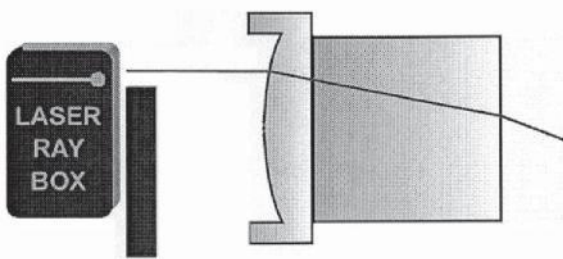
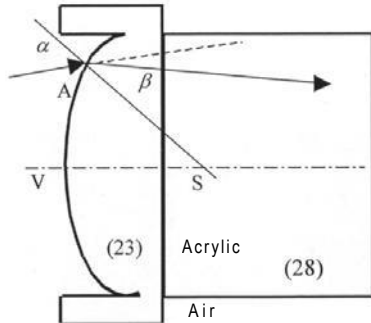


E12 Reflection of light on air prism
(U17301)
If the incidence angle of light to the edge of the prism (25) is smaller than critical angle (42°), the rays are reflected into the glass. If the angle is greater, a part of the light passes through the air prism.



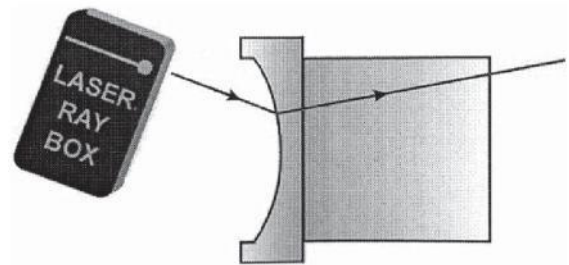
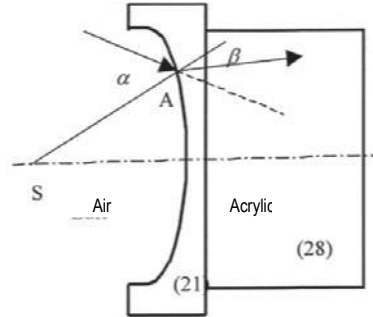
E13a Light ray passing a convex air-glass boundary (U17301)

When a ray impinges the air-glass boundary at point A, it is directed toward the normal. The normal is defined as the line from point A to the centre of boundary curvature S.



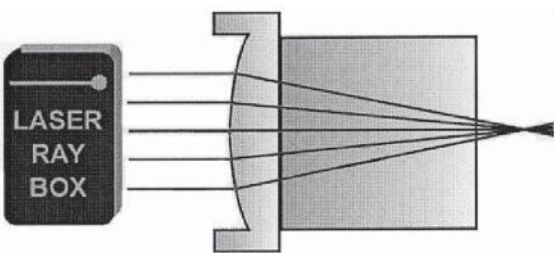
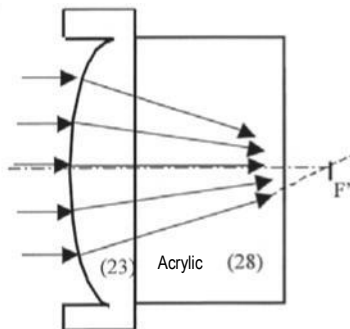
E14a Light ray passing through concave air-glass boundary (U17301)

When a ray impinges the boundary at point A, refraction towards the normal is observed. The normal is defined as the line from point A to the centre of boundary curvature S.



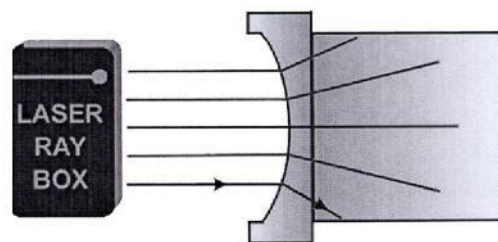
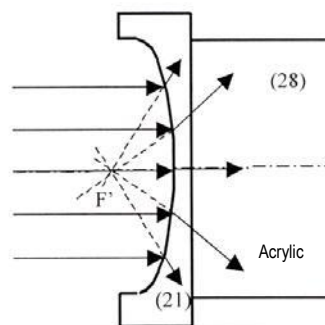
E13b Light beam passing through convex air-glass boundary (U17301)

Using a boundary of convenient curvature radius and an auxiliary glass element, where the rays are refracted, one can observe that the rays are met at the point F' in the optical axis – figure focus.



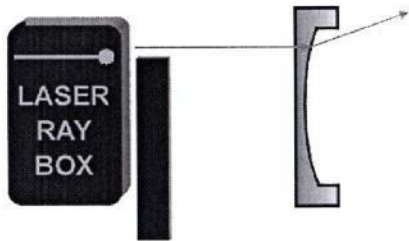
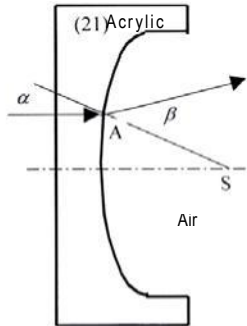
E14b Light beam passing through concave air-glass boundary (U17301)

The beam after passing the boundary is divergent. Elongating the refracted light to the other side one can find a point on the optical axis where the line meets. It is figure focus F'.



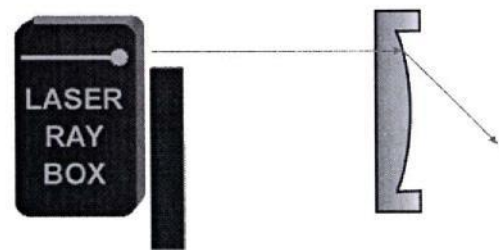
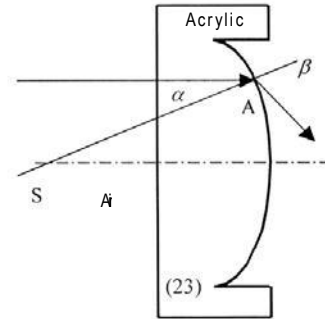
E15a Light ray passing through convex glass-air boundary
(U17301)

When a ray impinges the boundary at point A, refraction away from the normal is observed. The normal can be defined as the line from point A to the centre of boundary curvature S.



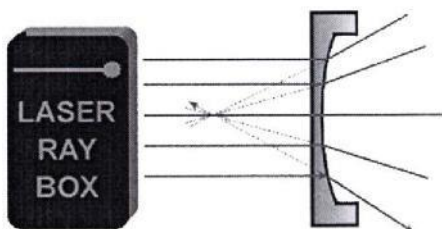
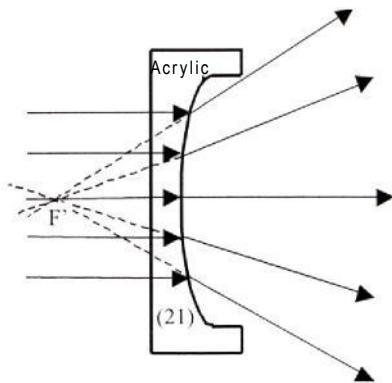
E16a Light ray passing through concave glass-air boundary
(U17301)

When a ray impinges the boundary at point A, refraction away from the normal is observed. The normal is defined as the line from point A to the centre of boundary curvature S.



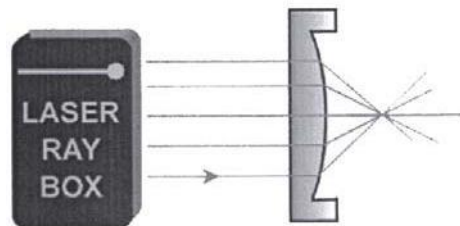
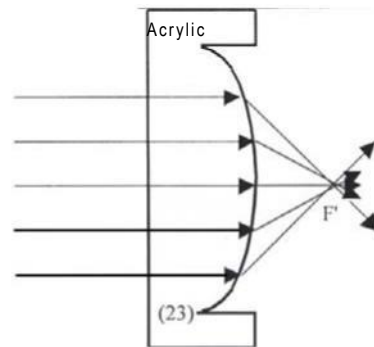
E15b Light beam passing through convex glass-air boundary
(U17301)

The beam after passing the boundary is divergent. Elongating the refracted light to the other side one can find a point on the optical axis where the line meets. It is figure focus F' .



E16b Light beam passing through concave glass-air boundary
(U17301)

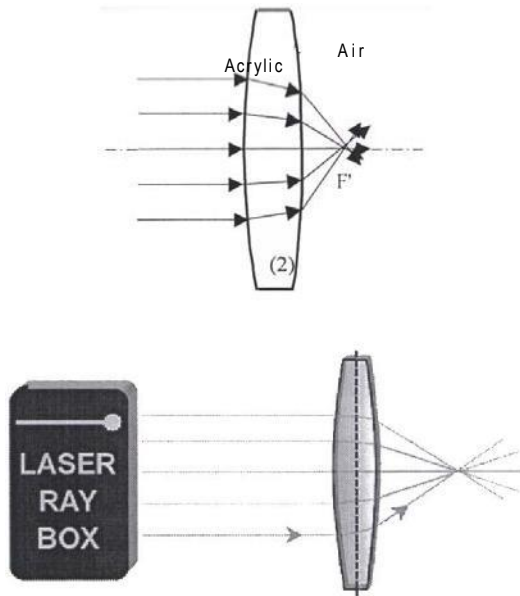
The beam is convergent after passing the boundary. Parallel rays meet in one point of the optical axis – figure focus F' .



focus F' .

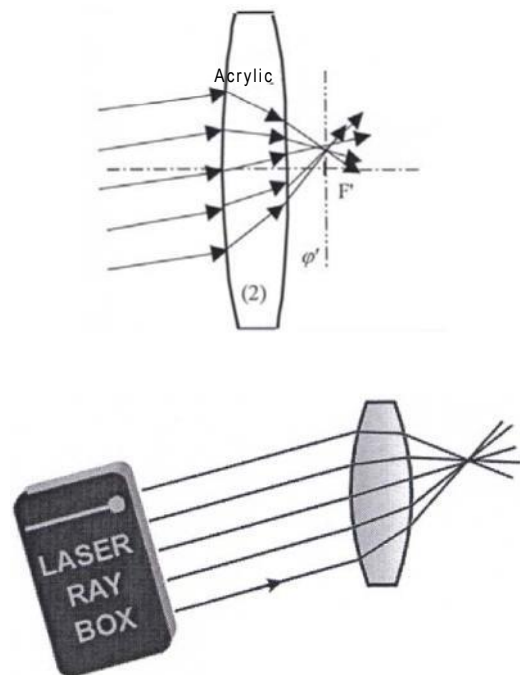
E17a Light beam passing through glass convex lens – beam is parallel to the optical axis
(U17300/U17301)

A convex glass lens behaves as a convergent optical system and the rays meet at figure focus F' after passing through the lens.



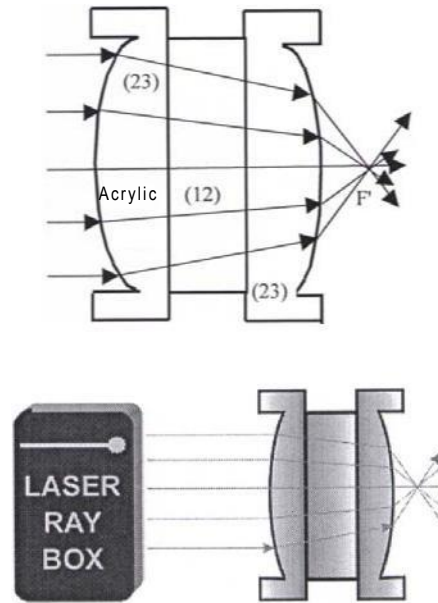
E17b Light beam passing through glass convex lens – the rays are non-parallel to the optical axis
(U17300/U17301)

The plane Π' which is perpendicular to the optical axis, combined with the figure focus F' is called a figure fo-cus plane. If a beam of perpendicular rays impinges the convex glass lens, the rays cross the plane Π' at one point.



E17c Light beam passing through thick glass convex lens
(U17301)

By inserting planparallel plates into the space between two elements (23), a model of a thick lens can be constructed. The thickness d of the lens can be changed. If the thickness increases the focal length of the lens decreases. For a critical thickness the lens changes from convergent to divergent.



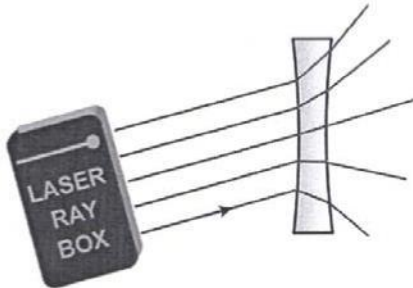
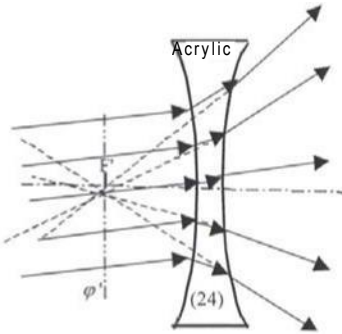
E18a Light beam passing through glass concave lens – the rays are parallel to the optical axis
(U17300/U17301)

The rays are divergent after passing a concave glass lens, they do not create a real figure. By elongating the rays it is seen that the lines have a common intersection – figure focus F' .



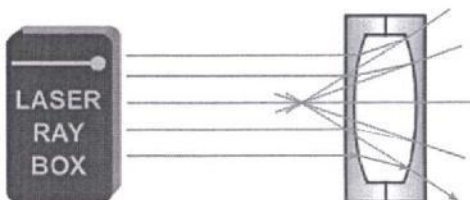
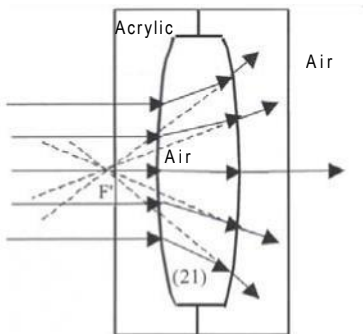
E18b Light beam passing through glass concave lens – the rays are non-parallel to the optical axis (U17300/U17301)

The plane Π' which is perpendicular to the optical axis, combined with the figure focus F' is called a figure focus plane. If a beam of perpendicular rays impinges the concave glass lens, the elongated lines of the rays cross the plane Π' at one point.



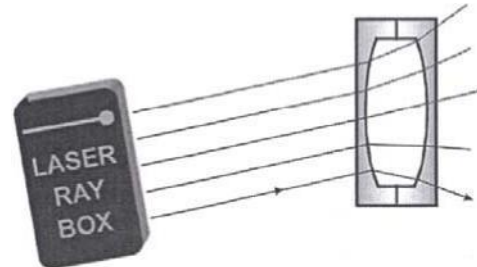
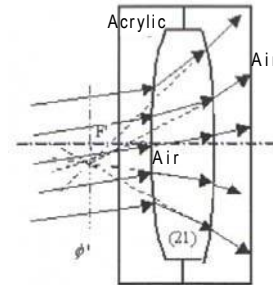
E19a Light beam passing through air convex lens – the rays are parallel to the optical axis (U17301)

The rays are divergent after passing a convex air lens, they do not create a real figure. By elongating the rays one can see the lines has a common intersection – figure focus F' .



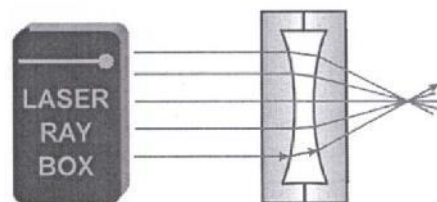
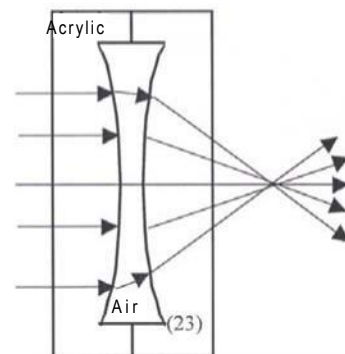
E19b Light beam passing through air convex lens – the rays are non-parallel to the optical axis (U17301)

The plane Π' which is perpendicular to the optical axis, combined with the figure focus F' is called a figure focus plane. If a beam of perpendicular rays impinges the convex air lens, the elongated lines of the rays cross the plane Π' at one point.



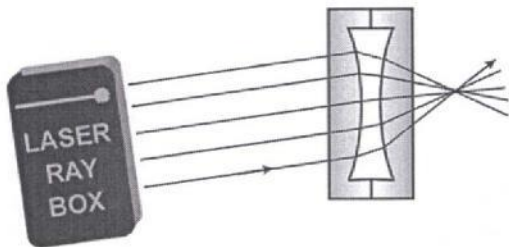
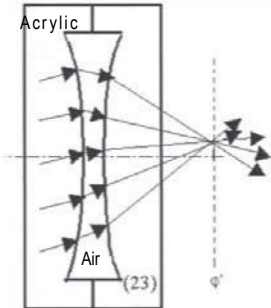
E20a Light beam passing through air concave lens – the rays are parallel to the optical axis (U17301)

A concave air lens behaves as a convergent optical system and the rays meet at figure focus F' after passing through the lens.



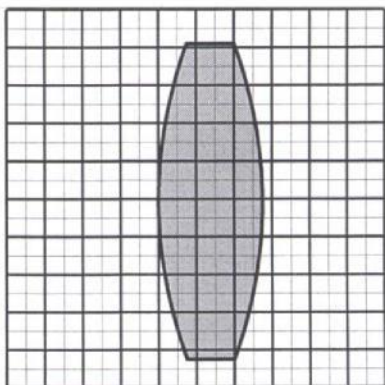
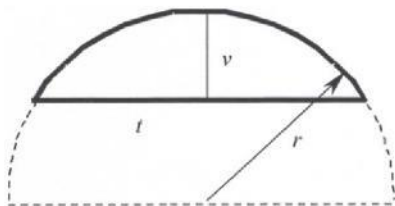
E20b Light beam passing through air concave lens – the rays are non-parallel to the optical axis (U17301)

The plane Π' which is perpendicular to the optical axis, combined with figure focus F' is called a figure focus plane. If a beam of perpendicular rays impinges the concave air lens, the rays cross the plane Π' at one point.



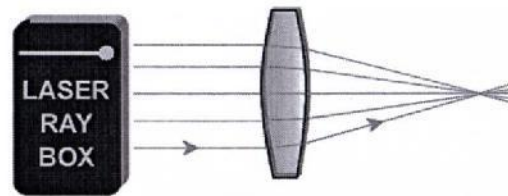
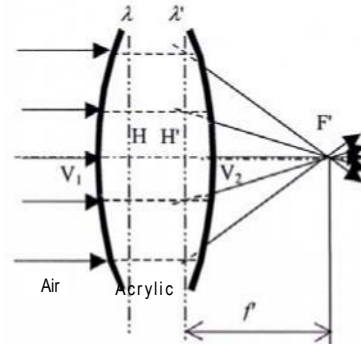
E21a Parameters of thick lenses – determination of radius of curvature (U17300/U17301)

The lenses in the set have cylindrical refraction surfaces with circular bottoms with equal radii of curvature. You can measure these radii by using a millimetre grid.



E21b Parameters of thick lenses – focal length (U17300/U17301)

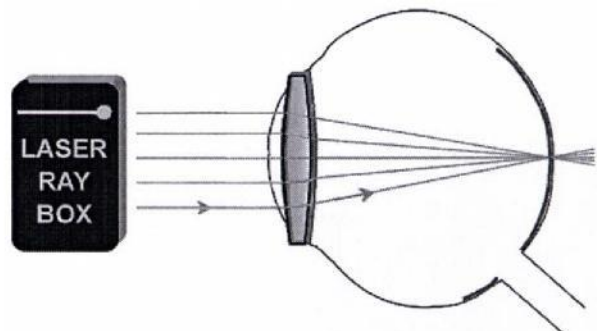
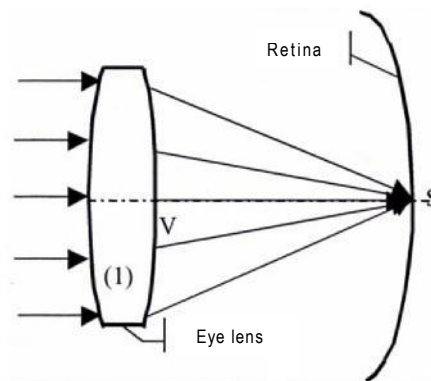
In the case of a thick lens (a lens with not negligible thickness) the definition of the focal length as a distance of the focus from the main planes (points – H and H'), must be taken into account.



E22a Model of a normal eye (U17300, transparency A)

Display rays parallel to the optical axis intersect after passing through uncorrected eye lens at one point of the retina.

Place the eye lens (1) directly behind the line O_2 .

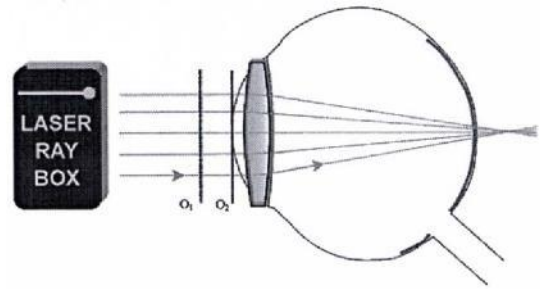
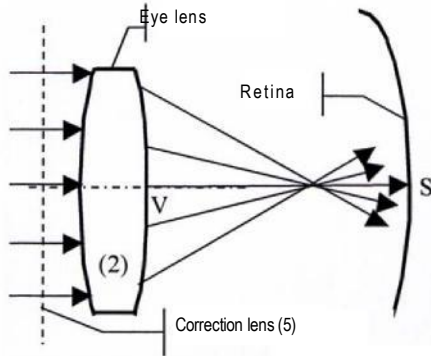


E22b Model of short-sighted eye

(U17300, transparency A)

Display rays parallel to the optical axis intersect after passing through uncorrected eye lens at one point of the optical axis before the retina.

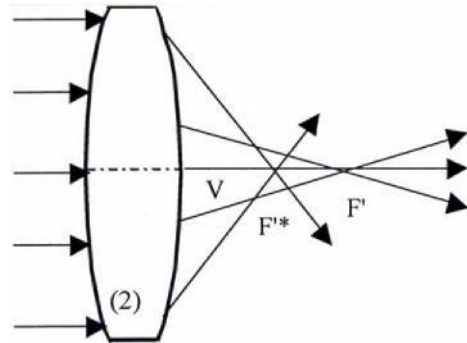
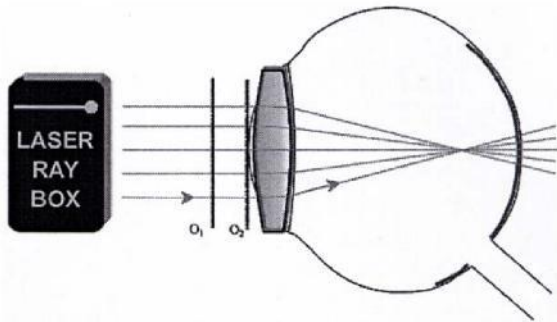
Place the eye lens (2) directly behind the line O_2 and the correction lens (5) between the lines O_1 and O_2 .



E23a Correction of spherical aberration by reducing the beam diameter

(U17300/U17301)

Spherical aberration of a lens can be reduced by reducing the diameter of the beam which impinges the lens. The rays which are far away from the optical axis must be obscured.



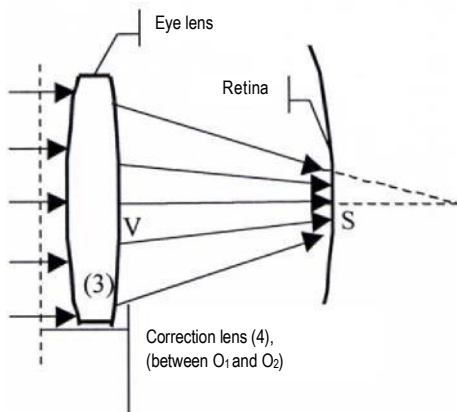
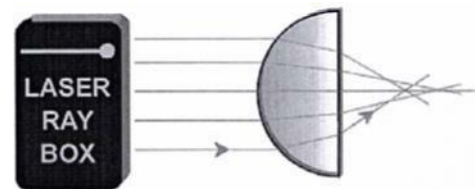
E22c Model of long-sighted eye

(U17300, transparency A)

Display rays parallel to the optical axis intersect after passing through uncorrected eye lens at one point of the optical axis after the retina. A correction lens must be convergent. The focal length f of the system of eye lens and the correction lens is:

$$= f \frac{1}{1 + \frac{f_2}{f_1}}$$

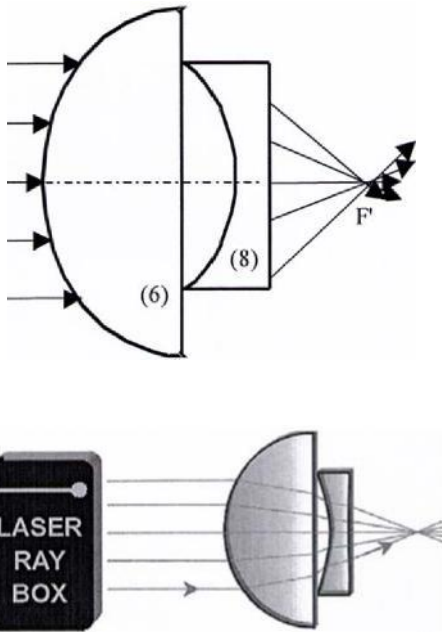
where f_1 is the focal length of the eye lens and f_2 is the focal length of the correction lens.



E23b Correction of spherical aberration by combination of lenses

(U17300, transparency E)

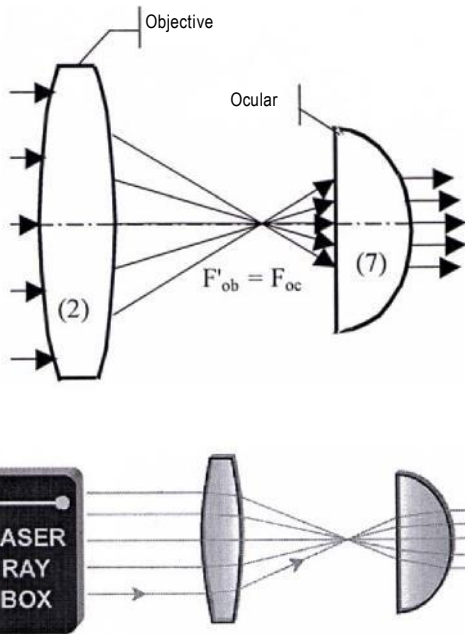
The spherical aberrations of divergent and convergent lenses have an inverse effect. By a convenient combination of these two types of lenses the aberration can be corrected. The aberration $\Delta f = f_1 - f_2$ is defined as the difference between the focal length f_1 of marginal beam rays and the focal length f_2 of paraxial rays. In the case of a convergent lens the aberration is of a plus sign and for a divergent lens it is a minus sign.



E24a Keplerian telescope

(U17300, transparency D)

The figure from Kepler's telescope is reversed. This can be verified by obscuring a marginal ray. One can see that if the top ray is obscured, in the output ray the bottom ray disappears. The figure is unreal and magnified.

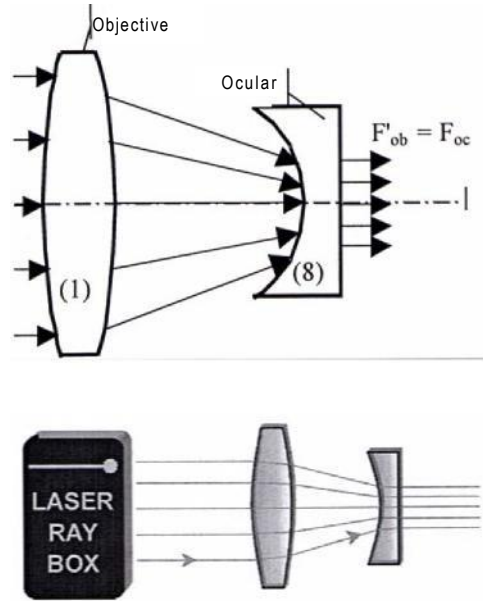


E24b Galileian telescope

(U17300, transparency C)

In this experiment the incident angle can be changed. The larger change of the output angle is observed (the viewing angle is magnified – the figure is magnified).

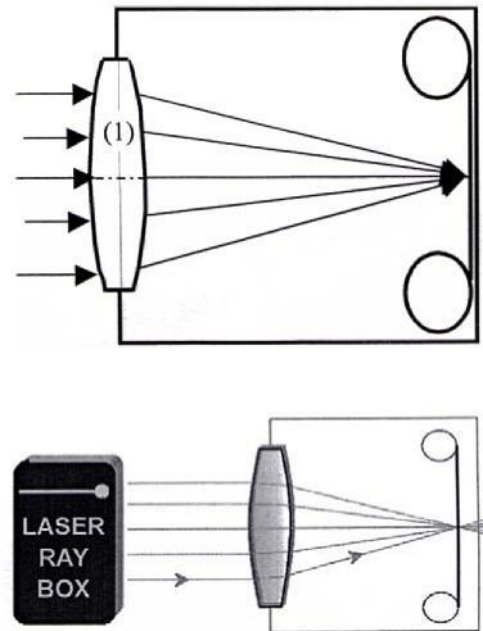
The figure is created by parallel rays, so it is unreal and magnified. If the top ray of the incident beam is obscured, the top ray of the output beam disappears.



E25 Camera

(U17300, transparency B)

The lens of the camera is a convergent optical system. The figure which appears on the rear part of the camera is real and reversed. It is directed onto the optical material.



Jeu d'optique laser de démonstration 1003049 et jeu complémentaire 1003050

Manuel d'utilisation

1/05 ALF

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Jeu d'optique laser de démonstration U17300 / 1003049
Jeu complémentaire laser de démonstration U17301 / 1003050

La colonne " Jeu d'appareils " propose le jeu d'appareils requis pour l'expérience en question, soit U17300, soit U17301, soit les deux.

Einleitung

Le jeu d'optique laser de démonstration permet le montage simple et clair d'expériences destinées à illustrer les principes de l'optique géométrique ainsi que le mode de fonctionnement de divers appareils optiques. Le laser à diodes, 5 rayons, U17302, servira de source lumineuse.

Ce manuel d'utilisation décrit de nombreuses expériences fondamentales utilisant les éléments optiques des deux jeux d'appareils U17300 et U17301. Chaque description d'expérience est composée de trois parties :

1. une description sommaire de l'expérience
2. une représentation graphique de l'expérience
3. une illustration du montage

Sous chaque titre, vous trouverez entre parenthèses le jeu d'appareils qui permet de réaliser l'expérience, U17300, U17301 ou U17300/U17301. La même indication est précisée dans la dernière colonne du sommaire.

Le laser à diodes U17302 constitue un élément central des expériences. Cinq diodes laser génèrent cinq rayons lumineux parallèles. Vous pouvez sélectionner le nombre de rayons lumineux émergents. Une plaque métallique fournie, présentant des alésages, est placée devant le laser à diodes. Evitez tout contact direct des yeux avec le rayon laser.

Éléments fournis

Jeu d'optique laser de démonstration U17300

- 1 Lentille biconcave
- 2 Lentille biconvexe
- 3 Lentille biconvexe
- 4 Lentille biconvexe
- 5 Lentille biconvexe
- 6 Petite lentille plan-concave
- 7 Petite lentille plan-convexe
- 8 Grande lentille plan-convexe

- 9 Miroir concave
- 10 Miroir convexe
- 11 Miroir plan
- 12 lame à faces parallèles
- 13 Prisme
- 14 Fibre optique

Feuilles

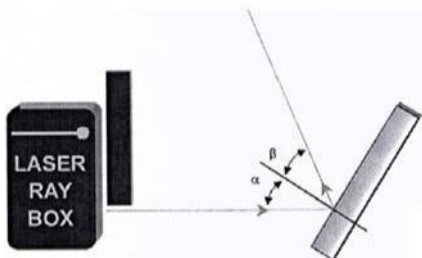
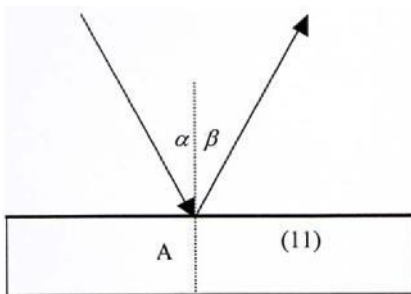
- A Modèle d'un œil
- B Appareil photo
- C Télescope d'après Galilée
- D Télescope d'après Kepler
- E Aberration sphérique
- F Graduation angulaire 360°

Jeu complémentaire U17301

- 21 Lentille d'air biconcave
- 22 Lentille biconcave
- 23 Lentille d'air biconvexe
- 24 Lentille biconvexe
- 25 Prisme d'air
- 26 Prisme équilatéral
- 27 2 prismes en angle droit
- 28 lame à faces parallèles carrée
- 29 2 lame à faces parallèles rectangulaires
- 11 2 miroirs plans

E1 Réflexion sur un miroir plan
(U17300/U17301)

Illustration de la loi de la réflexion. Un rayon lumineux qui rencontre la surface plane d'un miroir dans un angle d'incidence α est réfléchi dans un angle β . $\alpha = \beta$
Les deux angles sont mesurés par rapport à la normale.

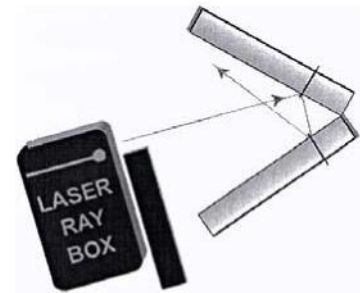
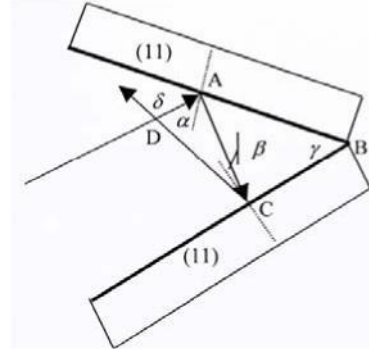


E2 Réflexion sur deux miroirs plans
(U17301)

Démonstration de l'équation :

$$\theta^{\text{TM}} = 2 \theta^{\text{C}}$$

l'angle θ^{TM} étant formé par le rayon incident et le rayon réfléchi et θ^{C} représentant l'angle entre les surfaces du miroir.

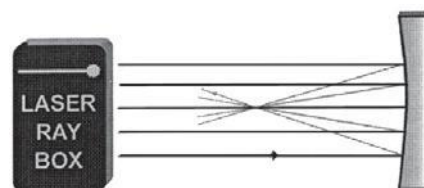
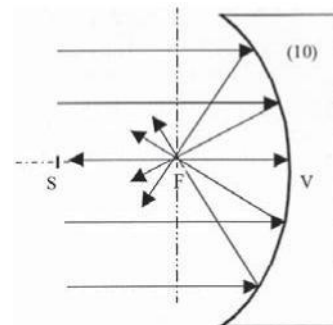


E3a Réflexion sur un miroir concave – Rayons lumineux parallèles à l'axe optique
(U17300)

La focale f d'un réflecteur de concentration est déterminée par la distance VF . Le rayon de courbure peut être calculé à l'aide de la formule

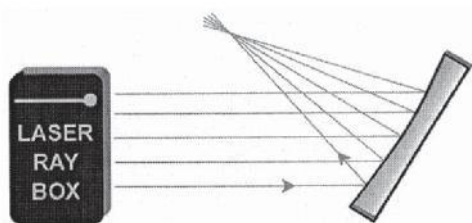
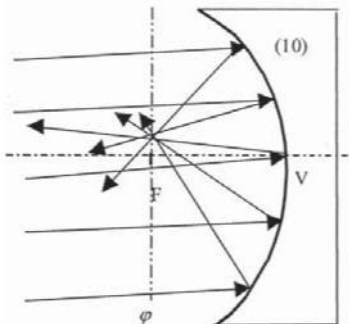
$$f = \frac{r}{2}$$

La distance VS est deux fois plus longue que VF .



E3b Réflexion sur un miroir concave – Rayons lumineux non parallèles à l'axe optique (U17300)

L'axe Π est perpendiculaire à l'axe optique et traverse le foyer. On l'appelle le plan focal. Les rayons incidents parallèles sont réfléchis et se rencontrent sur le plan focal Π . Si les rayons sont parallèles à l'axe optique, le foyer F se situe par-dessus.

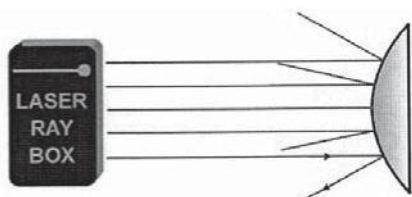
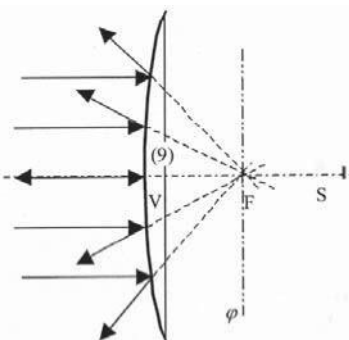


E4a Réflexion sur un miroir convexe – Rayons lumineux parallèles à l'axe optique (U17300)

Les rayons réfléchis semblent partir d'un point situé derrière le miroir. Il s'agit du foyer virtuel. La distance VF détermine la focale du miroir. Le rayon de courbure peut être calculé à l'aide de la formule

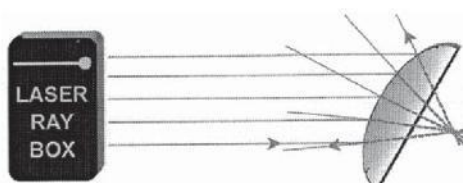
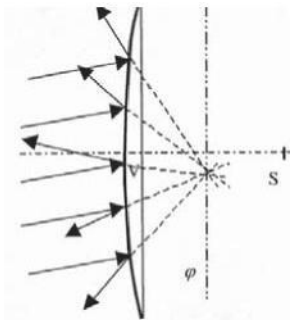
$$f = \frac{r}{2}$$

La distance VS est deux fois plus longue que VF.



E4b Réflexion sur un miroir convexe – Rayons lumineux non parallèles à l'axe optique (U17300)

L'axe Π est perpendiculaire à l'axe optique et traverse le foyer. On l'appelle le plan focal. Si les rayons tombant sur le miroir sont parallèles, ils sont divergés de telle sorte qu'on a l'impression qu'ils partent d'un point situé sur le plan focal Π derrière le miroir.

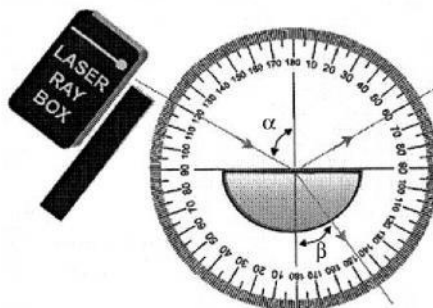
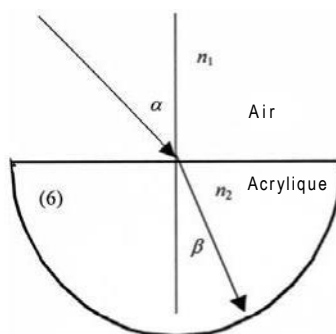


E5a Réfraction d'un rayon lumineux lors du passage de l'air vers l'acrylique (U17300, feuille F)

Lors du passage d'un rayon d'un milieu d'indice de réfraction n_1 vers un milieu d'indice de réfraction n_2 , son changement de direction est déterminé par la loi de la réfraction de Snellius :

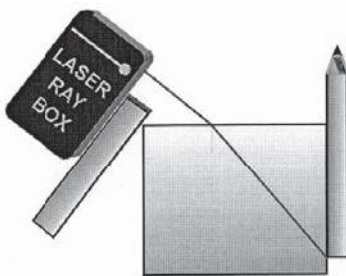
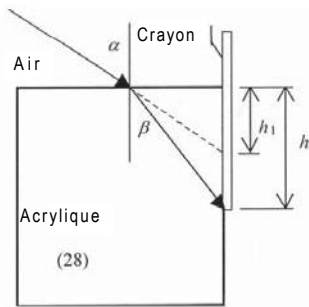
$$n_1 \sin \alpha = n_2 \sin \beta$$

α est l'angle d'incidence dans le milieu n_1 et β l'angle de réfraction dans le milieu n_2 .



E5b Profondeur virtuelle d'un objet
(U17301)

Expérience permettant d'observer la profondeur virtuelle d'un objet dans de l'eau ou derrière de l'acrylique, vu depuis l'air.

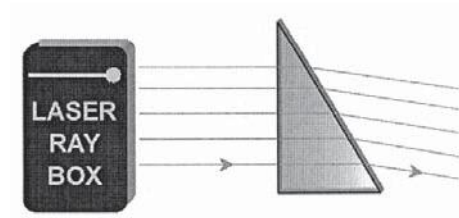
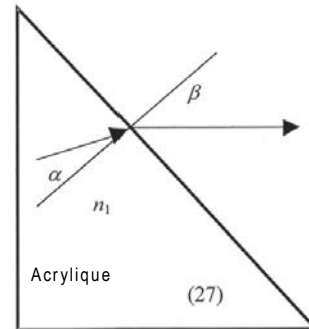


E6b Réfraction sur un prisme acrylique
(U17300/U17301)

Lors du passage d'un rayon lumineux de l'acrylique vers l'air, on peut écrire la loi de Snellius sous la forme suivante :

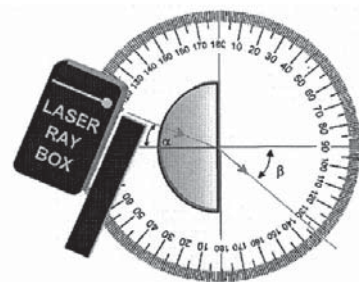
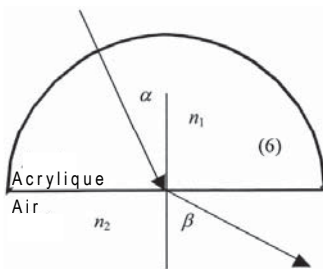
$$n_1 \sin \alpha = n_2 \sin \beta$$

Indice de réfraction $n_2 = 1$.



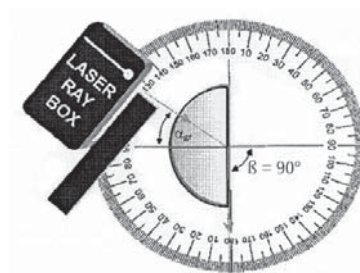
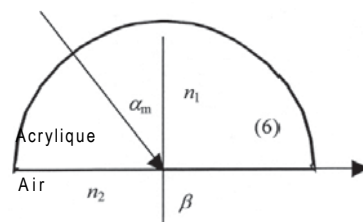
E6a Réfraction d'un rayon lumineux lors du passage de l'acrylique vers l'air
(U17300, feuille F)

L'angle de réfraction β est supérieur à l'angle d'incidence α . Le rayon est réfracté en s'écartant de la normale.



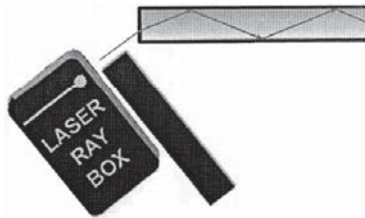
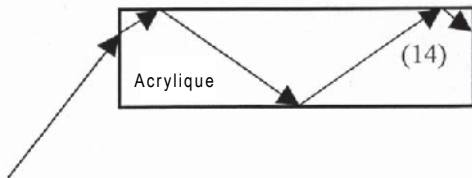
E6c Angle critique, réflexion totale
(U17300, feuille F)

Plus l'angle d'incidence est élevé, plus l'angle de réfraction est important. Si $n_1 < n_2$, on obtient un angle critique α_c . Le rayon réfracté se situe alors à la surface limite entre les deux milieux. Si l'angle d'incidence est supérieur à l'angle critique, il n'y a plus de réfraction et toute la lumière est réfléchi. Dans ce cas, on parle de réflexion totale.



E6d Réflexion totale – Propagation de la lumière dans des fibres optiques
(U17300)

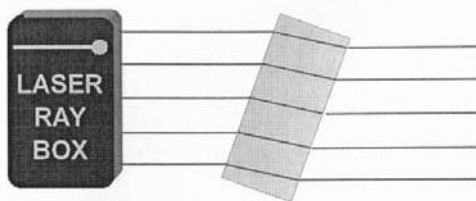
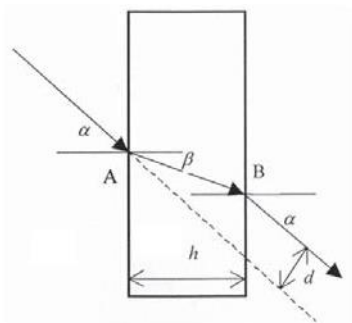
De la lumière se propage dans une fibre optique par la réflexion totale. Le paramètre, l'ouverture numérique, détermine l'angle qui ne doit pas être dépassé. Il correspond au sinus de l'angle d'entrée maximum de la lumière. Lorsque la fibre optique est pliée, ce paramètre détermine également le plus petit rayon. Il ne peut pas passer au-dessous de la valeur minimum lorsque la fibre optique est installée.



E7 Décalage d'un rayon lumineux, lame acrylique à faces parallèles
(U17300/U17301)

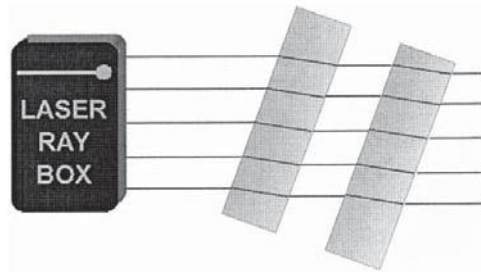
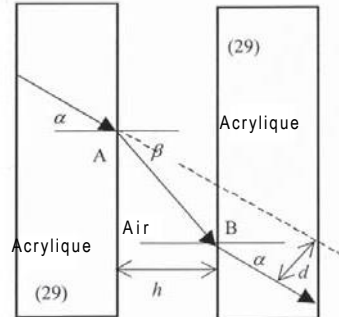
Lorsqu'un rayon lumineux traverse une lame à faces parallèles, sa direction n'est pas modifiée. Le rayon émergent est décalé de la distance d . Avec une épaisseur de lame h , on obtient pour d :

$$d = h \frac{\sin(\alpha - \beta)}{\cos \beta}$$



E8 Décalage d'un rayon lumineux, air entre deux lames acryliques à faces parallèles
(U17301)

Dans ce cas, on observe un décalage entre le rayon incident et le rayon émergent. En revanche, ce décalage va dans le sens contraire à celui observé dans le cas de la plaque acrylique.



E9a Déflexion d'un rayon lumineux à travers un prisme acrylique
(U17300/U17301)

Dans un prisme acrylique, un rayon incident est réfracté au point A vers la normale. Au point d'émergence B, la réfraction s'écarte de la normale. La somme de tous les angles de réfraction est l'angle de déflexion Δ . Il s'agit de l'angle entre le rayon incident et le rayon émergent.

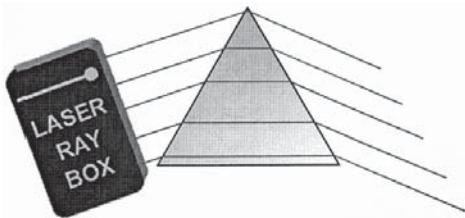
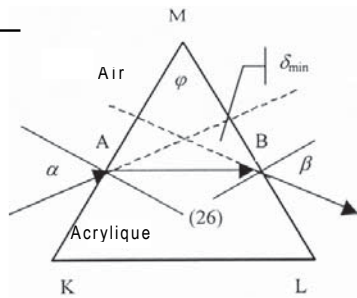
Air Acrylique



E9b Déflexion minimum à travers un prisme acrylique
(U17300/U17301)

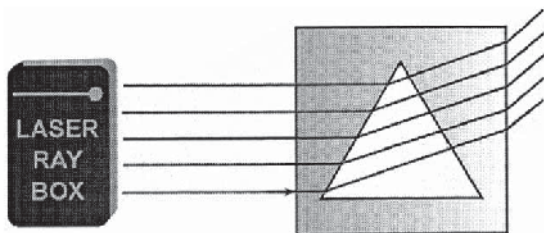
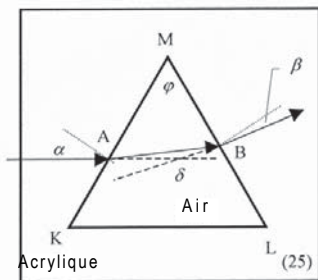
On peut montrer que l'angle d'incidence α , avec un angle de déflexion minimum δ_{min}^M , est égal à l'angle d'émergence β . Dans le prisme, le rayon réfracté est alors parallèle au côté qui n'est pas traversé. On peut appliquer l'équation suivante pour calculer l'indice de réfraction du prisme :

$$n = \frac{\sin \frac{\alpha + \beta}{2}}{\sin \frac{\phi}{2}}$$



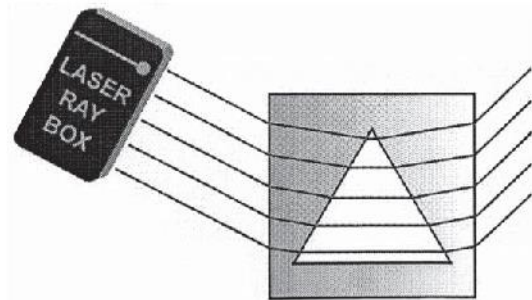
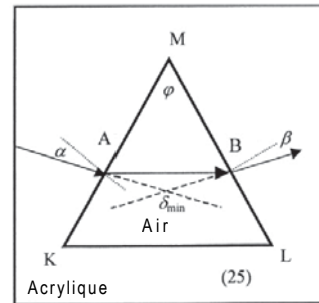
E10a Déflexion d'un rayon lumineux à travers un prisme d'air
(U17301)

De la lumière traverse la surface limite acrylique-air au point A. 1er rayon est réfracté en s'écartant de la normale. Au point B, il est réfracté dans la direction de la normale. La somme de tous les angles de réfraction est l'angle de déflexion δ^M . Il s'agit de l'angle entre le rayon incident et le rayon émergent.



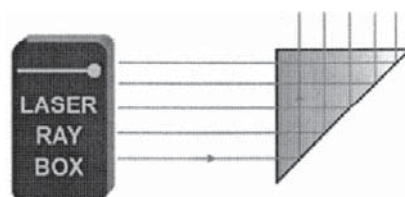
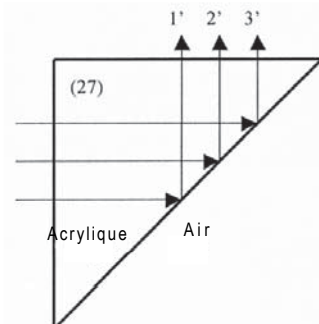
E10b Déflexion minimum à travers un prisme d'air
(U17301)

En présence d'un angle de déflexion minimum δ_{min}^M , l'angle d'incidence α est égal à l'angle d'émergence β . Dans le prisme, le rayon réfracté est alors parallèle au côté qui n'est pas traversé. On peut appliquer l'équation suivante pour calculer l'indice de réfraction du prisme : (voir E9b). 1er sens de la déflexion est l'inverse de celui d'un prisme acrylique.



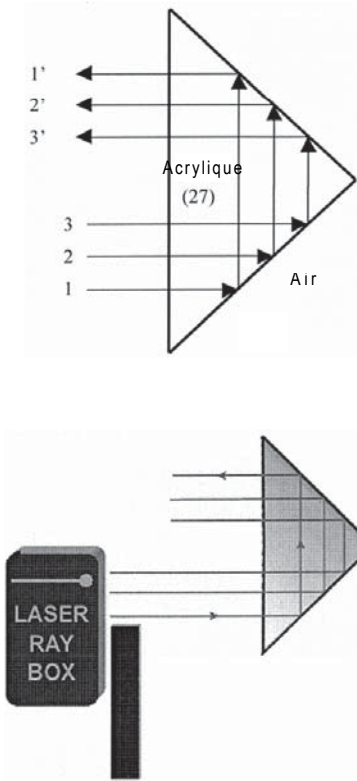
E11a Réflexion sur une arête d'un prisme acrylique
(U17301)

Lorsqu'ils touchent l'arête, les rayons sont entièrement réfléchis. Si l'on tourne légèrement le prisme, on peut observer tant une réfraction qu'une réflexion.



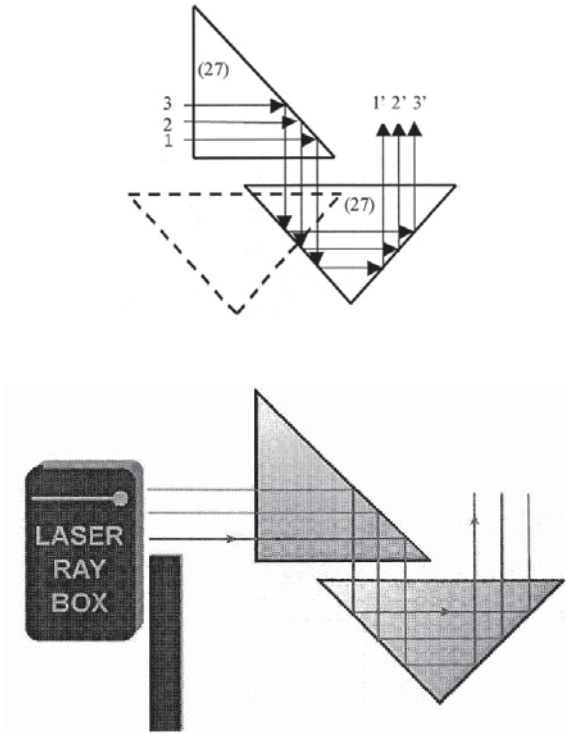
E11b Réflexion sur deux arêtes d'un prisme acrylique (U17301)

Dans ce cas, les conditions sont remplies pour obtenir une réflexion totale sur les deux arêtes. Si le rayon incident supérieur est masqué, le rayon émergent inférieur disparaît. L'image est inversée à 180°.



E11d Réflexion sur deux prismes acryliques (U17301)

Les conditions sont remplies pour obtenir une réflexion totale sur toutes les arêtes des prismes.

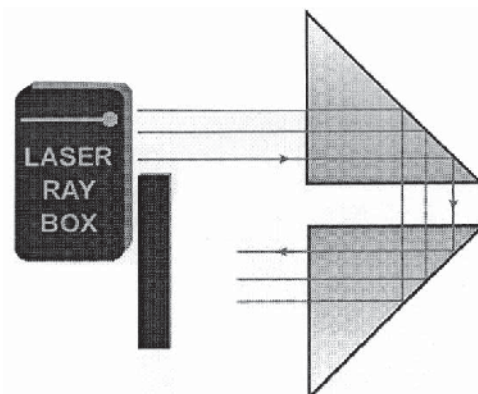
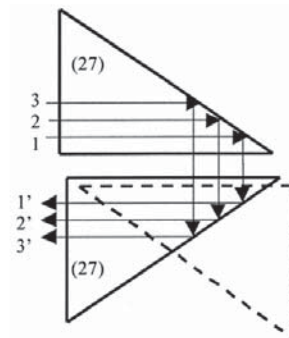
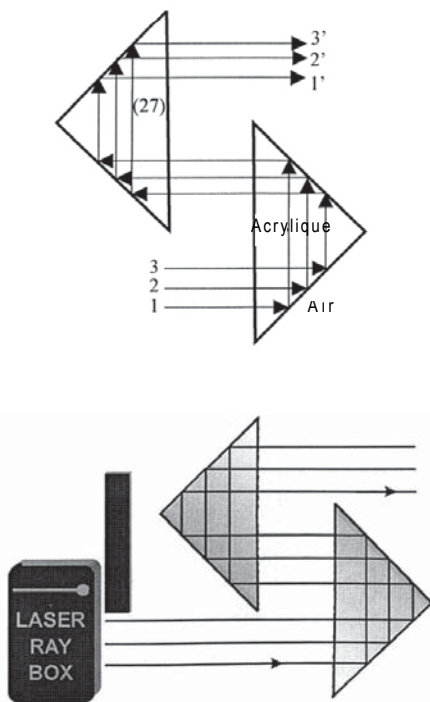


E11e Réflexion sur deux prismes acryliques (U17301)

Les conditions sont remplies pour obtenir une réflexion totale sur toutes les arêtes des prismes.

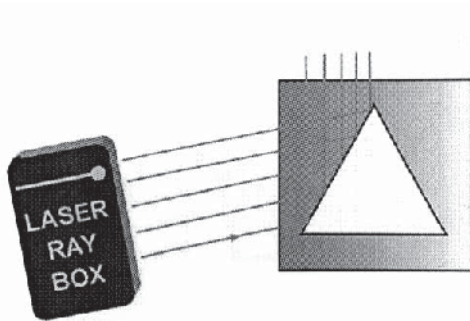
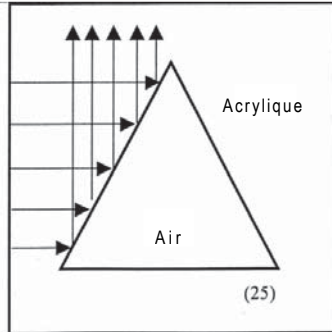
E11c Réflexion sur deux prismes acryliques (U17301)

Les conditions sont remplies pour obtenir une réflexion totale sur toutes les arêtes des prismes.



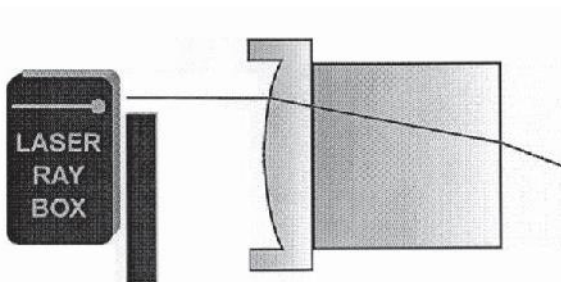
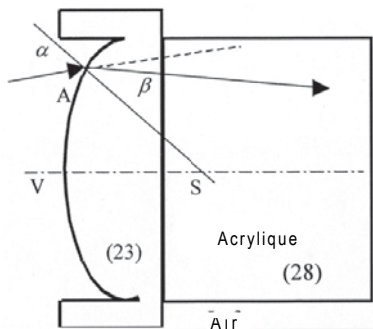
[12 Réflexion sur un prisme d'air
(U17301)

Si l'angle d'incidence des rayons lumineux est inférieur à l'angle critique (42°), les rayons sont réfléchis vers l'acrylique. Si l'angle est supérieur, une partie de la lumière traversera le prisme d'air.



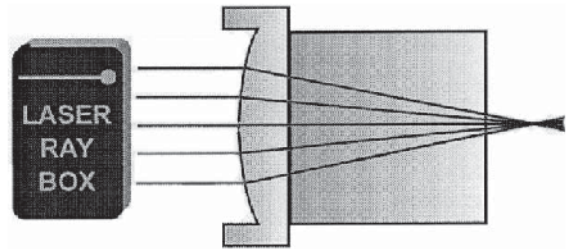
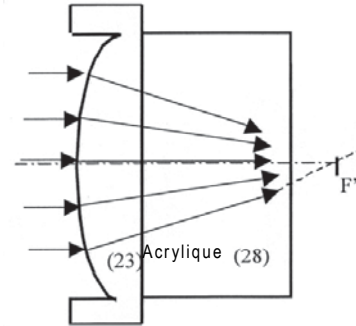
[13a Passage d'un rayon lumineux à travers une surface limite convexe air-acrylique
(U17301)

Si un rayon lumineux traverse la surface limite air-acrylique au point A, il est réfracté vers la normale. La normale est la droite reliant le point A au point central de courbure S.



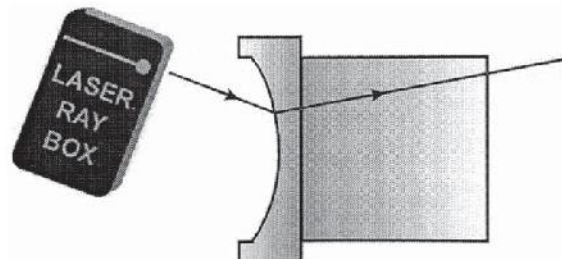
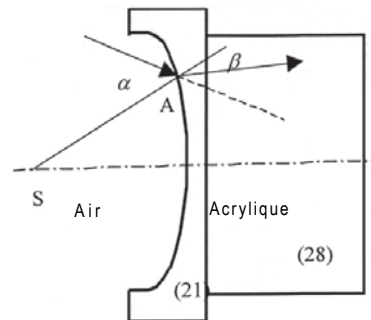
[13b Passage de rayons lumineux à travers une surface limite convexe air-acrylique
(U17301)

Les rayons incidents sont réfractés à deux reprises et se rencontrent sur l'axe optique au point F', au foyer.



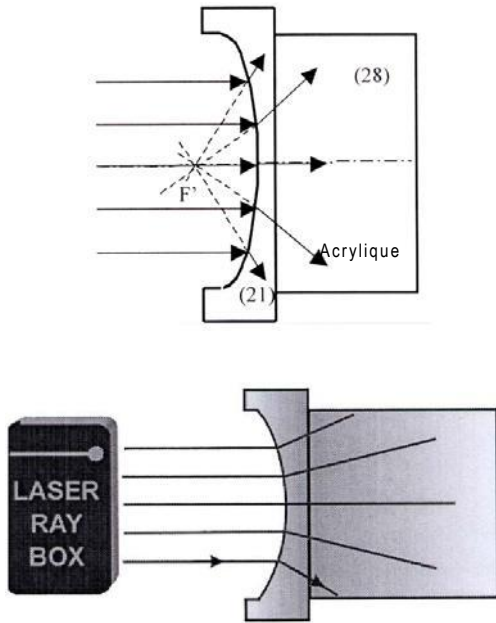
[14a Passage d'un rayon lumineux à travers une surface limite concave air-acrylique
(U17301)

Si le rayon lumineux rencontre la surface limite au point A, on observe une réfraction vers la normale. La normale est la droite reliant le point A au point central de courbure S.



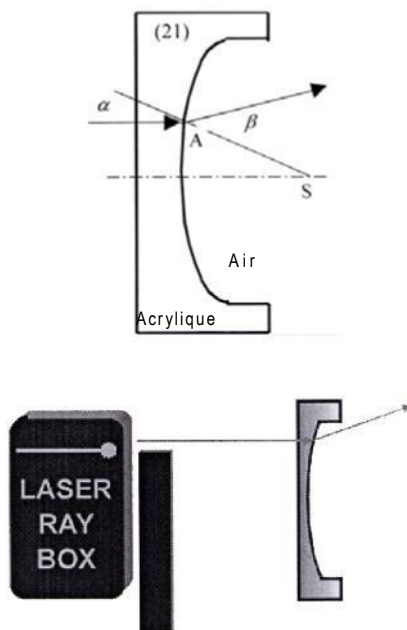
E14b Passage de rayons lumineux à travers une surface limite concave air-acrylique
(U17301)

Lorsque le faisceau a traversé la surface limite acrylique-air, il subit une réfraction divergente. Si les rayons réfractés sont prolongés vers l'arrière, ils se rencontrent en un point de l'axe optique. Ce point est le foyer virtuel F' .



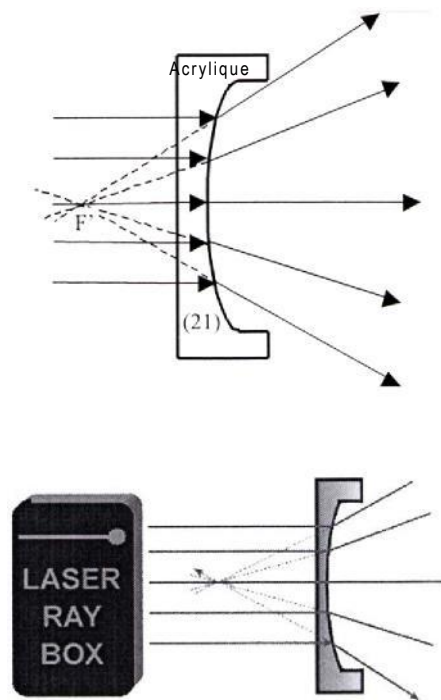
E15a Passage d'un rayon lumineux à travers une surface limite convexe acrylique-air
(U17301)

Lorsque le faisceau a traversé le point A, il est réfracté en s'écartant de la normale. La normale est la droite reliant le point A au point central de courbure S.



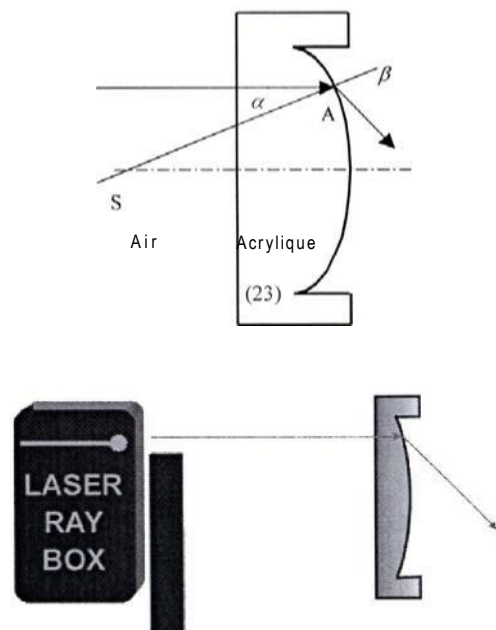
E15b Passage de rayons lumineux à travers une surface limite convexe acrylique-air
(U17301)

Lorsque le faisceau a traversé la surface limite acrylique-air, il subit une réfraction divergente. Si les rayons réfractés sont prolongés vers l'arrière, ils se rencontrent en un point de l'axe optique. Ce point est le foyer virtuel F' .



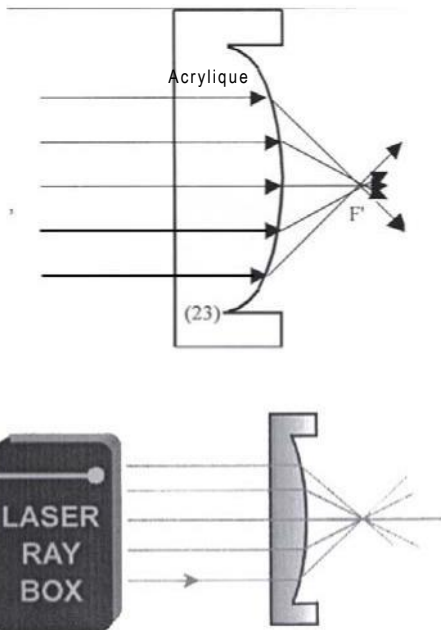
E16a Passage d'un rayon lumineux à travers une surface limite concave acrylique-air
(U17301)

Lorsque le faisceau a traversé le point A, il est réfracté en s'écartant de la normale. La normale est la droite reliant le point A au point central de courbure S.



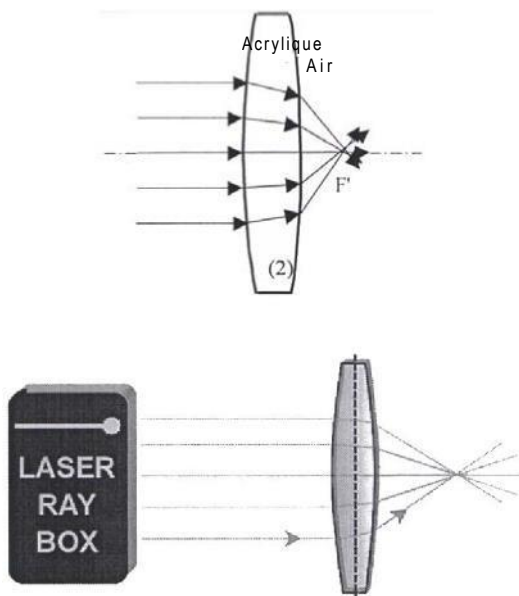
E16b Passage de rayons lumineux à travers une surface limite concave acrylique-air
(U17301)

Lorsque le faisceau a traversé la surface limite, il devient convergent. Des rayons parallèles se rencontrent en un point de l'axe optique, le foyer F' .



E17a Passage de rayons lumineux à travers une lentille convexe – Rayons lumineux parallèles à l'axe optique
(U17300/U17301)

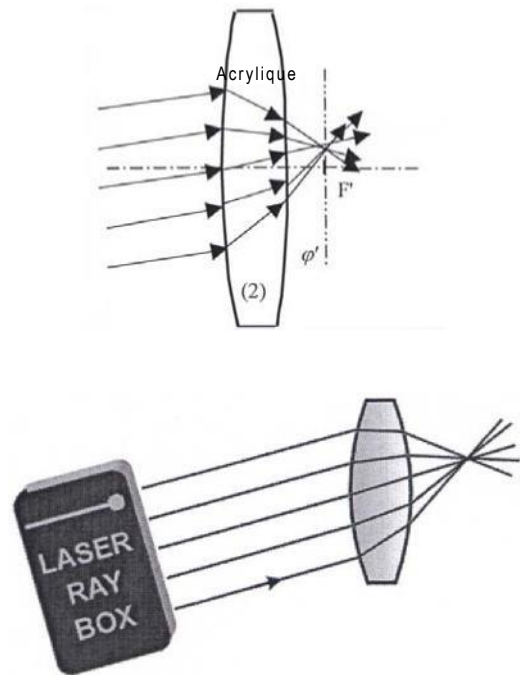
Une lentille acrylique convexe est une lentille de convergence et, après avoir traversé la lentille, les rayons lumineux se rencontrent au foyer F' .



E17b Passage de rayons lumineux à travers une lentille convexe – Rayons lumineux non parallèles à l'axe optique
(U17300/U17301)

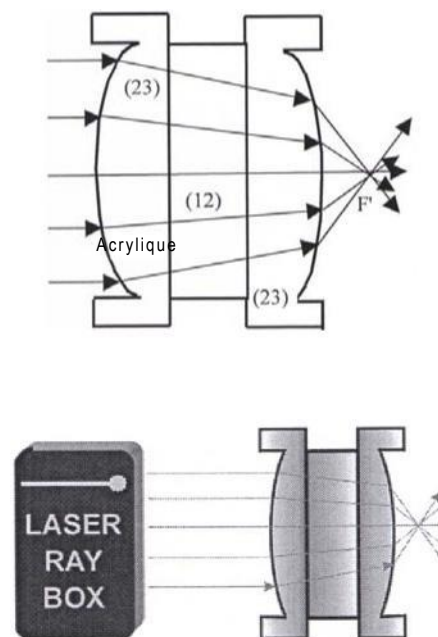
L'axe $\Pi\Pi'$ est perpendiculaire à l'axe optique et traverse le foyer F' . On l'appelle le plan focal. Les rayons

incidents sont réfractés et se rencontrent en un point sur l'axe $\Pi\Pi'$.



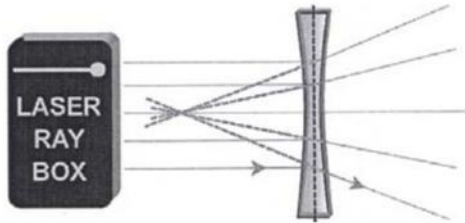
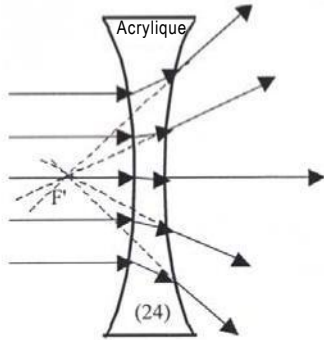
E17c Passage de rayons lumineux à travers une lentille acrylique convexe épaisse
(U17301)

En plaçant une lame à faces parallèles entre deux lentilles (23), on peut illustrer le modèle d'une lentille épaisse. En modifiant l'épaisseur d de la lentille, on modifie en même temps la focale. Plus la lentille est épaisse, plus la focale est petite. A partir d'une épaisseur critique, la lentille de convergence devient une lentille divergente.



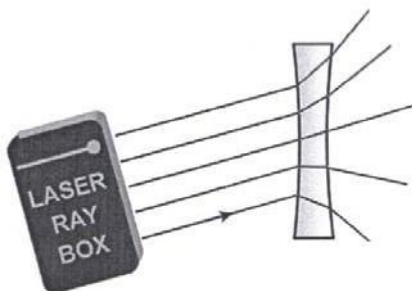
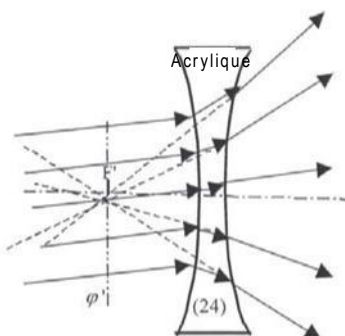
E18a Passage de rayons lumineux à travers une lentille concave – Rayons lumineux parallèles à l'axe optique
(U17300/U17301)

Après avoir traversé la lentille, les rayons lumineux sont divergents. La lentille ne projette aucune d'image. Prolongés vers l'arrière, les rayons se rencontrent au foyer virtuel F' .



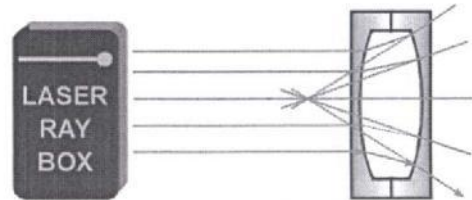
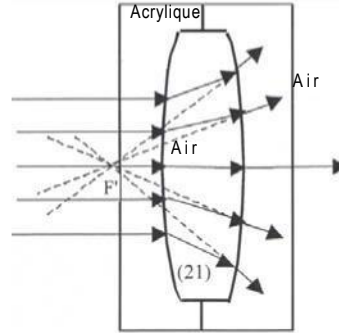
E18b Passage de rayons lumineux à travers une lentille concave – Rayons lumineux non parallèles à l'axe optique
(U17300/U17301)

L'axe Π' est perpendiculaire à l'axe optique et traverse le foyer virtuel F' . On l'appelle le plan focal. Si les rayons réfractés sont prolongés, ils se rencontrent en un point sur l'axe Π' .



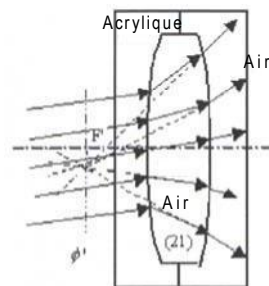
E19a Passage de rayons lumineux à travers une lentille d'air convexe – Rayons lumineux parallèles à l'axe optique
(U17301)

Après avoir traversé la lentille, les rayons lumineux sont divergents. La lentille ne projette aucune d'image. Prolongés vers l'arrière, les rayons se rencontrent au foyer virtuel F' .

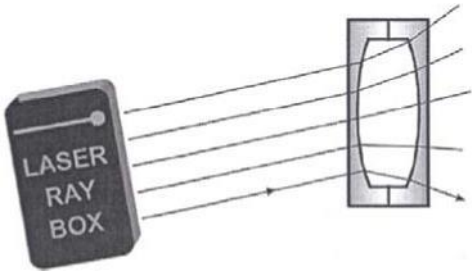


E19b Passage de rayons lumineux à travers une lentille d'air convexe – Rayons lumineux non parallèles à l'axe optique
(U17301)

L'axe Π' est perpendiculaire à l'axe optique et traverse le foyer virtuel F' . On l'appelle le plan focal. Si les rayons réfractés sont prolongés, ils se rencontrent en un point sur l'axe Π' .

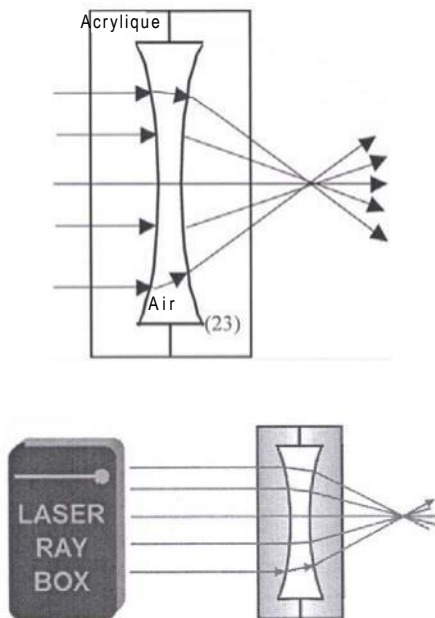


sur l'axe Π' .



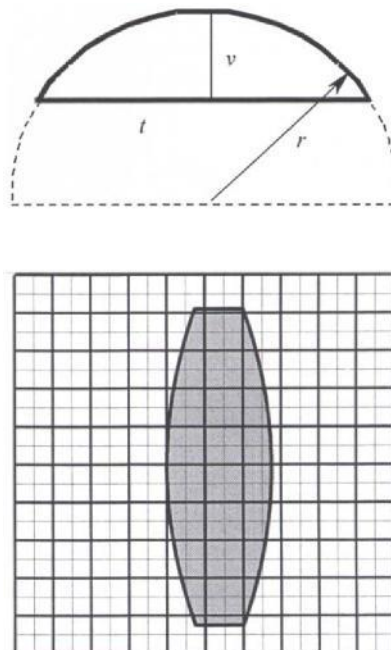
E20a Passage de rayons lumineux à travers une lentille d'air concave – Rayons lumineux parallèles à l'axe optique
(U17301)

Une lentille d'air concave se comporte comme une lentille de convergence et, après avoir traversé la lentille, les rayons lumineux se rencontrent au foyer F' .



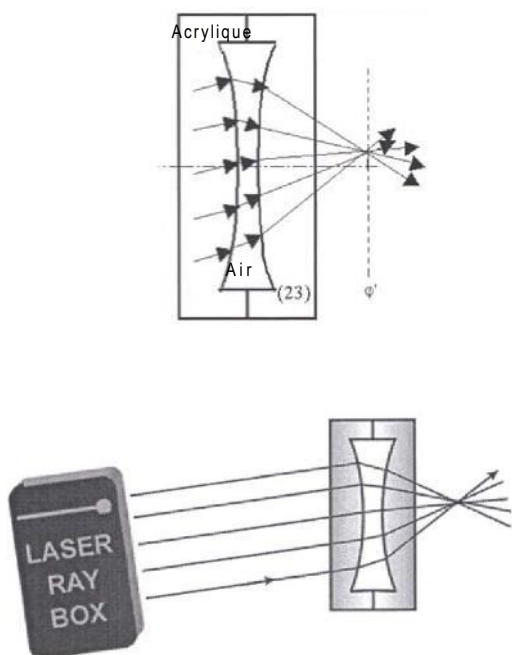
E21a Paramètres de lentilles épaisses – Détermination du rayon de courbure
(U17300/U17301)

Les lentilles du jeu d'optique laser présentent une surface de réfraction cylindrique sur base circulaire avec les mêmes rayons de courbure. Du papier millimétrique permet de déterminer ces rayons.



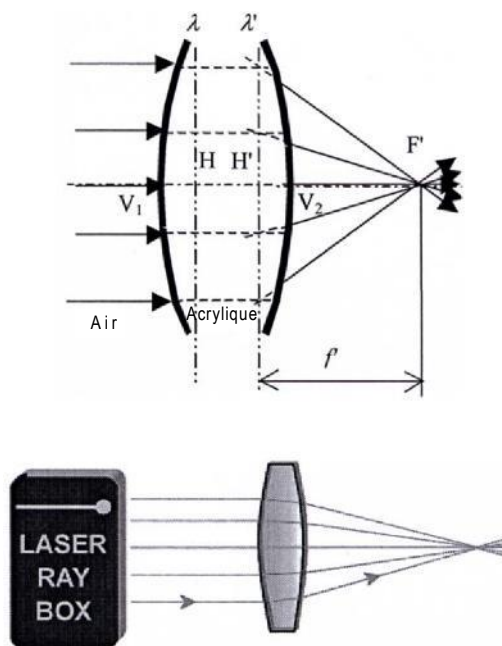
E20b Passage de rayons lumineux à travers une lentille d'air concave – Rayons lumineux parallèles à l'axe optique
(U17301)

L'axe $\Pi\Pi'$ est perpendiculaire à l'axe optique et traverse le foyer F' . On l'appelle le plan focal. Si les rayons réfractés sont prolongés, ils se rencontrent en un point sur l'axe $\Pi\Pi'$.



E21b Paramètres de lentilles épaisses – Distance focale
(U17300/U17301)

Ce sont des lentilles dont l'épaisseur n'est pas négligeable. Lors de la définition de la focale, il faut tenir compte de l'écart entre les deux plans principaux H et H' .

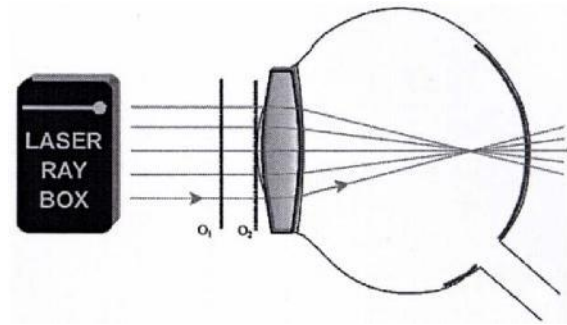
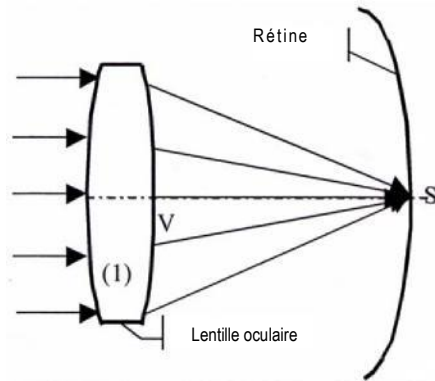


E22a Modèle d'un œil

(U17300, feuille A)

Les rayons parallèles à l'axe optique sont réfractés par la lentille oculaire et se rencontrent en un point sur la rétine.

Placer la lentille oculaire (1) directement derrière la ligne O_2 .



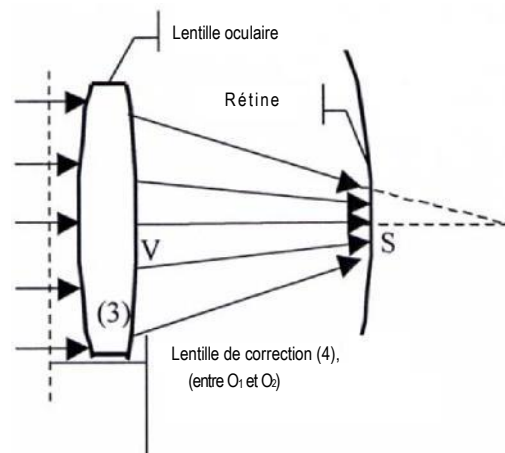
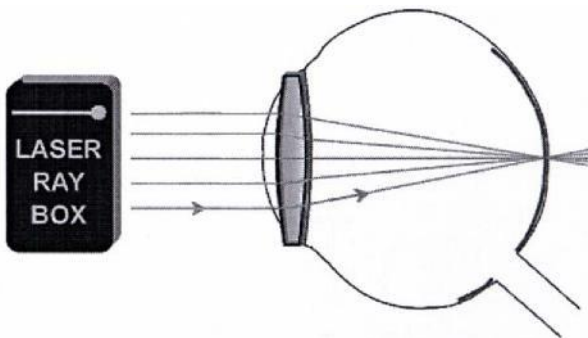
E22c Modèle d'un œil, hypermétropie

(U17300, feuille A)

Les rayons parallèles à l'axe optique sont réfractés par la lentille oculaire et se rencontrent en un point derrière la rétine. Une lentille de correction est une lentille de convergence. L'équation suivante permet de calculer la focale f du système de lentilles :

$$= f \frac{1}{1 + \frac{f_2}{f_1}}$$

f_1 étant la focale de la lentille oculaire et f_2 la lentille de correction.

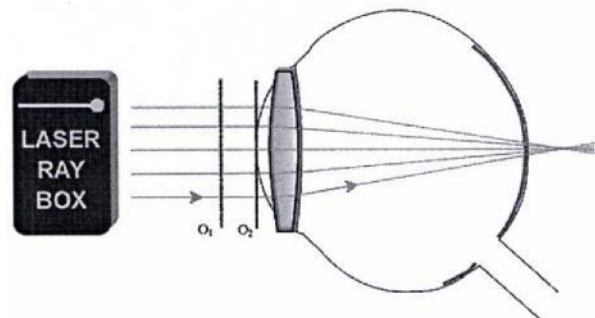
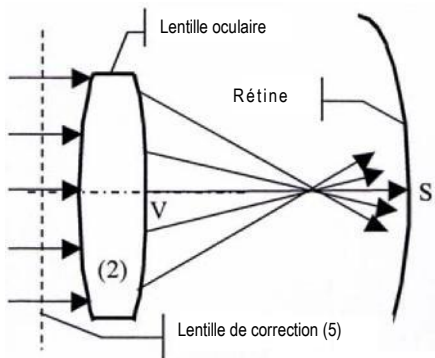


E22b Modèle d'un œil, myopie

(U17300, feuille A)

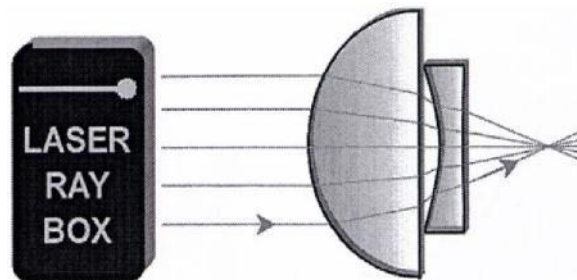
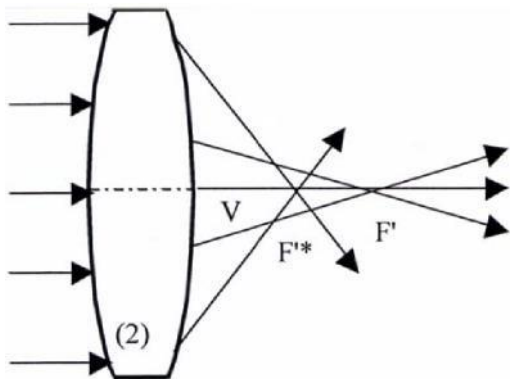
Les rayons parallèles à l'axe optique sont réfractés par la lentille oculaire et se rencontrent en un point devant la rétine.

Placez la lentille oculaire (2) directement derrière la ligne O_2 et la lentille de correction (5) entre les lignes O_1 et O_2 .



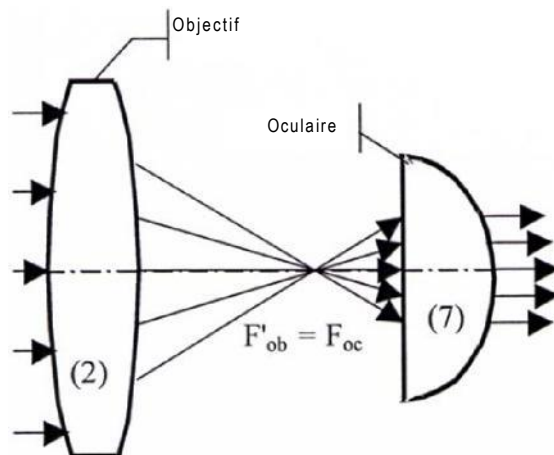
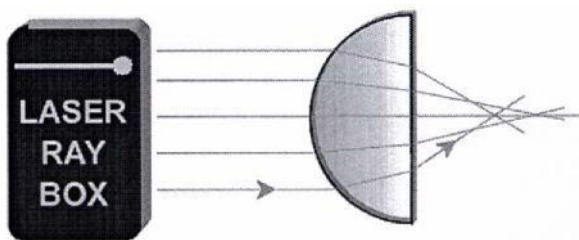
E23a Correction d'une aberration sphérique par la réduction du diamètre de faisceau
(U17300/U17301)

Pour réduire l'aberration sphérique d'une lentille, on peut diminuer le diamètre du faisceau qui traverse la lentille. Il suffit de masquer les rayons se trouvant sur les bords extérieurs.



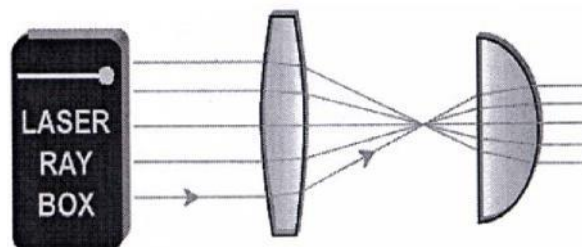
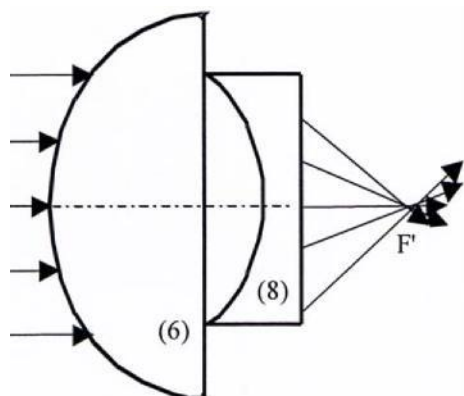
E24a Télescope d'après Kepler
(U17300, feuille D)

L'objectif dans le télescope de Kepler génère une image réelle réduite de l'objet observé, agrandie par l'oculaire qui fait fonction de loupe. L'image est inversée (le haut et le bas, ainsi que la gauche et la droite sont inversés) et fortement agrandie. Pour illustrer ce phénomène, masquez l'un des rayons se trouvant sur les bords extérieurs. Si le rayon incident supérieur est masqué, le rayon émergent inférieur disparaît.



E23b Correction de l'aberration sphérique par une combinaison de lentilles
(U17300, feuille E)

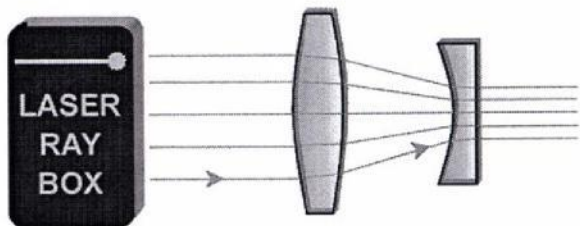
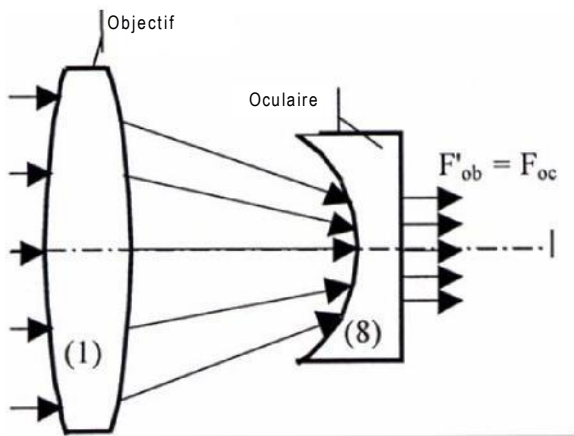
L'aberration sphérique de lentilles de convergence et de divergence ont un effet inverse. Une combinaison de lentilles permet de corriger cette erreur. L'aberration $\otimes f = f_1 - f_2$ est définie comme la différence entre la focale f_1 des rayons extérieurs et la focale f_2 des rayons intérieurs. Avec les lentilles convergentes, l'aberration a un signe positif et avec les lentilles divergentes, elle présente un signe négatif.



E24b Télescope d'après Galilée

(U17300, feuille C)

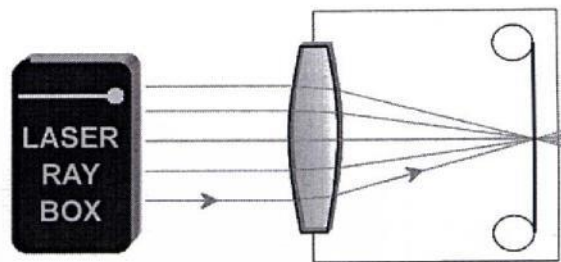
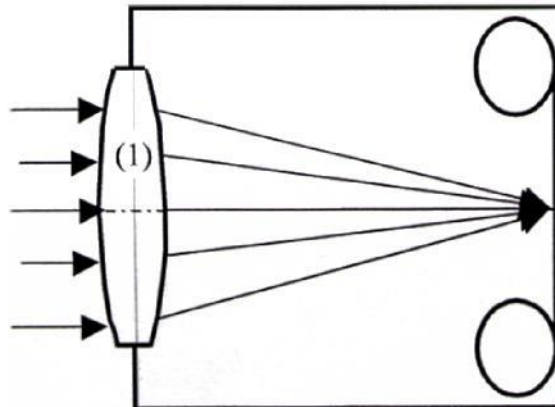
Dans la lunette de Galilée, les rayons provenant de l'objectif rencontrent une lentille divergente avant d'atteindre le foyer. Les rayons atteignent l'œil parallèlement. L'image de l'objet est agrandie, droite et à l'envers.



E25 Appareil photo

(U17300, feuille B)

La lentille de l'appareil photo est une lentille de convergence. Sur le film se trouvant à l'arrière de l'appareil, elle génère une image réelle, mais à l'envers, d'un objet.



1003049 Set dimostrativo di ottiche per laser (U17300) e 1003050 set supplementare (U17301)

Istruzioni per l'uso

1/05 ALF

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Set dimostrativo di ottiche per laser U17300 / 1003049
 Kit aggiuntivo U17301 / 1003050

La colonna "Kit da utilizzare" elenca i kit necessari per i rispettivi esperimenti, 1003049, 1003050 o entrambi.

Introduzione

Il set dimostrativo di ottiche per laser consente di ottenere strutture per esperimenti semplici e chiare per la rappresentazione dei principi dell'ottica geometrica e del funzionamento di apparecchi ottici diversi. Come sorgente luminosa si utilizza il laser a diodi a 5 raggi U17302.

Le presenti istruzioni per l'uso contengono le descrizioni di vari esperimenti fondamentali con gli elementi ottici dei due kit U17300 e U17301. Ciascuna descrizione degli esperimenti è suddivisa in tre parti:

1. Una descrizione semplice dell'esperimento
2. Una rappresentazione grafica dell'esperimento
3. Una raffigurazione della struttura dell'esperimento

Sotto il titolo dell'esperimento, tra parentesi è indicato il kit da utilizzare per l'esecuzione dell'esperimento, U17300, U17301 o U17300/U17301. La stessa nota è riportata anche nell'ultima colonna del sommario. Una parte molto importante delle strutture degli esperimenti è il laser a diodi U17302. Cinque diodi laser generano cinque fasci luminosi paralleli. È possibile scegliere il numero dei fasci luminosi emessi. A tale scopo, la dotazione del laser comprende una piastra di metallo con fori da collocare davanti al laser a diodi. Durante l'uso del laser, evitare di rivolgere lo sguardo direttamente verso il raggio laser.

Fornitura

Set dimostrativo di ottiche per laser U17300

- 1 Lente biconcava
- 2 Lente biconvessa
- 3 Lente biconvessa
- 4 Lente biconvessa
- 5 Lente biconvessa
- 6 Lente pianoconcava piccola
- 7 Lente pianoconvessa piccola
- 8 Lente pianoconvessa grande
- 9 Specchio, concavo
- 10 Specchio, convesso
- 11 Specchio piano
- 12 Lastra pianparallela
- 13 Prisma
- 14 Fotoconduttore

Pellicole

- A Modello di occhio
- B Fotocamera
- C Telescopio galileiano
- D Telescopio kepleriano
- E Aberrazione sferica
- F Scala angolare 360°

Set supplementare U17301

- 21 Lente di aria biconcava
- 22 Lente biconcava
- 23 Lente di aria biconvessa
- 24 Lente biconvessa
- 25 Prisma di aria
- 26 Prisma equilatero
- 27 2 prismi rettangolari
- 28 Lastra pianparallela, quadrata
- 29 2 lastre pianparallele, rettangolari 11
- 2 Specchio piano

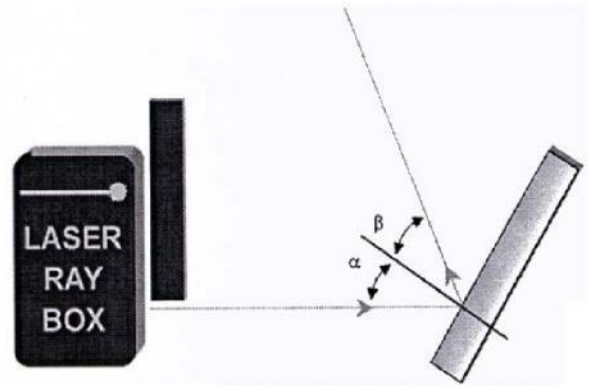
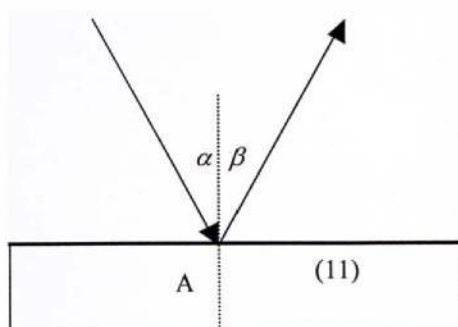
E1 Riflessione su specchio piano

(U17300/U17301)

Rappresentazione della legge di riflessione. Un fascio luminoso incidente sotto l'angolo di incidenza α su una superficie a specchio piano, viene riflesso sotto l'angolo β

$$\alpha = \beta$$

Entrambi gli angoli vengono misurati verso la perpendicolare incidente.



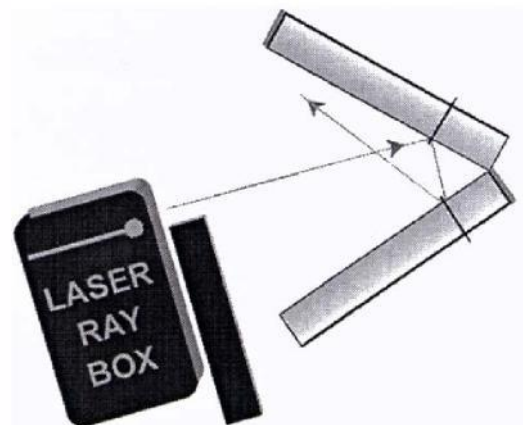
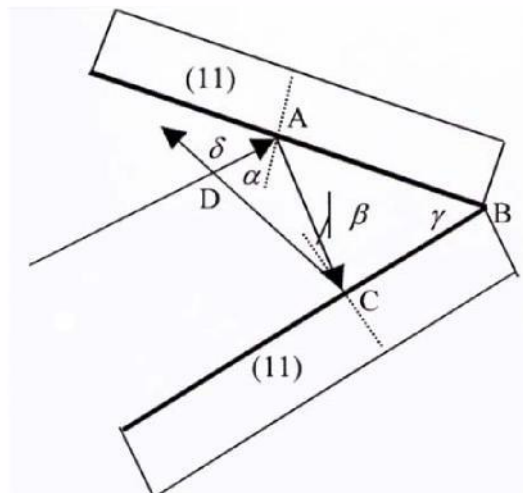
E2 Riflessione su due specchi piani

(U17301)

Dimostrazione del rapporto:

$$\theta^m = 2 \phi$$

dove θ^m è l'angolo tra il fascio luminoso incidente e quello riflesso e ϕ è l'angolo tra le superfici degli specchi.

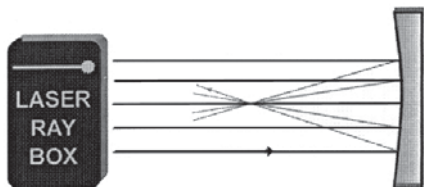
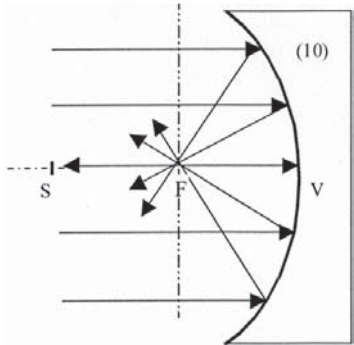


E3a Riflessione su specchio concavo – Fasci luminosi paralleli all'asse ottico
(U17300)

La distanza focale f di uno specchio concavo è determinata dalla lunghezza della distanza VF. Il raggio di curvatura può essere calcolato con la formula

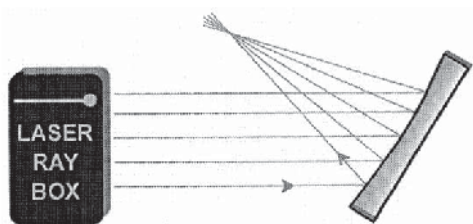
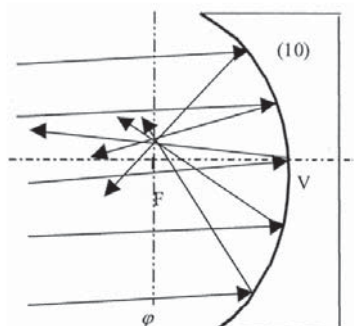
$$f = \frac{r}{2}$$

La distanza VS è il doppio della distanza VF.



E3b Riflessione su specchio concavo – Fasci luminosi non paralleli all'asse ottico
(U17300)

L'asse Π è perpendicolare all'asse ottico e attraversa il fuoco. Viene definito piano focale. I raggi paralleli incidenti vengono riflessi e si incontrano in un punto sul piano focale Π . Se i raggi sono paralleli all'asse ottico, il punto si trova sull'asse e viene chiamato fuoco F.

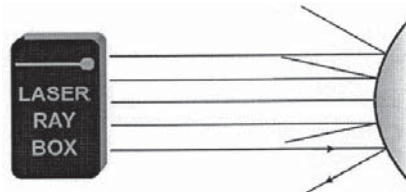
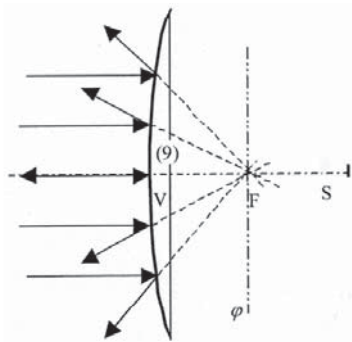


E4a Riflessione su specchio convesso – Fasci luminosi paralleli all'asse ottico
(U17300)

I raggi riflessi sembrano partire da un punto dietro lo specchio. Questo punto si chiama fuoco virtuale. La lunghezza della linea VF determina la distanza focale dello specchio. Il raggio di curvatura può essere calcolato con la formula

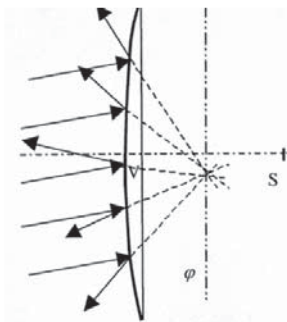
$$f = \frac{r}{2}$$

La distanza VS è il doppio della distanza VF.



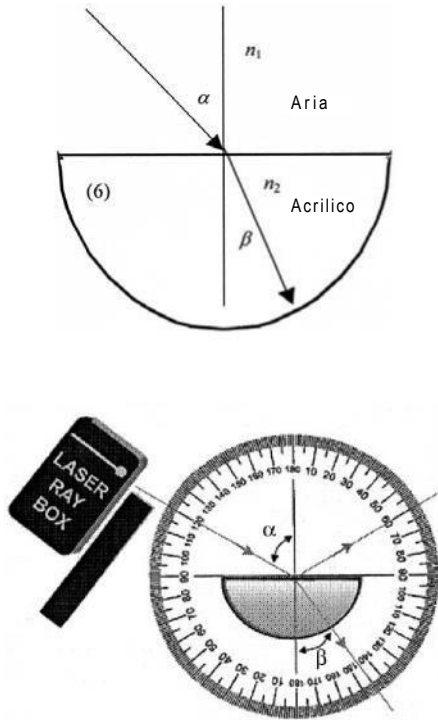
E4b Riflessione su specchio convesso – Fasci luminosi non paralleli all'asse ottico
(U17300)

L'asse Π è perpendicolare all'asse ottico e attraversa il fuoco. Viene definito piano focale. Se lo specchio viene colpito da raggi paralleli, questi vengono diffusi in modo che sembrano partire da un punto sul piano focale Π dietro lo specchio.



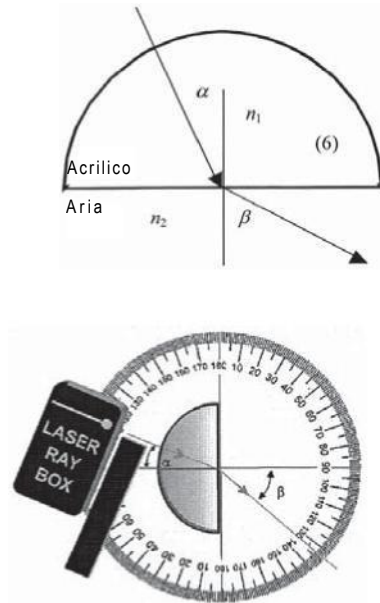
E5a Rifrazione di un fascio luminoso durante il passaggio dall'aria all'acrilico (U17300, pellicola F)

Se un fascio luminoso passa da un mezzo con indice di rifrazione n_1 in un altro mezzo con indice di rifrazione n_2 , è possibile determinarne la deviazione di direzione con la legge di rifrazione di Snellius: $n_1 \sin \alpha = n_2 \sin \beta$
 α è l'angolo di incidenza nel mezzo n_1 e β è l'angolo di rifrazione nel mezzo n_2 .



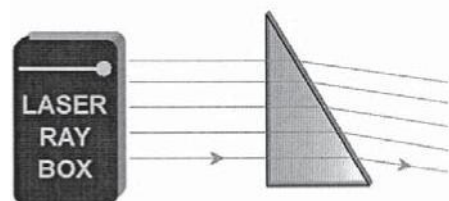
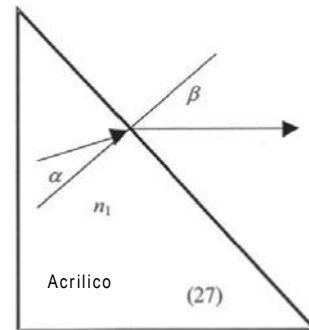
E6a Rifrazione di un fascio luminoso durante il passaggio dall'acrilico all'aria (U17300, pellicola F)

L'angolo di rifrazione β è maggiore dell'angolo di incidenza α . Il raggio viene interrotto dalla perpendicolare incidente.



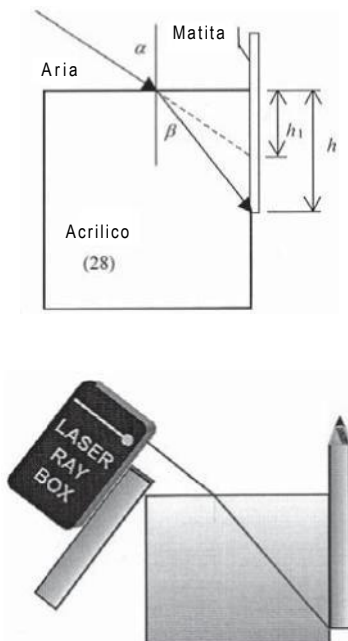
E6b Rifrazione su un prisma di acrilico (U17300/U17301)

Se un fascio luminoso passa dall'acrilico all'aria, la legge di Snellius può essere scritta nella forma seguente: $n_1 \sin \alpha = \sin \beta$
 Indice di rifrazione dell'aria $n_2 = 1$.



E5b Profondità apparente degli oggetti (U17301)

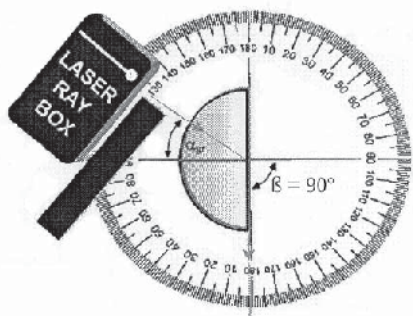
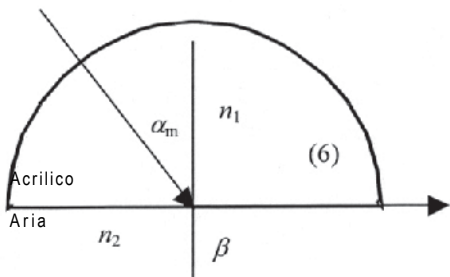
Struttura dell'esperimento per l'osservazione delle profondità apparenti di un oggetto in acqua o dietro acrilico visto dall'aria.



E6c Angolo critico, riflessione totale (U17300, pellicola F)

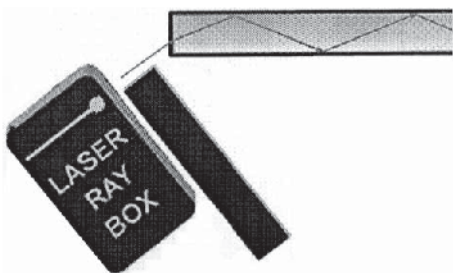
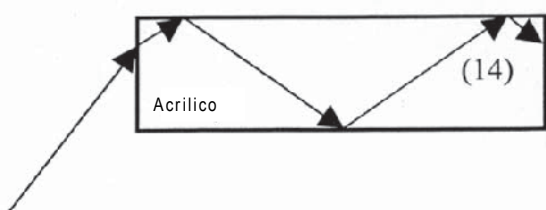
Tanto più grande è l'angolo di incidenza, quanto più grande è l'angolo di rifrazione. Se $n_1 < n_2$, esiste un angolo critico α_c . Il raggio interrotto si trova pertanto sulla superficie limite tra i due mezzi. Se l'angolo di

incidenza è maggiore dell'angolo critico, non si verifica più alcuna rifrazione e tutta la luce viene riflessa. In tal caso si parla di riflessione totale.



E6d Riflessione totale – Diffusione di luce in fotoconduttori (U17300)

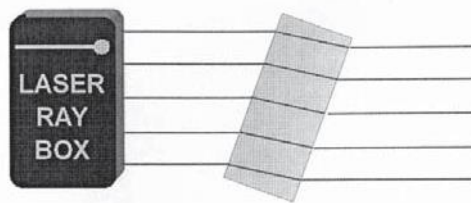
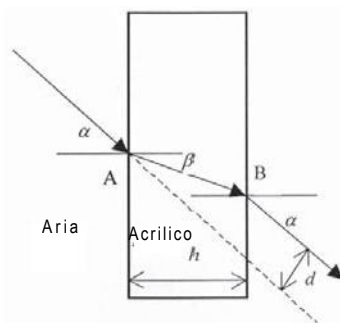
La luce si diffonde mediante la riflessione totale in un fotoconduttore. Il parametro apertura numerica determina l'angolo da non superare. Corrisponde al seno dell'angolo di ingresso massimo della luce. Anche il raggio minimo viene determinato da questo parametro quando il fotoconduttore è piegato e non può essere inferiore quando il fotoconduttore è installato.



E7 Spostamento di fasci luminosi mediante lastra di acrilico pianparallela (U17300/U17301)

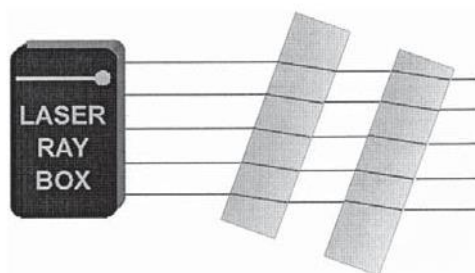
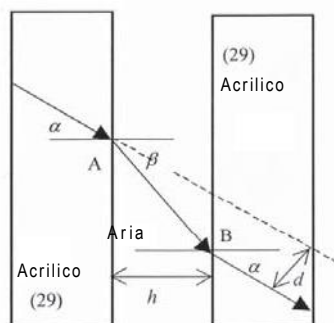
Se un fascio luminoso attraversa una lastra pianparallela la sua direzione non cambia. Il raggio uscente viene spostato del valore d . Con spessore della piastra h , d è uguale a:

$$d = h \frac{\sin^2 I}{\cos I}$$



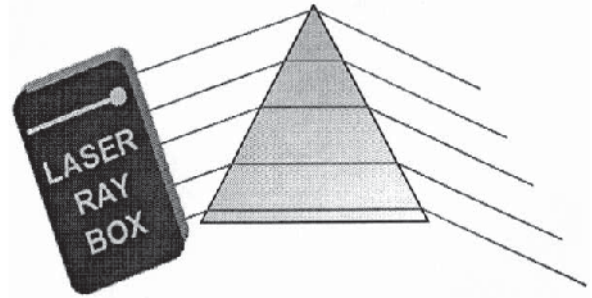
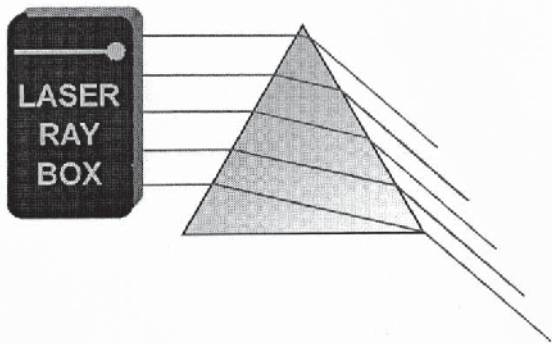
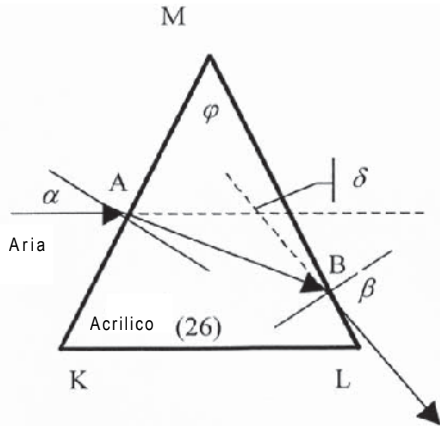
E8 Spostamento di un fascio luminoso mediante aria tra due lastre di acrilico pianparallele (U17301)

In questo caso si verifica uno spostamento tra il fascio luminoso incidente e quello uscente. Lo spostamento va in direzione opposta rispetto a quella nella lastra di acrilico.



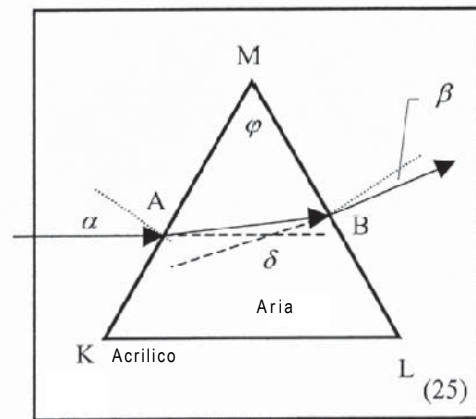
E9a Deviazione di un fascio luminoso attraverso un prisma di acrilico
(U17300/U17301)

In un prisma di acrilico un fascio luminoso incidente viene interrotto nel punto A verso la perpendicolare incidente. Sul punto di uscita B la rifrazione si verifica lontano dalla perpendicolare incidente. 1a somma di tutti gli angoli di rifrazione è l'angolo di deflessione δ . Si tratta dell'angolo che si forma tra il fascio luminoso incidente e quello uscente.



E10a Deviazione di un fascio luminoso attraverso un prisma di aria
(U17301)

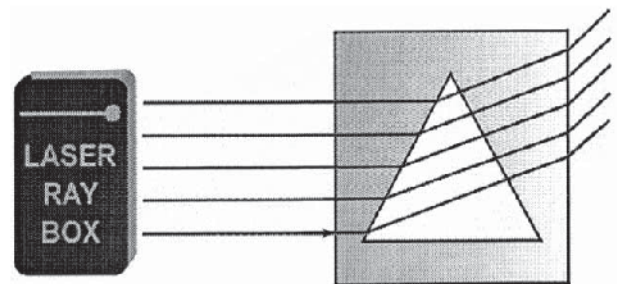
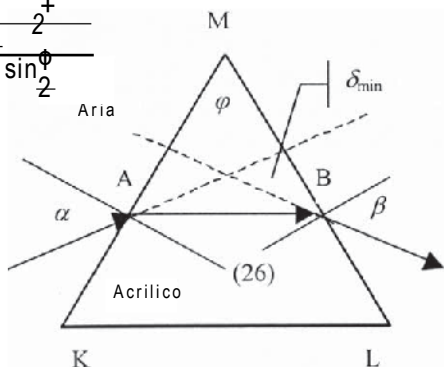
La luce penetra nel punto A attraverso la superficie limite di acrilico-aria. Il fascio luminoso viene interrotto dalla perpendicolare incidente. Il fascio luminoso viene interrotto nel punto di uscita B verso la perpendicolare incidente. 1a somma di tutti gli angoli di rifrazione è l'angolo di deflessione δ . Si tratta dell'angolo che si forma tra il fascio luminoso incidente e quello uscente.



E9b Deviazione minima attraverso un prisma di acrilico
(U17300/U17301)

È possibile dimostrare che l'angolo di incidenza α , in caso di angolo di deflessione minima δ_{min} , è uguale all'angolo di uscita β . Il raggio interrotto scorre quindi nel prisma parallelo al lato che non viene attraversato. Per l'indice di rifrazione del prisma vale la formula seguente:

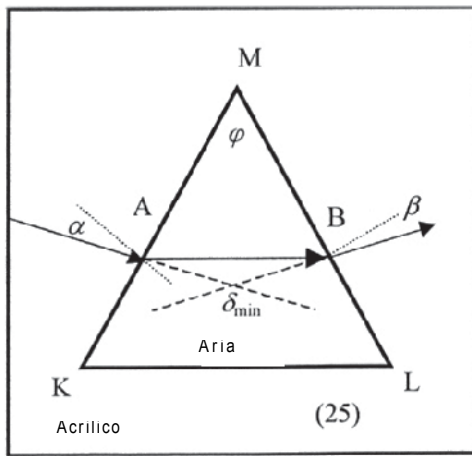
$$n = \frac{\sin \frac{\delta_{min} + \phi}{2}}{\sin \frac{\phi}{2}}$$



E10b Deviazione minima attraverso un prisma di aria
(U17301)

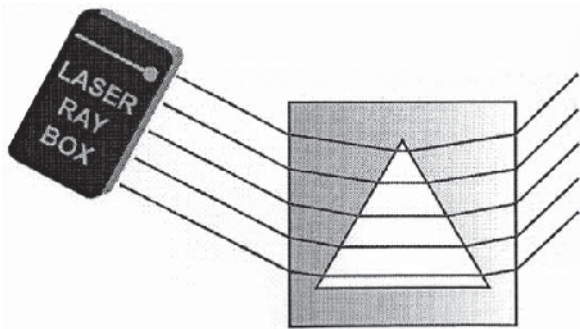
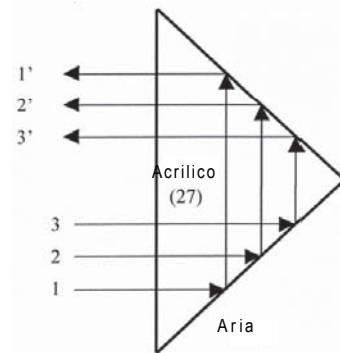
Nel caso della deflessione minima δ_{min} , l'angolo di incidenza α è uguale all'angolo di uscita β . Il raggio interrotto scorre quindi nel prisma parallelo al lato che

non viene attraversato. Per l'indice di rifrazione del prisma vale la formula seguente: (ved. E9b). La direzione della deviazione risulta opposta a quella nel prisma di acrilico.



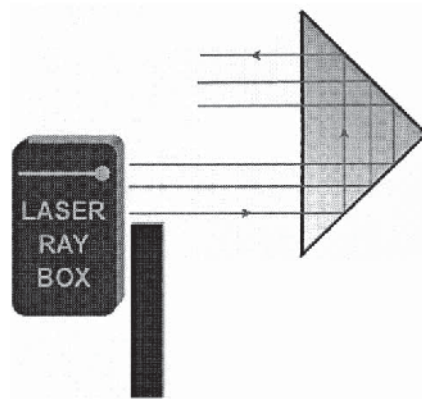
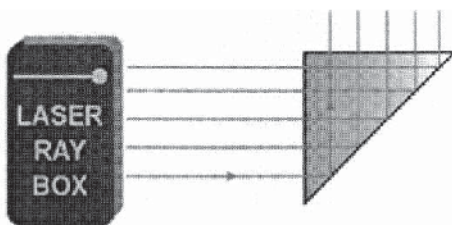
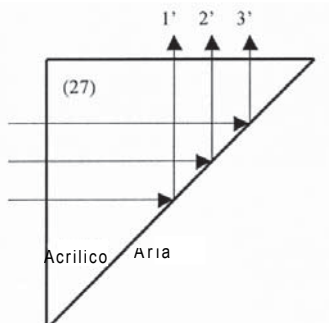
E11b Riflessione su due bordi di un prisma di acrilico (U17301)

In questo caso, le condizioni per la riflessione totale sono soddisfatte su entrambi i bordi del prisma. Se il raggio incidente superiore viene oscurato, il raggio uscente inferiore scompare. L'immagine risulta ruotata di 180°.



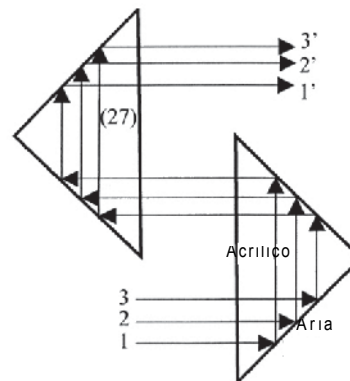
E11a Riflessione su un bordo di un prisma di acrilico (U17301)

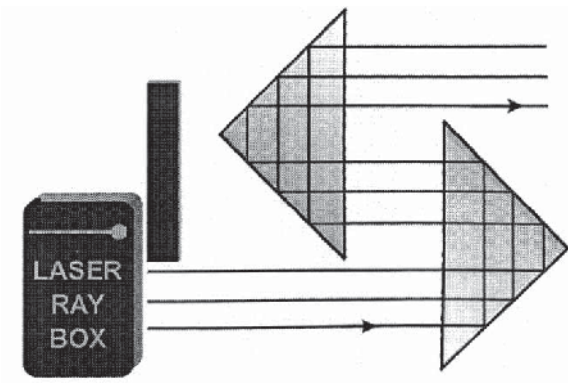
Se i fasci luminosi si incontrano sul bordo, vengono riflessi completamente. Ruotando leggermente il prisma, è possibile osservare sia la rifrazione che la riflessione.



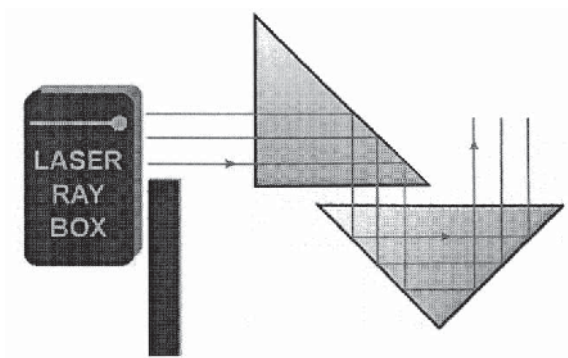
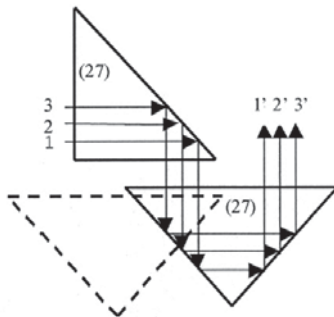
E11c Riflessione su due prismi di acrilico (U17301)

Le condizioni per la riflessione totale sono soddisfatte su tutti i bordi del prisma.

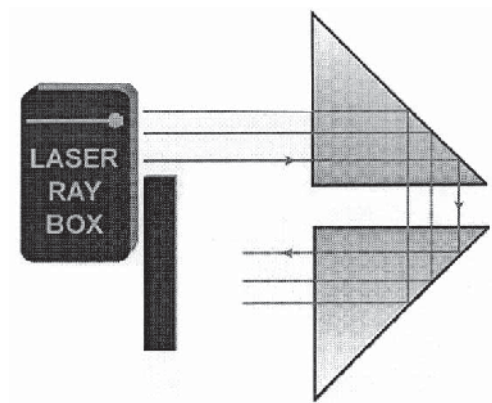
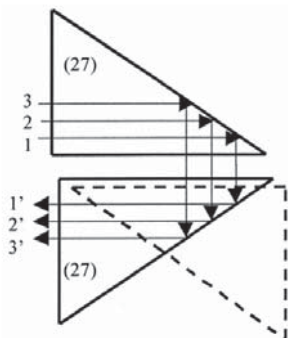




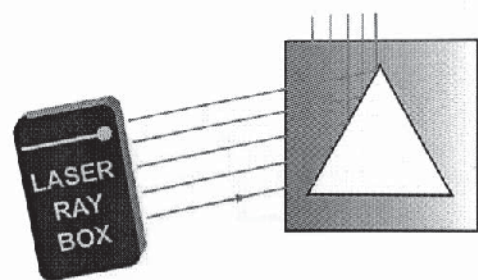
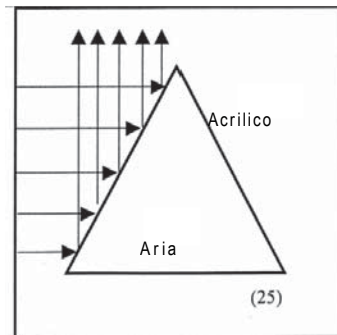
E11d Riflessione su due prismi di acrilico (U17301)
Le condizioni per la riflessione totale sono soddisfatte su tutti i bordi del prisma.



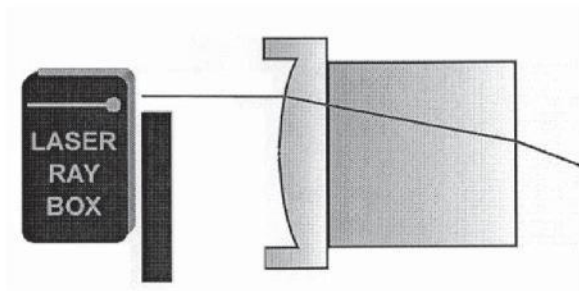
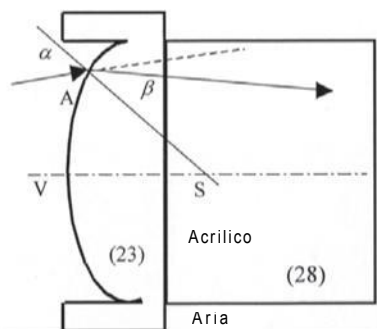
E11e Riflessione su due prismi di acrilico (U17301)
Le condizioni per la riflessione totale sono soddisfatte su tutti i bordi del prisma.



E12 Riflessione su un prisma di aria (U17301)
Se l'angolo di incidenza dei fasci luminosi è inferiore all'angolo critico (42°), i fasci luminosi vengono riflessi nell'acrilico. Se l'angolo è maggiore, una parte della luce attraversa il prisma di aria.

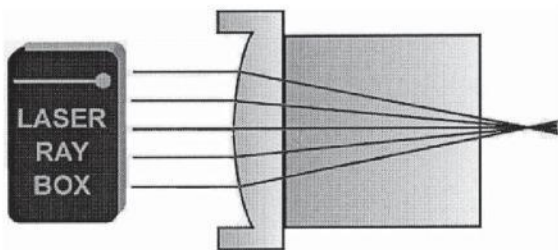
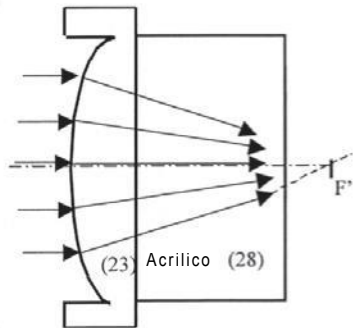


E13a Passaggio di un fascio luminoso attraverso una superficie limite convessa di aria-acrilico (U17301)
Se un fascio luminoso penetra nel punto A attraverso la superficie limite di aria-acrilico, viene interrotto verso la perpendicolare incidente. La perpendicolare incidente è definita come la linea retta dal punto A al punto centrale della curva S.



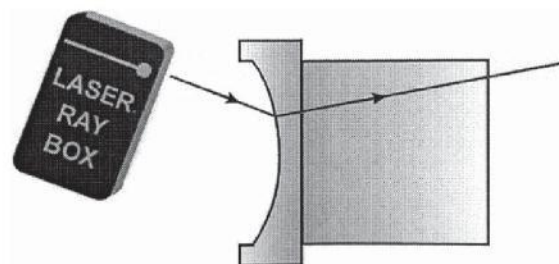
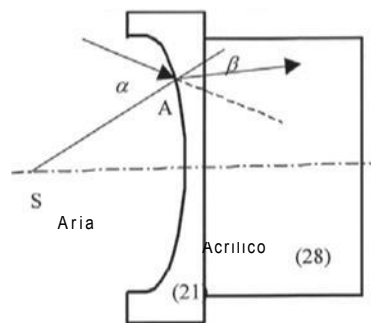
E13b Passaggio di fasci luminosi attraverso una superficie limite convessa di aria-acrilico (U17301)

I fasci luminosi incidenti vengono interrotti due volte e si incontrano nel punto F' sull'asse ottico, ovvero il fuoco.



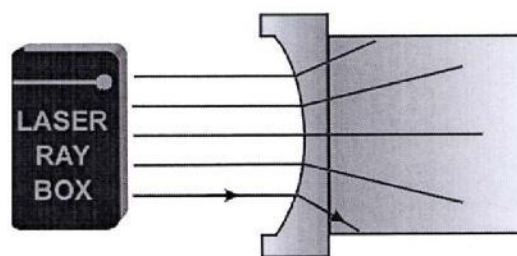
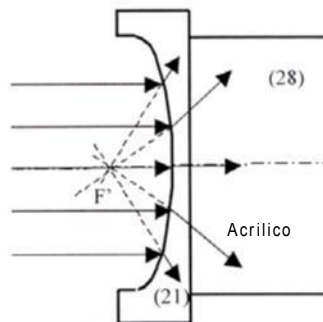
E14a Passaggio di un fascio luminoso attraverso una superficie limite concava di aria-acrilico (U17301)

Se un fascio luminoso penetra sulla superficie limite attraverso il punto A, è possibile osservare una rifrazione verso la perpendicolare incidente. La perpendicolare incidente è definita come la linea retta dal punto A al punto centrale della curva S.



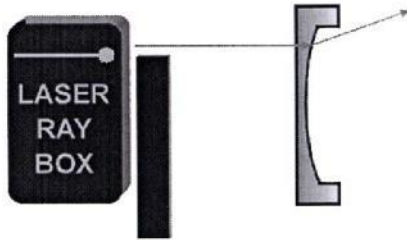
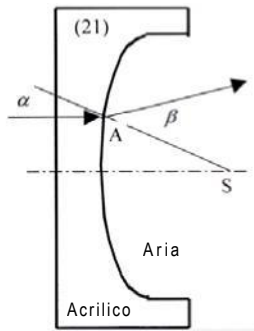
E14b Passaggio di fasci luminosi attraverso una superficie limite concava di aria-acrilico (U17301)

Dopo aver attraversato la superficie limite di acrilico-aria, il fascio di raggi viene interrotto in modo divergente. Se i raggi interrotti vengono allungati all'indietro, si incontrano in un punto sull'asse ottico. Questo punto viene definito fuoco virtuale F' .



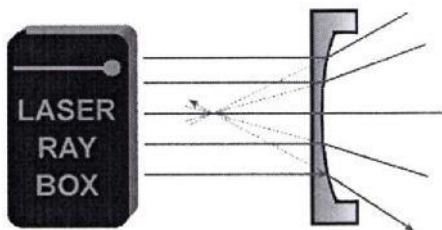
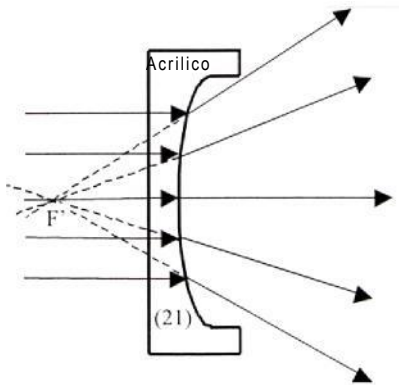
E15a Passaggio di un fascio luminoso attraverso una superficie limite convessa di acrilico-aria (U17301)

Dopo aver attraversato il punto A, il fascio luminoso viene interrotto dalla perpendicolare incidente. La perpendicolare incidente è definita come la linea retta dal punto A al punto centrale della curva S.



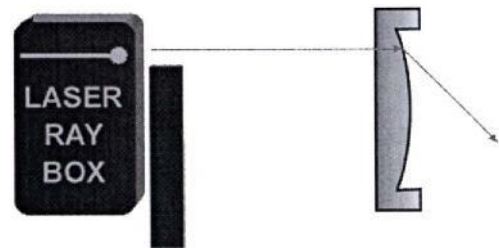
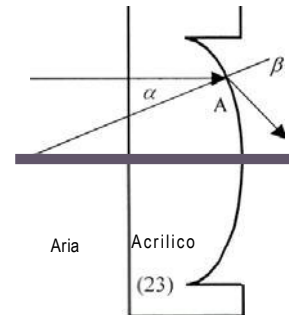
E15b Passaggio di fasci luminosi attraverso una superficie limite convessa di aria-acrilico (U17301)

Dopo aver attraversato la superficie limite di acrilico-aria, il fascio di raggi viene interrotto in modo divergente. Se i raggi interrotti vengono allungati all'indietro, si incontrano in un punto sull'asse ottico. Questo punto viene definito fuoco virtuale F' .



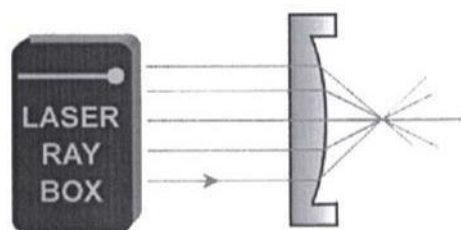
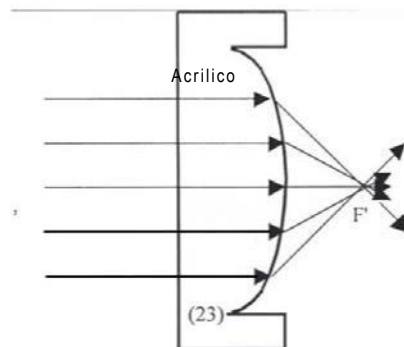
E16a Passaggio di un fascio luminoso attraverso una superficie limite concava di acrilico-aria (U17301)

Dopo aver attraversato il punto A, il fascio luminoso viene interrotto dalla perpendicolare incidente. La perpendicolare incidente è definita come la linea retta dal punto A al punto centrale della curva S.



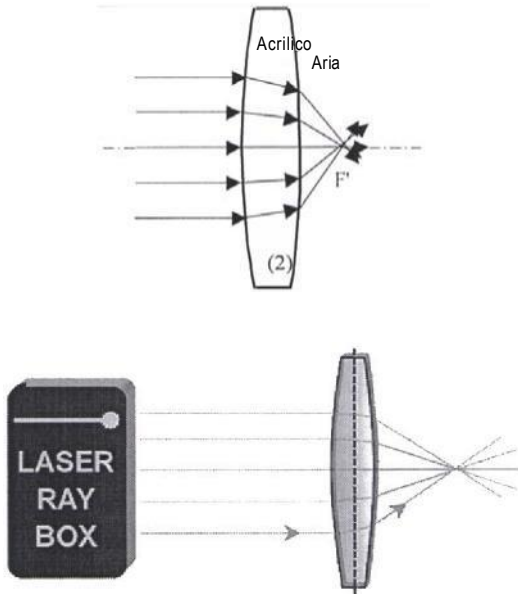
E16b Passaggio di fasci luminosi attraverso una superficie limite concava di acrilico-aria (U17301)

Dopo aver attraversato la superficie limite, il fascio di raggi risulta convergente. I raggi paralleli si incontrano in un punto sull'asse ottico, ovvero il fuoco F' .



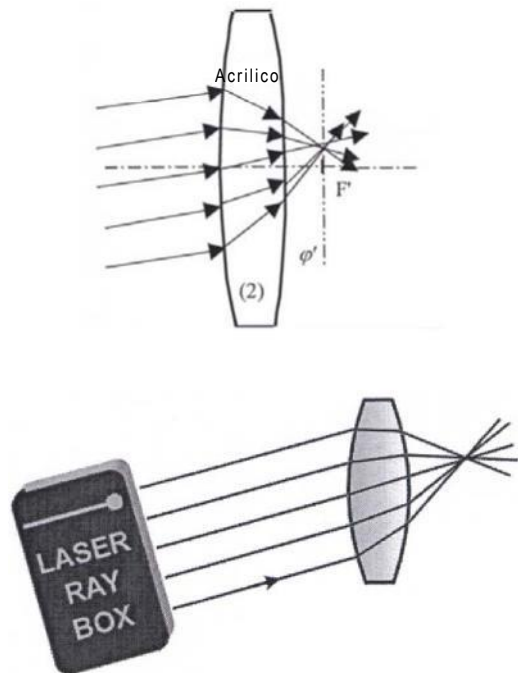
E17a Passaggio di fasci luminosi attraverso una lente convessa di acrilico – fasci luminosi paralleli all'asse ottico
(U17300/U17301)

Una lente di acrilico convessa funge da lente colletttrice e i fasci luminosi si incontrano, dopo aver attraversato la lente, nel fuoco F' .



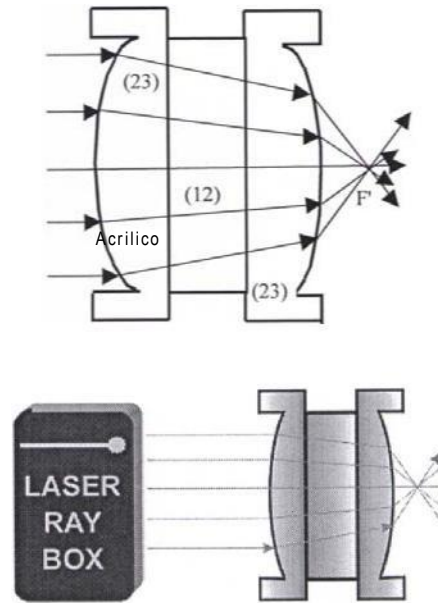
E17b Passaggio di fasci luminosi attraverso una lente convessa di acrilico – fasci luminosi non paralleli all'asse ottico
(U17300/U17301)

L'asse Π' è perpendicolare all'asse ottico e attraversa il fuoco F' . Viene definito piano focale. I raggi incidenti vengono interrotti e si incontrano in un punto sull'asse Π' .



E17c Passaggio di fasci luminosi attraverso una lente convessa di acrilico spessa
(U17301)

Collocando una lastra pianparallela tra due lenti (23), è possibile realizzare un modello di lente spessa. Modificando lo spessore d della lente, cambia anche la distanza focale. Maggiore è lo spessore della lente, minore è la distanza focale. A partire da uno spessore critico, la lente passa da colletttrice a divergente.



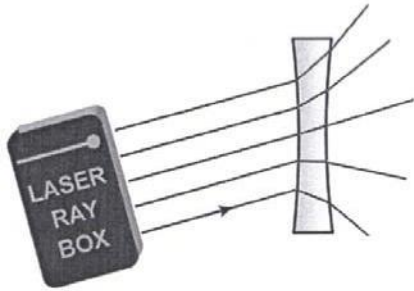
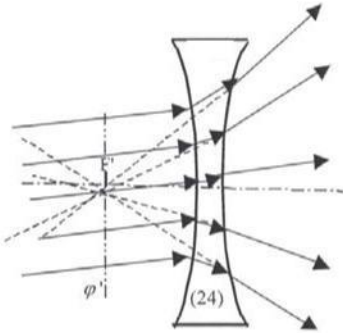
E18a Passaggio di fasci luminosi attraverso una lente concava di acrilico – fasci luminosi paralleli all'asse ottico
(U17300/U17301)

I fasci luminosi sono divergenti dopo avere attraversato la lente. Non danno forma ad alcun oggetto. Allungati all'indietro, i raggi si incontrano nel fuoco virtuale F' .



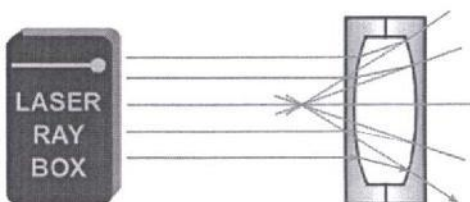
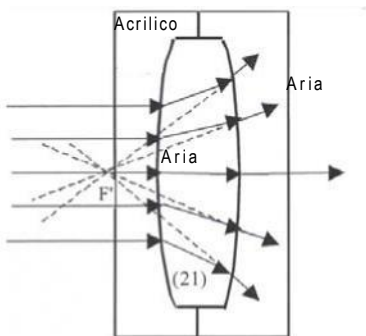
E18b Passaggio di fasci luminosi attraverso una lente concava di acrilico – fasci luminosi non paralleli all'asse ottico (U17300/U17301)

L'asse Π' è perpendicolare all'asse ottico e attraversa il fuoco virtuale F' . Viene definito piano focale. I prolungamenti dei raggi interrotti si incontrano in un punto sull'asse Π' .



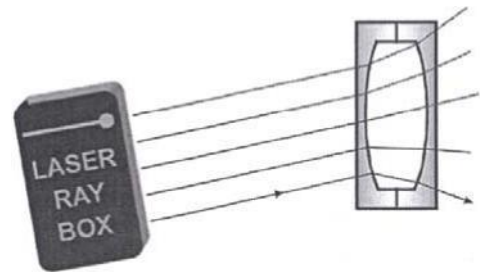
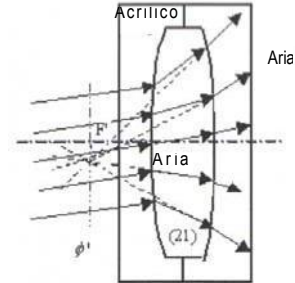
E19a Passaggio di fasci luminosi attraverso una lente convessa di aria – fasci luminosi paralleli all'asse ottico (U17301)

I fasci luminosi sono divergenti dopo avere attraversato la lente. Non danno forma ad alcun oggetto. Allungati all'indietro, i raggi si incontrano nel fuoco virtuale F' .



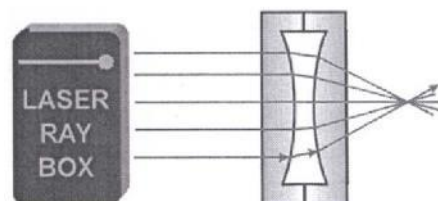
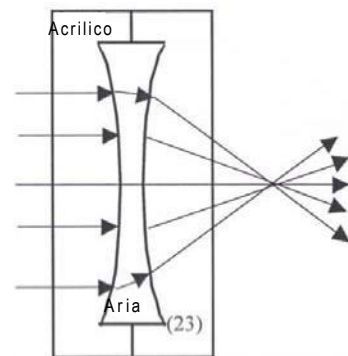
E19b Passaggio di fasci luminosi attraverso una lente convessa di aria – fasci luminosi non paralleli all'asse ottico (U17301)

L'asse Π' è perpendicolare all'asse ottico e attraversa il fuoco virtuale F' . Viene definito piano focale. I prolungamenti dei raggi interrotti si incontrano in un punto sull'asse Π' .



E20a Passaggio di fasci luminosi attraverso una lente concava di aria – fasci luminosi paralleli all'asse ottico (U17301)

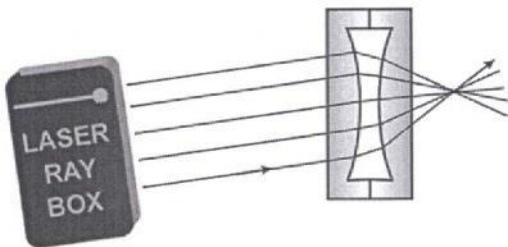
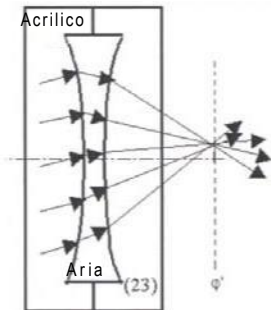
Una lente concava di aria funge da lente collettrice e i raggi interrotti si incontrano nel fuoco F' dopo aver



attraversato la lente.

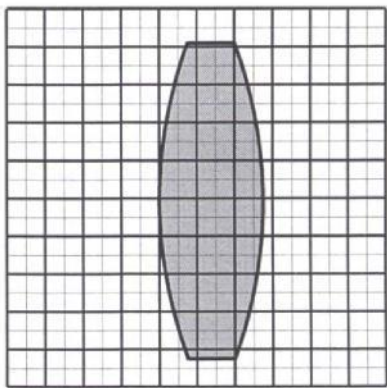
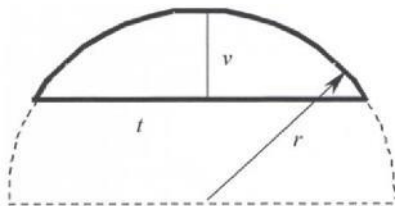
E20b Passaggio di fasci luminosi attraverso una lente concava di aria – fasci luminosi paralleli all'asse ottico
(U17301)

L'asse Π' è perpendicolare all'asse ottico e attraversa il fuoco F' . Viene definito piano focale. I raggi interrotti si incontrano un punto sull'asse Π' .



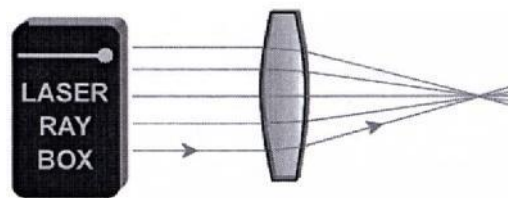
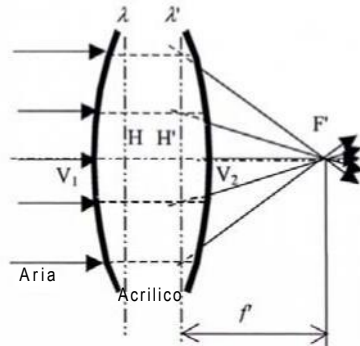
E21a Parametri di lenti spesse – determinazione del raggio di curvatura
(U17300/U17301)

Le lenti del set di ottiche per laser sono caratterizzate da una superficie di rifrazione cilindrica su una superficie di base circolare con raggi di curvatura identici. Questi raggi possono essere determinati con l'ausilio della carta millimetrata.



E21b Parametri di lenti spesse – distanza focale
(U17300/U17301)

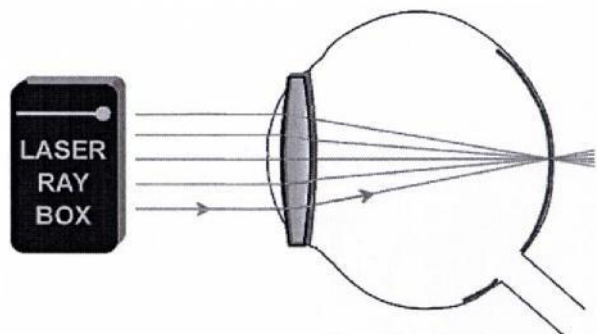
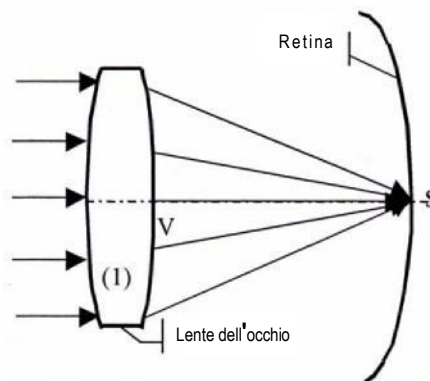
Le lenti spesse sono lenti il cui spessore non può essere ignorato. Nella definizione della distanza focale, è necessario tenere in considerazione la distanza tra i due piani principali H e H' .



E22a Modello di occhio
(U17300, pellicola A)

I fasci luminosi paralleli all'asse ottico vengono interrotti dalla lente dell'occhio e si incontrano in un punto sulla retina.

Collocare la lente dell'occhio (1) direttamente dietro la linea O_2 .

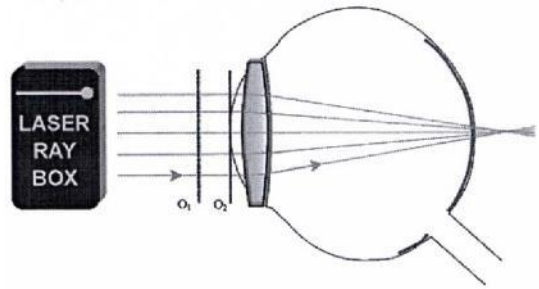


E22b Modello di occhio miope

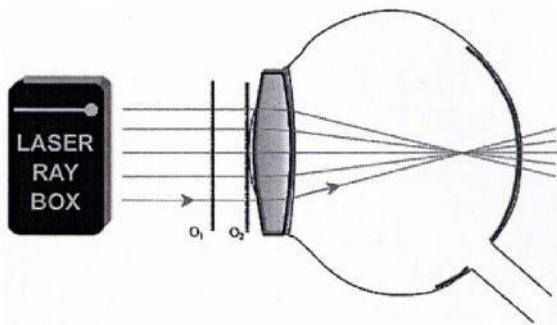
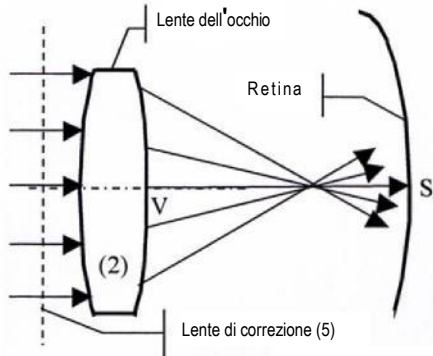
(U17300, pellicola A)

I fasci luminosi paralleli all'asse ottico vengono interrotti dalla lente dell'occhio e si incontrano in un punto davanti alla retina.

Collocare la lente dell'occhio (2) direttamente dietro la linea O_2 e la lente di correzione (5) tra le linee O_1 e O_2 .



E22c Modello di occhio ipermetrope

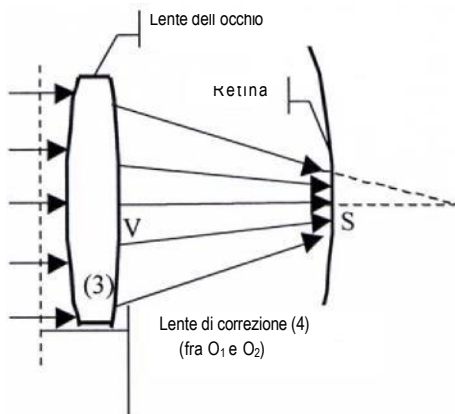


(U17300, pellicola A)

I fasci luminosi paralleli all'asse ottico vengono interrotti dalla lente dell'occhio e si incontrano in un punto dietro la retina. La lente di correzione è una lente colletttrice. Per la distanza focale f del sistema di lenti, vale la formula seguente:

$$f = \frac{f_1 f_2}{f_1 + f_2}$$

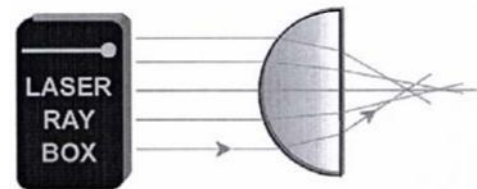
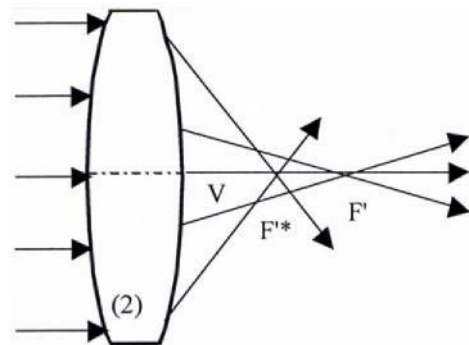
dove f_1 è la distanza focale della lente dell'occhio e f_2 è la distanza focale della lente di correzione.



E23a Correzione dell'aberrazione sferica mediante riduzione del diametro del fascio di raggi

(U17300/U17301)

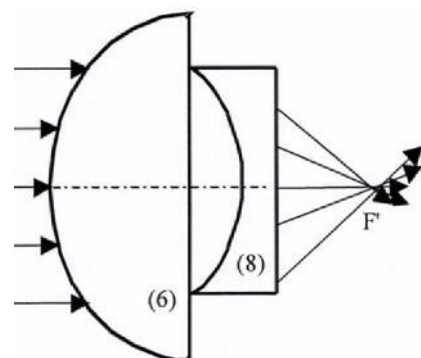
L'aberrazione sferica di una lente può essere ridotta riducendo il diametro del fascio di raggi che attraversa la lente. A tale scopo, oscurare i raggi più esterni.

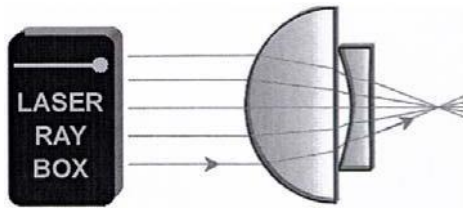


E23b Correzione dell'aberrazione sferica mediante una combinazione di lenti

(U17300, pellicola E)

Le aberrazioni sferiche di lenti colletttrici e divergenti hanno effetti inversi. L'errore può essere corretto mediante una combinazione di lenti. L'aberrazione $\Delta f = f_1 - f_2$ è definita come la differenza tra la distanza focale f_1 dei raggi esterni e la distanza focale f_2 dei raggi interni. Nelle lenti colletttrici, l'aberrazione ha un segno positivo, mentre nelle lenti divergenti ha un segno negativo.

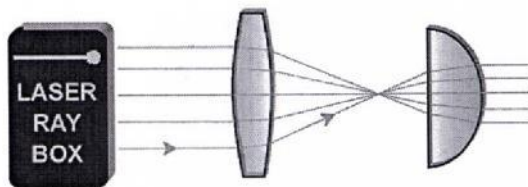
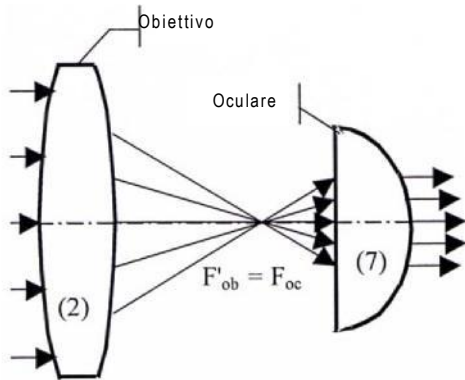
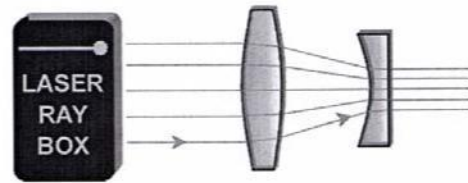
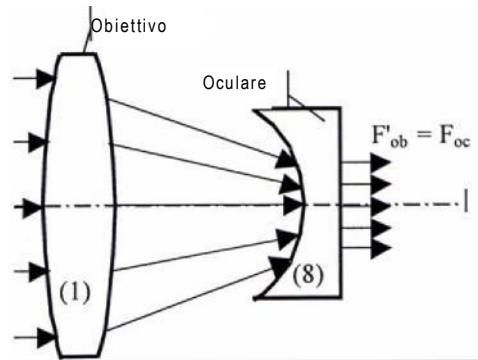




E24a Telescopio kepleriano

(U17300, pellicola D)

L'obiettivo del telescopio kepleriano genera un'immagine reale ridotta dell'oggetto osservato, che viene ingrandito dall'oculare come attraverso una lente. Si forma quindi un'immagine invertita (da sopra a sotto e da destra a sinistra) e fortemente ingrandita. Per dimostrare questo comportamento, oscurare uno dei fasci luminosi esterni. Se viene oscurato il raggio incidente più in alto, scompare il raggio uscente più in basso.



E24b Telescopio galileiano

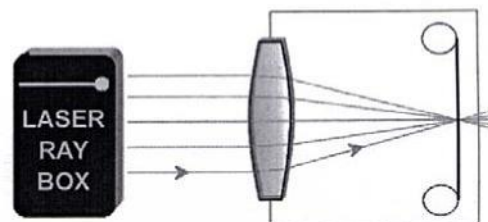
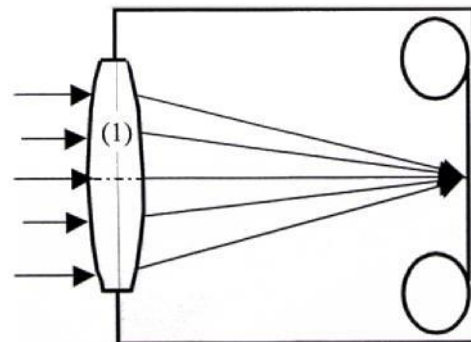
(U17300, pellicola C)

Nel cannocchiale galileiano, i raggi provenienti dall'obiettivo si incontrano su una lente divergente prima di raggiungere il fuoco. I raggi raggiungono l'occhio come raggi paralleli. L'immagine dell'oggetto risulta ingrandita, verticale e non speculare.

E25 Fotocamera

(U17300, pellicola B)

La lente della fotocamera è una lente collettrice. L'immagine che appare sulla pellicola posta nella parte posteriore della fotocamera è reale e capovolta.



1003049 Juego de demostración de óptica de laser (U17300) y 1003050 juego complementario (U17301)

Instrucciones de servicio

1/05 ALF

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Juego demostración de óptica de láser U17300 / 1003049
Equipo complementario U17301 / 1003050

En la columna "Equipo" se enumeran los componentes de equipo necesarios para cada experimento, provenientes de U17300 y U17301, o de ambos juegos.

Introducción

El equipo de demostración de óptica de láser permite un montaje de experimentos sencillo y claro para la representación de los fundamentos de la geometría óptica, al igual que para el funcionamiento de diferentes equipos de óptica. Como fuente de luz, se emplea el láser de diodos de 5 rayos U17302.

En estas instrucciones de uso se describen numerosos experimentos básicos con los elementos ópticos de los juegos de equipos U17300 y U17301. Cada descripción experimental se compone de tres partes:

1. Sencilla descripción del experimento
2. Representación gráfica del experimento
3. Imagen del montaje experimental

Debajo del título respectivo, se anota entre paréntesis con qué equipo se puede llevar a cabo el experimento, esto es, U17300, U17301 o U17300/U17301. La misma indicación se encuentra en la última columna de la sinopsis del índice.

El láser de diodos U17302 es un componente muy importante de los arreglos experimentales. Cinco diodos láser generan cinco rayos de luz paralelos. La cantidad de rayos emitidos es seleccionable. Para ello, delante

del láser de diodos, se coloca la placa metálica con perforaciones, incluida en el suministro. Durante el uso de este equipo, se debe evitar un contacto ocular directo con el rayo láser.

Volumen de suministro

Juego demostración de óptica de láser U17300

- 1 Lente bicóncava
- 2 Lente biconvexa
- 3 Lente biconvexa
- 4 Lente biconvexa
- 5 Lente biconvexa
- 6 Pequeña lente plano cóncava
- 7 Pequeña lente plano convexa
- 8 Lente grande plano convexa
- 9 Espejo, cóncavo
- 10 Espejo, convexo
- 11 Espejo plano
- 12 Placa planoparalela
- 13 Prisma
- 14 Conductor óptico

Láminas

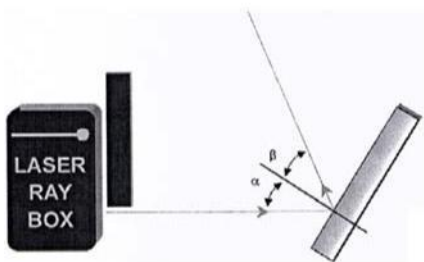
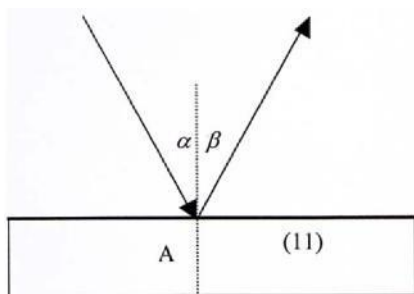
- A Modelo del ojo humano
- B Cámara
- C Telescopio según Galilei
- D Telescopio según Kepler
- E Aberración esférica
- F Escala angular de 360°

Juego complementario U17301

- 21 Lente biconcava de aire
- 22 Lente biconcava
- 23 Lente biconvexa de aire
- 24 Lente biconvexa
- 25 Prisma de aire
- 26 Prisma equilateral
- 27 2 prismas rectangulares
- 28 Placa planoparalela, cuadrada
- 29 2 placas planoparalelas, cuadrangulares
- 11 2 espejos planos

E1 Reflexión en un espejo plano
(U17300/U17301)

Representación de la ley de reflexión. Un rayo de luz que incide sobre una superficie especular plana, con un ángulo de incidencia α , se refleja con el ángulo β $\alpha = \beta$
Ambos ángulos se miden con la normal.

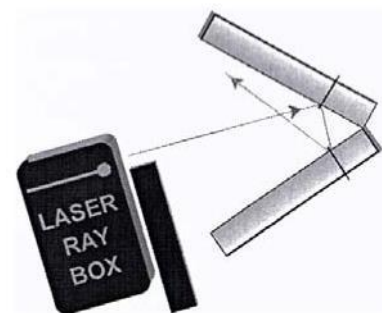
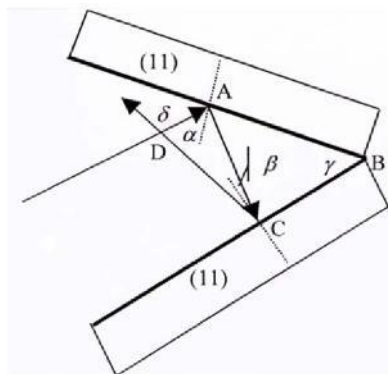


E2 Reflexión en dos espejos planos
(U17301)

Demostración de la relación:

$$\alpha^{\text{TM}} = 2 \alpha^{\text{C}}$$

en donde el ángulo α^{TM} está formado por el rayo de incidencia, y el reflectante α^{C} es el ángulo entre las superficies especulares.

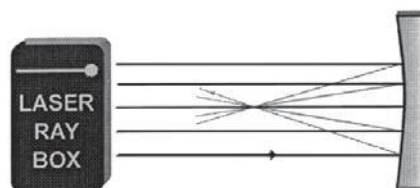
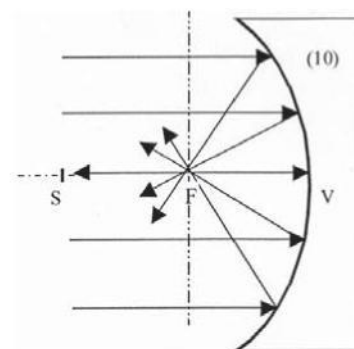


E3a Reflexión en un espejo cóncavo – rayos de luz paralelos al eje óptico
(U17300)

La distancia focal f de un espejo hueco se determina por medio de la longitud de la distancia VF . El radio de curvatura se puede determinar a partir de la fórmula:

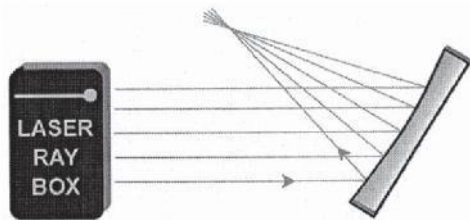
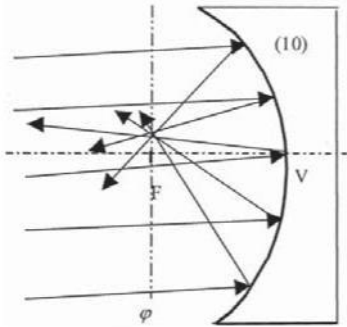
$$f = \frac{r}{2}$$

La distancia VS es dos veces más larga que VF .



E3b Reflexión en un espejo cóncavo – rayos de luz no paralelos al eje óptico
(U17300)

El eje Π presenta un posición vertical en relación al eje óptico y pasa por el foco. Recibe el nombre de plano focal. Los rayos de incidencia paralela se reflejan y se encuentran en un punto del plano focal Π . Si los rayos son paralelos al eje óptico, el punto se encontrará por encima y recibe el nombre de punto focal F.

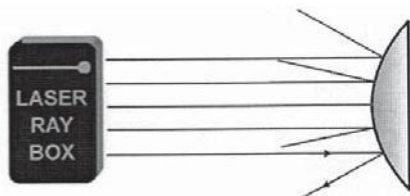
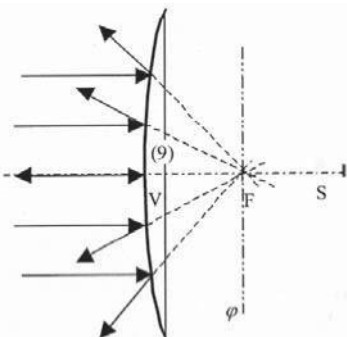


E4a Reflexión en espejo convexo – rayos de luz paralelos al eje óptico
(U17300)

Los rayos reflectantes parecen provenir de un punto que se encuentra por detrás del espejo. A éste se lo denomina foco virtual. La longitud de la línea VF determina la distancia focal del espejo. El radio de curvatura se puede determinar a partir de la fórmula:

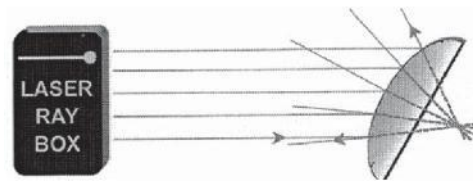
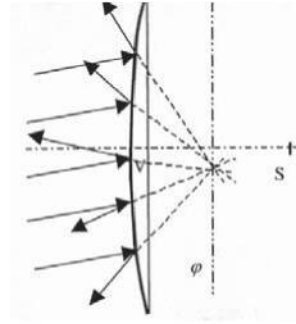
$$f = \frac{r}{2}$$

La distancia VS es dos veces más larga que VF.



E4b Reflexión en espejo convexo – rayos de luz no paralelos al eje óptico
(U17300)

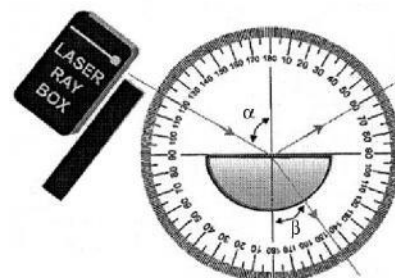
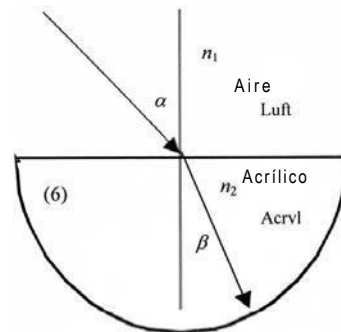
El eje Π presenta un posición vertical en relación al eje óptico y pasa por el foco. Recibe el nombre de plano focal. Si sobre el espejo inciden rayos paralelos, éstos se dispersan de manera que parecen provenir de un punto del plano focal Π que se encuentra detrás del espejo.



E5a Refracción de un rayo de luz durante su paso del aire al acrílico
(U17300, lámina F)

Cuando un rayo de luz pasa de un medio con un índice de refracción n_1 a otro medio con un índice de refracción n_2 su cambio de dirección se determina por medio de la ley de refracción de Snellius: $n_1 \sin \alpha = n_2 \sin \beta$

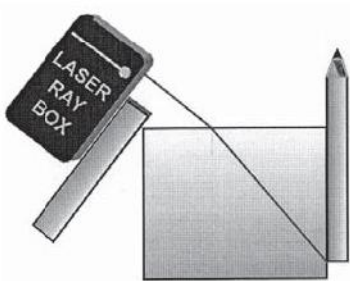
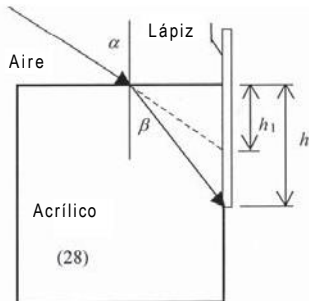
Aquí, α es el ángulo de incidencia en el medio n_1 y β es el ángulo de refracción en el medio n_2 .



E5b Profundidad aparente de un objeto

(U17301)

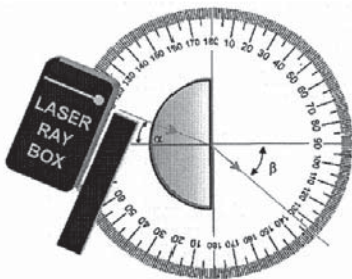
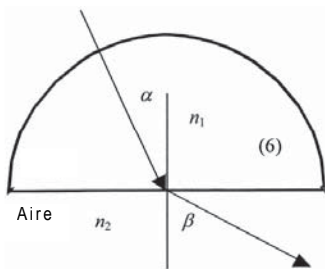
Montaje experimental para la observación de la profundidad aparente de un objeto que se encuentra sumergido en el agua, o detrás de material acrílico, observado desde fuera.



E6a Refracción de un rayo de luz durante su paso del acrílico al aire

(U17300, lámina F)

El ángulo de refracción β es mayor que el ángulo de incidencia α . El rayo se rompe en la normal.



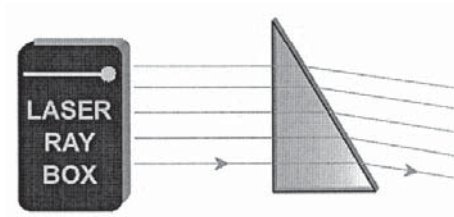
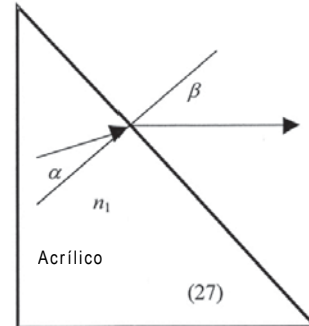
E6b Refracción en un prisma acrílico

(U17300/U17301)

Durante el paso de un rayo de luz de acrílico hacia el aire, la ley de Snellius se puede describir de la siguiente manera:

$$n_1 \sin \alpha = n_2 \sin \beta$$

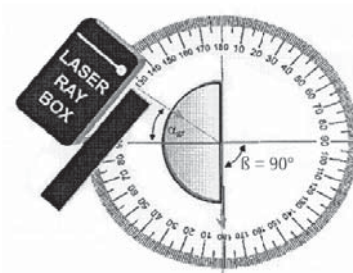
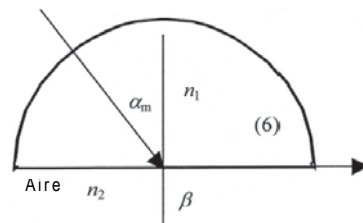
El índice de refracción del aire es $n_2 = 1$.



E6c Ángulo crítico, reflexión total

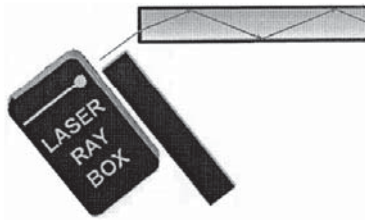
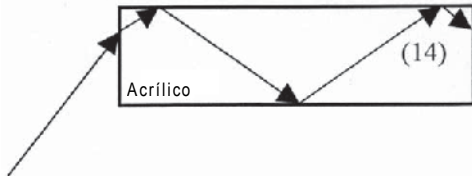
(U17300, lámina F)

Mientras mayor sea el ángulo de incidencia, mayor será el ángulo de refracción. Si $n_1 < n_2$, existe un ángulo crítico α_c . El rayo cortado se encuentra entonces en la superficie limitante de ambos medios. Si el ángulo de incidencia es mayor que el ángulo crítico, entonces ya no se encuentra presente ninguna refracción y se refleja toda la luz. En este caso se habla de reflexión total.



E6d Reflexión total – propagación de la luz en conductores ópticos (U17300)

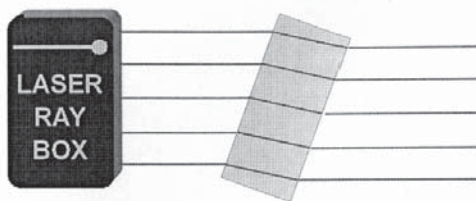
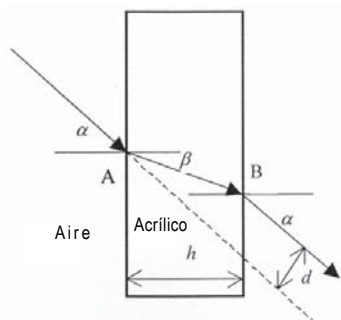
En un conductor óptico, la luz se propaga gracias a la reflexión total. El parámetro denominado apertura numérica determina, en este caso, el ángulo que no se debe sobrepasar. Corresponde al seno del ángulo máximo de incidencia de la luz. Por medio de este parámetro también se determina el radio menor, en el caso de que el conductor se pliegue. Cuando se instala el conductor óptico, este radio no se debe sobrepasar.



E7 Desplazamiento de un haz de luz, placa acrílica planoparalela (U17300/U17301)

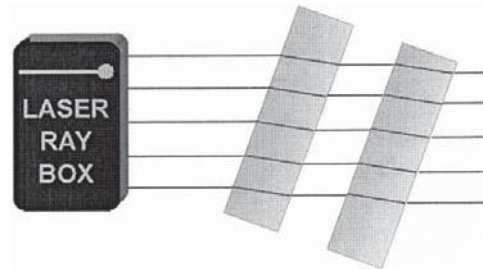
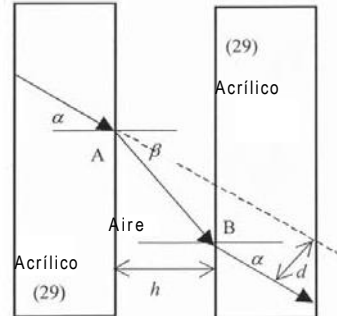
Si un rayo de luz atraviesa una placa planoparalela, su dirección no se modifica. El rayo de reflexión se ha desplazado en una distancia d . Si se tiene un espesor de placa h , para d se obtiene:

$$d = h \frac{\sin(\alpha - \beta)}{\cos \beta}$$



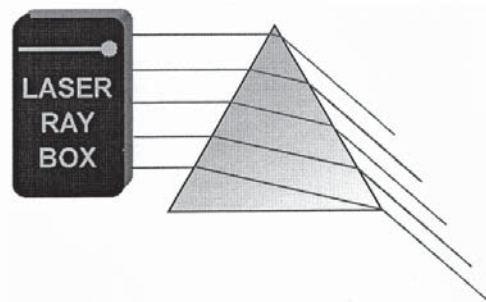
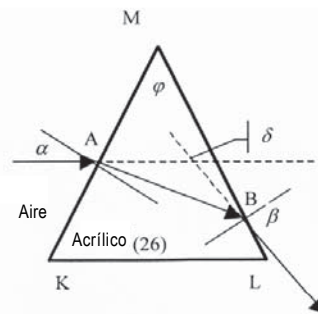
E8 Desplazamiento de un rayo de luz, presencia de aire entre dos placas acrílicas planoparalelas (U17301)

En este caso se presenta un desplazamiento entre el rayo incidente y el reflejado. No obstante, el desplazamiento va en dirección contraria al de la placa acrílica.



E9a Desviación de un rayo de luz por medio de un prisma acrílico (U17300/U17301)

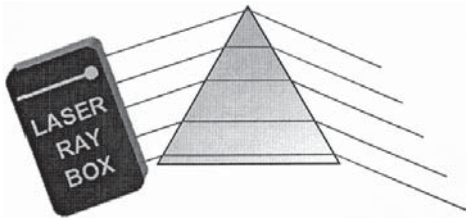
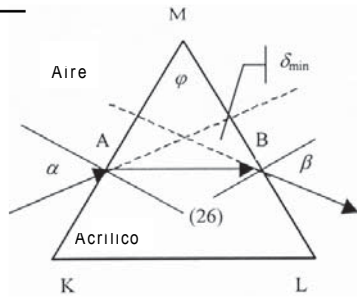
En un prisma acrílico, un rayo de luz incidente sobre el punto A se corta hacia el eje de incidencia. En el punto de salida B, la refracción se realiza en un lugar distante de la normal. La suma de todos los ángulos de refracción conforma el ángulo de desviación δ . Se trata del ángulo entre la luz incidente y el rayo de luz reflejado.



E9b Desviación mínima por medio de un prisma acrílico
(U17300/U17301)

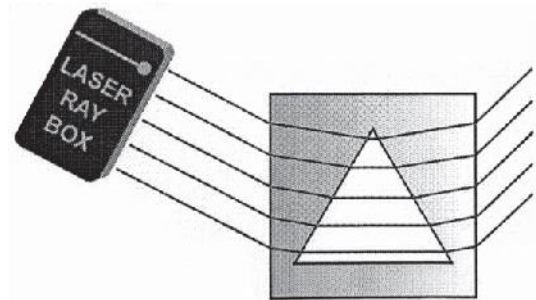
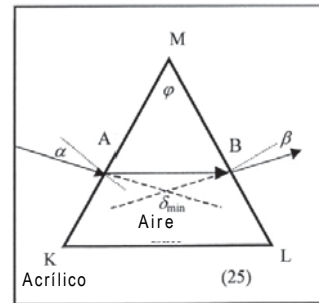
Se puede demostrar que el ángulo de incidencia α , con el ángulo mínimo de desviación δ_{min} , es igual al ángulo de salida β . El rayo interrumpido pasa por el prisma paralelamente al lado por el que no pasa la luz. Para el índice de refracción del prisma es válido:

$$n = \frac{\sin \frac{\alpha + \beta}{2}}{\sin \frac{\phi}{2}}$$



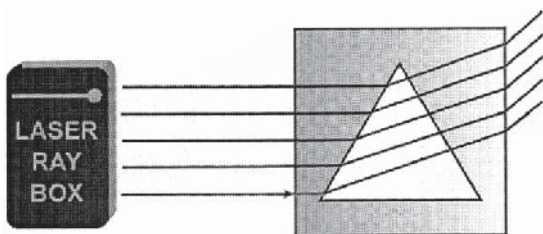
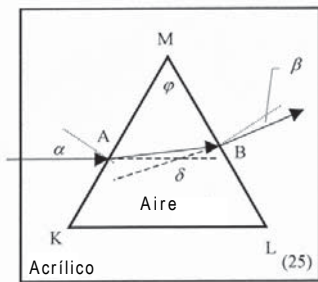
E10b Desviación mínima por medio de un prisma de aire
(U17301)

En el caso de que se tenga la desviación mínima δ_{min} , el ángulo de incidencia α es igual al ángulo de reflexión β . El rayo partido pasa a través del prisma paralelo al lado que no atraviesa. Para el índice de refracción del prisma es válido: (véase E9b). 1a dirección de la desviación es inversa a la de un prisma acrílico.



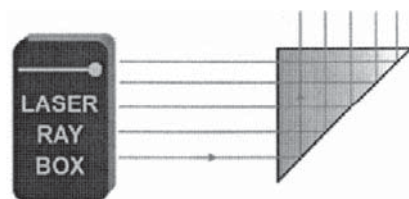
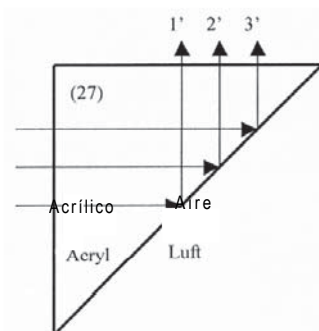
E10a Desviación de un rayo de luz por medio de un prisma de aire
(U17301)

1a luz incide en el punto A a través de la superficie de separación acrílico-aire. 1a normal corta y desplaza el rayo de luz. En el punto de salida B, se corta hacia la normal. 1a suma de todos los ángulos de refracción conforma el ángulo de desviación δ . Se trata del ángulo entre la luz incidente y el rayo de luz reflejado.



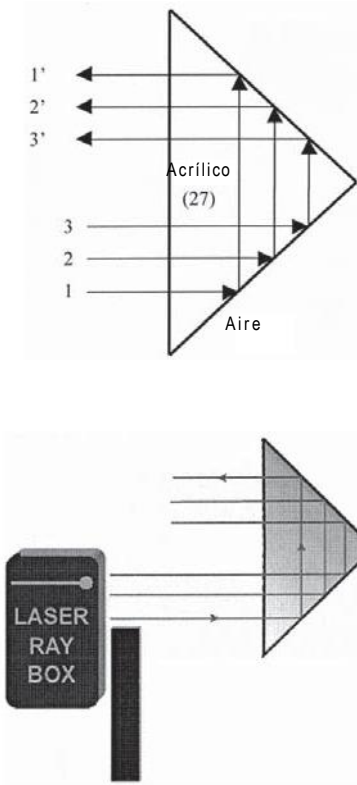
E11a Reflexión en una cara de un prisma acrílico (U17301)

Cuando los rayos de luz llegan a la base del prisma, se reflejan totalmente. Si se gira levemente el prisma, se puede observar refracción al igual que reflexión.

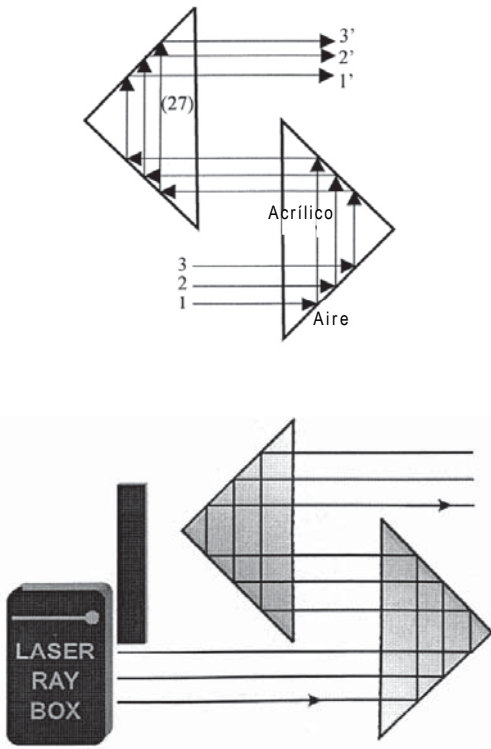


E11b Reflexión en dos caras de un prisma acrílico (U17301)

En este caso se cumplen las condiciones para la reflexión total en ambas caras. Si el rayo superior se suprime, desaparece el rayo inferior de reflexión. La imagen tiene un giro de 180° .

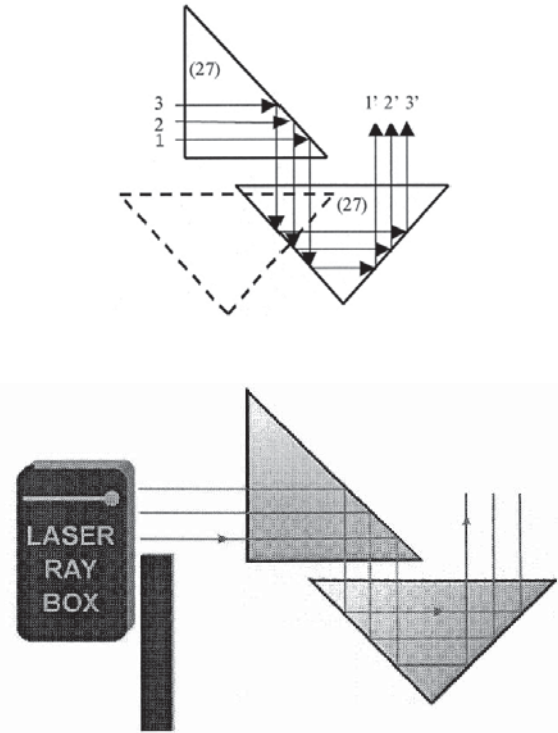


E11c Reflexión en dos prismas acrílicos (U17301) Las condiciones para la reflexión total se cumplen en todas las caras del prisma.



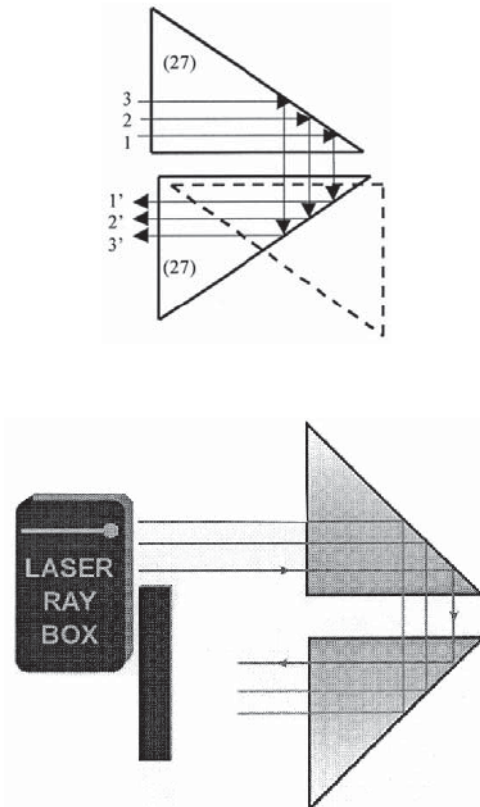
E11d Reflexión en dos prismas acrílicos (U17301)

Las condiciones para la reflexión total se cumplen en todas las caras del prisma.



E11e Reflexión en dos prismas acrílicos (U17301)

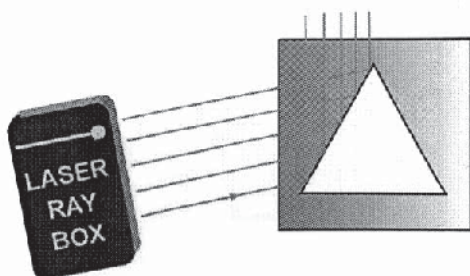
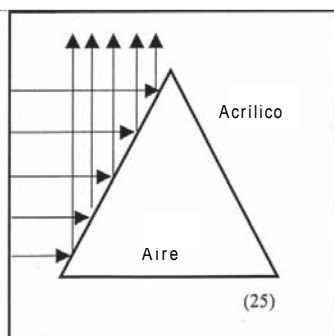
Las condiciones para la reflexión total se cumplen en todas las caras del prisma.



[12 Reflexión en un prisma de aire

(U17301)

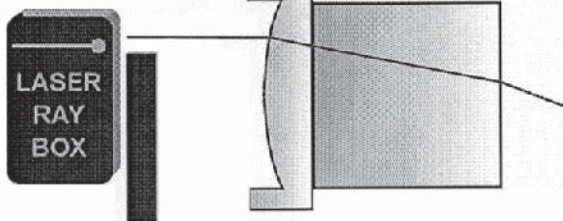
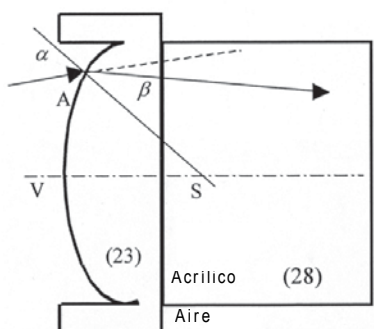
Si el ángulo de incidencia de los rayos de luz es menor que el ángulo crítico (42°), los rayos de luz se reflejan en el material acrílico. Si el ángulo es mayor, una parte de la luz atraviesa el prisma de aire.



[13a Paso de un haz de luz a través de una superficie convexa de separación de aire-acrílico

(U17301)

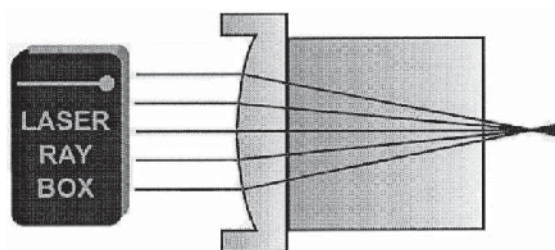
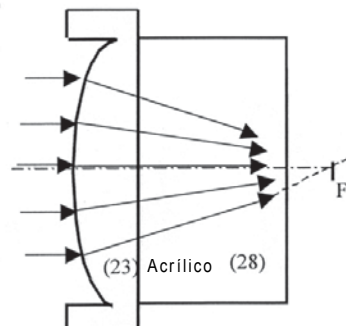
Si un rayo de luz incide en el punto A, a través de la superficie de separación aire-acrílico, se parte hacia la normal. La normal es la recta que va del punto A al punto central de curvatura S.



[13b Paso de rayos de luz a través de una superficie de separación convexa de aire-acrílico

(U17301)

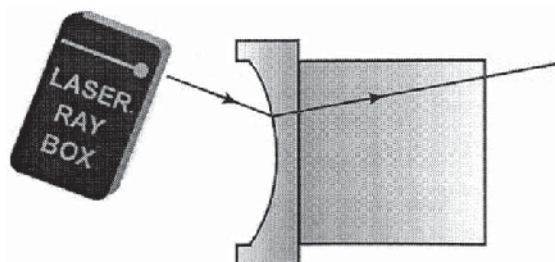
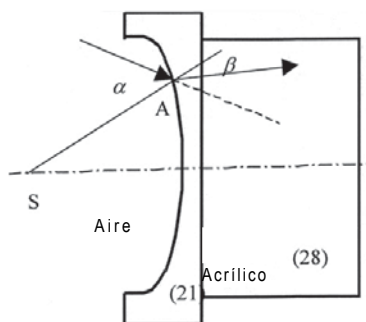
Los rayos de luz incidentes se parten dos veces y se encuentran en el punto F' del eje óptico, esto es, el punto focal.



[14a Paso de un haz de luz a través de una superficie de separación cóncava de aire-acrílico

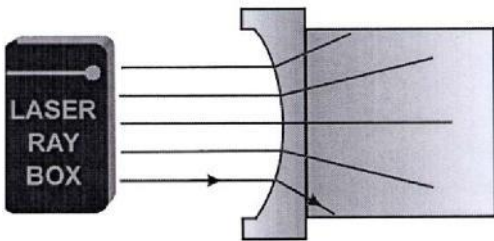
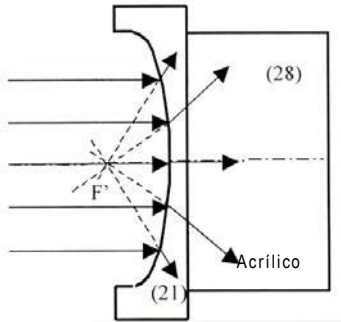
(U17301)

Si el rayo de luz incide sobre la superficie, a través del punto A, se observa una refracción hacia la normal. La normal es la recta que va del punto A al punto central de curvatura S.



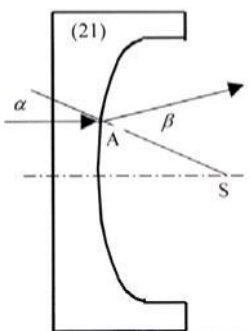
E14b Paso de rayos de luz a través de una superficie de separación cóncava de aire-acrílico (U17301)

Después del paso a través de la superficie de aire-acrílico, el haz de rayos se parte de manera divergente. Si los rayos partidos se prolongan hacia atrás, se encuentran en un punto del eje óptico. Este punto se denomina punto focal virtual F' .



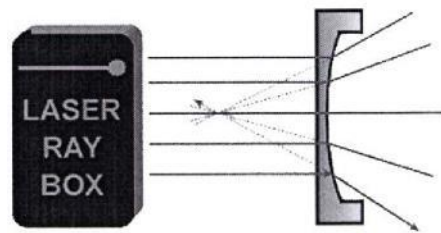
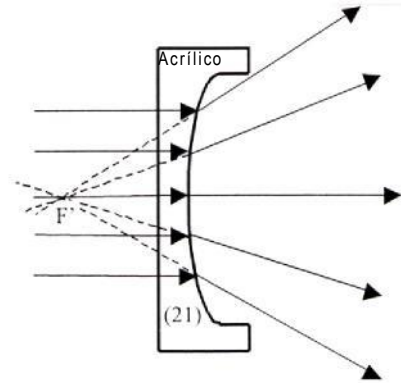
E15a Paso de un rayo de luz a través de una superficie de separación convexa de aire-acrílico (U17301)

Después de que el rayo de luz ha atravesado el punto A, se ve desplazado de la normal. La normal es la recta que va del punto A al punto central de curvatura S.



E15b Paso de rayos de luz a través de una superficie de separación convexa de acrílico-aire (U17301)

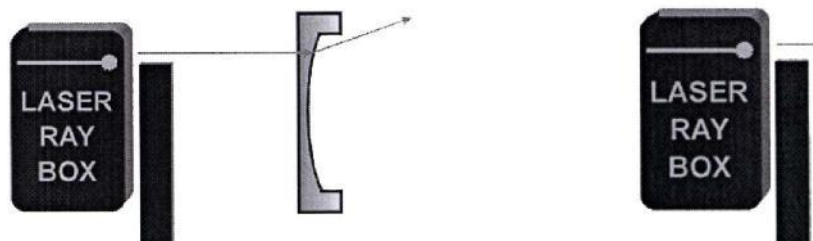
Después del paso a través de la superficie de aire-acrílico, el haz de rayos se parte de manera divergente. Si los rayos partidos se prolongan hacia atrás, se encuentran en un punto del eje óptico. Este punto se denomina punto focal virtual F' .



E16a Paso de rayos de luz a través de una superficie de separación cóncava de aire-acrílico (U17301)

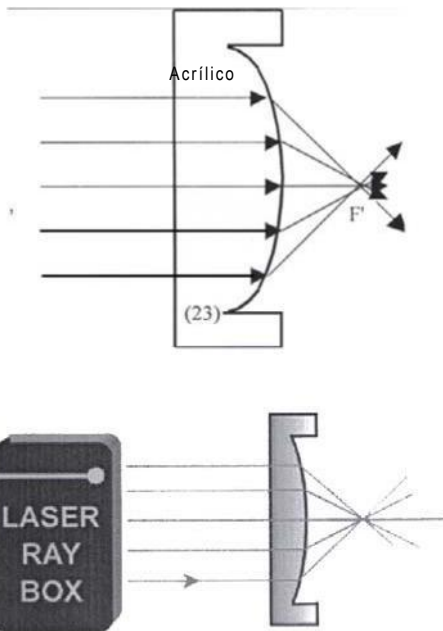
Después de que el rayo de luz ha atravesado el punto A, se ve desplazado por la normal. La normal es la recta que va del punto A al punto central de curvatura S.

Aire
Acrílico



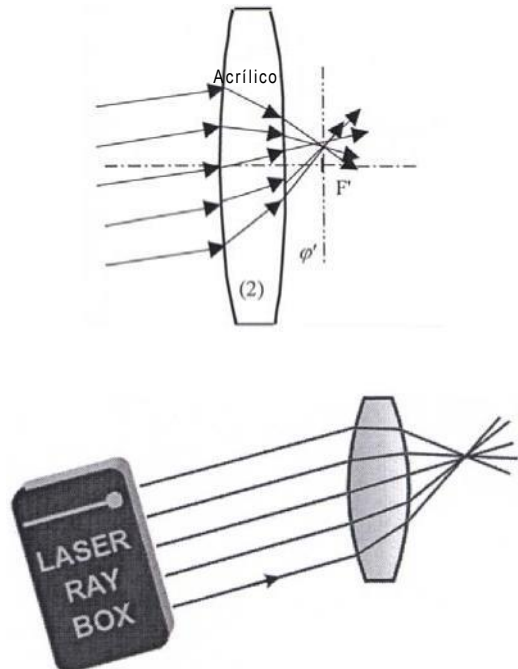
E16b Paso de rayos de luz a través de una superficie de separación cóncava de acrílico-aire (U17301)

Después de atravesar la superficie de separación, el haz de rayos se vuelve convergente. Los rayos paralelos se encuentran en un punto del eje óptico, esto es, el punto focal F' .



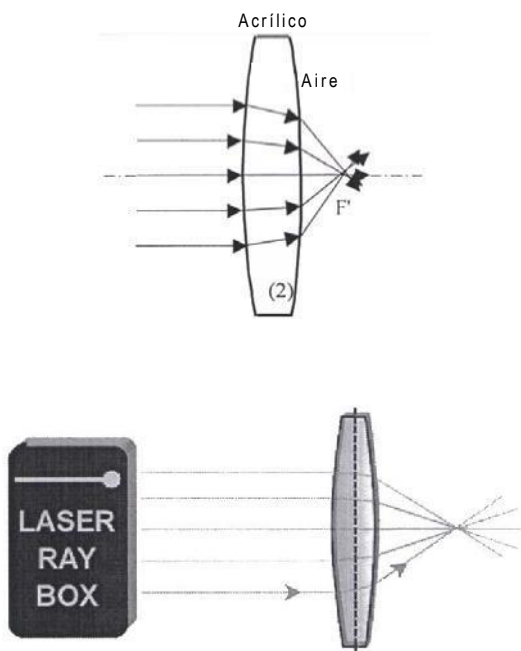
E17b Paso de rayos de luz a través de una lente acrílica convexa – rayos de luz no paralelos al eje óptico (U17300/U17301)

El eje Π' presenta un posición vertical en relación al eje óptico y pasa por el punto focal F' . Recibe el nombre de plano focal. Los rayos incidentes se parten y se encuentran en un punto del eje Π' .



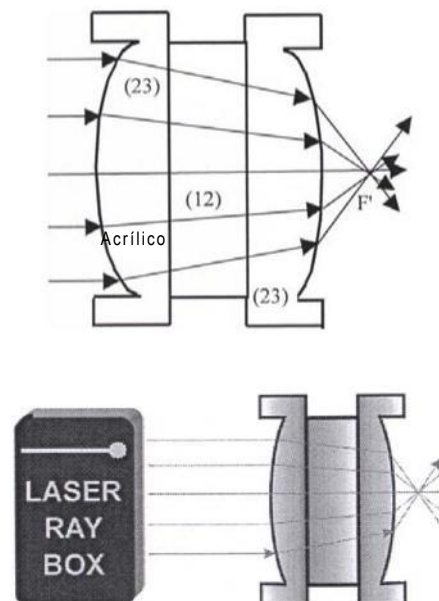
E17a Paso de rayos de luz a través de una lente acrílica convexa – rayos de luz paralelos al eje óptico (U17300/U17301)

Una lente acrílica convexa es una lente convergente y, una vez que la han atravesado, los rayos de luz se encuentran en el punto focal F' .



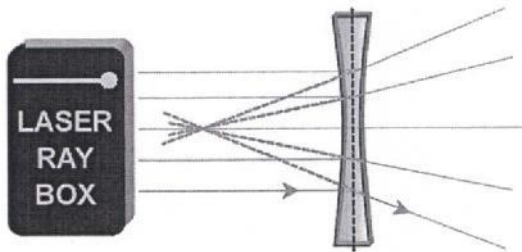
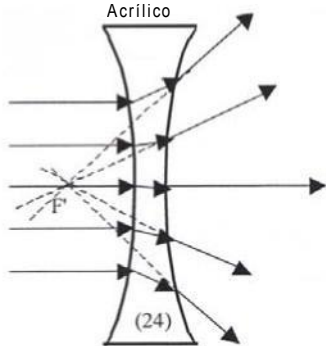
E17c Paso de rayos de luz a través de una lente acrílica convexa gruesa (U17301)

Se puede obtener el modelo de una lente gruesa emplazando una placa planoparalela ente dos lentes (23): Al modificarse el espesor d de la lente, varía también la distancia focal; mientras más gruesa sea la lente, la distancia focal será menor. A partir de un espesor crítico, la lente convergente se convierte en una lente divergente.



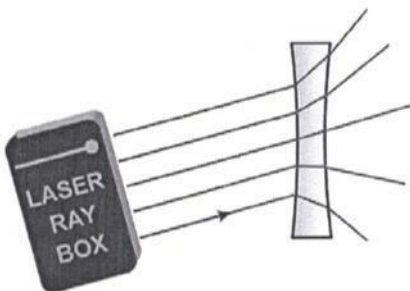
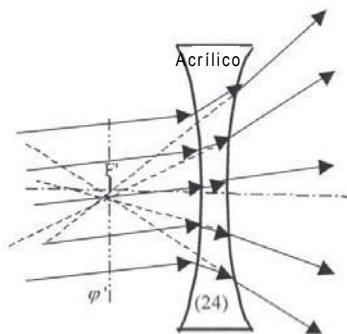
E18a Paso de rayos de luz a través de una lente acrílica cóncava – rayos de luz paralelos al eje óptico (U17300/U17301)

Después de atravesar la lente, los rayos de luz se vuelven divergentes. No reflejan ningún objeto. Si se prolongan hacia atrás, se encuentran en el punto focal virtual F' .



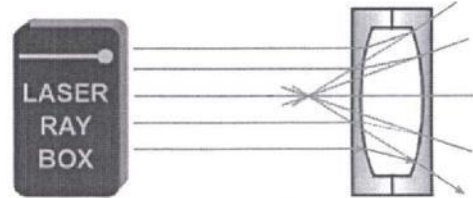
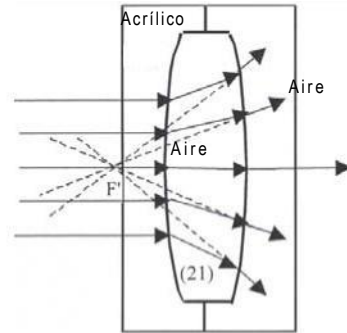
E18b Paso de rayos de luz a través de una lente acrílica cóncava – rayos de luz no paralelos al eje óptico (U17300/U17301)

El eje Π' presenta un posición vertical en relación al eje óptico y pasa por el punto focal virtual F' . Recibe el nombre de plano focal. La prolongación de los rayos desviados se encuentra en un punto del eje Π' .



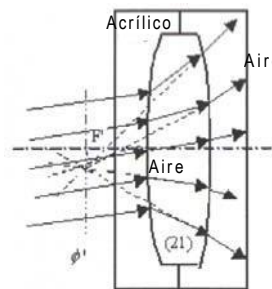
E19a Paso de rayos de luz a través de una lente de aire convexa – rayos de luz paralelos al eje óptico (U17301)

Después de atravesar la lente, los rayos de luz se vuelven divergentes. No reflejan ningún objeto. Si se prolongan hacia atrás, se encuentran en el punto focal virtual F' .

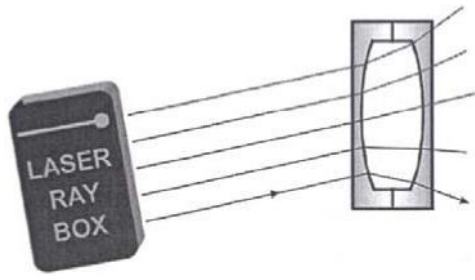


E19b Paso de rayos de luz a través de una lente de aire convexa – rayos de luz no paralelos al eje óptico (U17301)

El eje Π' presenta un posición vertical en relación al eje óptico y pasa por el punto focal virtual F' . Recibe el nombre de plano focal. La prolongación de los rayos desviados se encuentra en un punto del eje Π' .

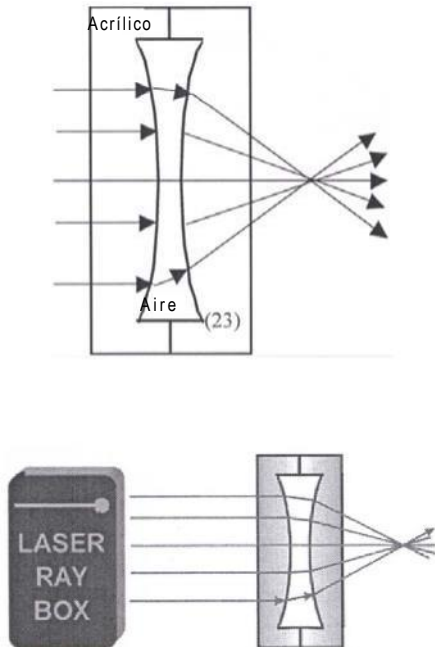


desviados se encuentra en un punto del eje Π' .



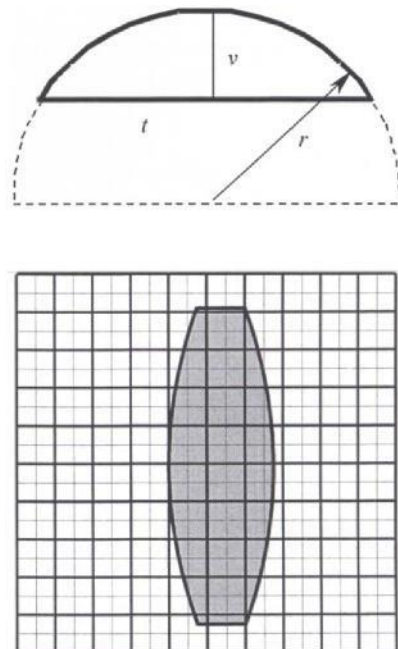
E20a Paso de rayos de luz a través de una lente de aire cóncava – rayos de luz paralelos al eje óptico
(U17301)

Una lente de aire cóncava se comporta como una lente convergente y los rayos desviados se encuentran en el punto focal F' después de atravesar la lente.



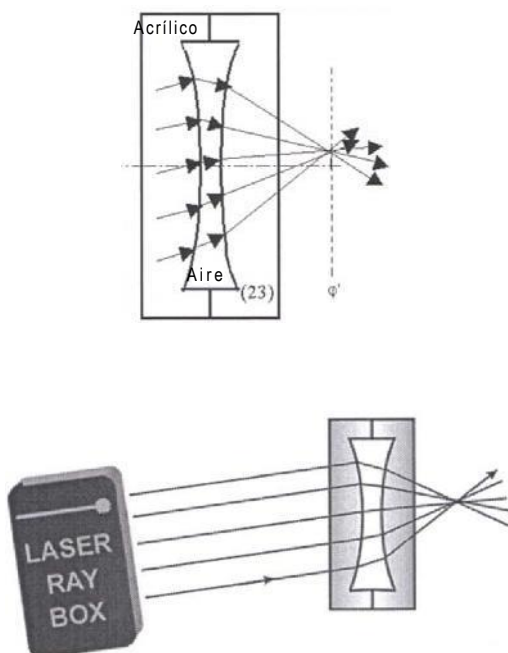
E21a Parámetros de lentes gruesas – determinación del radio de curvatura
(U17300/U17301)

En el juego de óptica de láser, las lentes poseen una superficie de refracción cilíndrica, sobre una superficie base circular, con iguales radios de curvatura. Estos radios se pueden determinar empleando papel milimetrado.



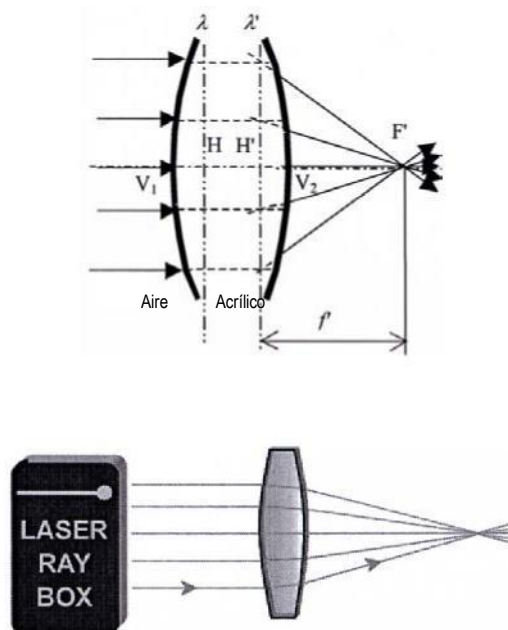
E20b Paso de rayos de luz a través de una lente de aire cóncava – rayos de luz paralelos al eje óptico
(U17301)

El eje Π' presenta un posición vertical en relación al eje óptico y pasa por el punto focal F' . Recibe el nombre de plano focal. La prolongación de los rayos desviados se encuentra en un punto del eje Π' .



E21b Parámetros de lentes gruesas – distancia focal
(U17300/U17301)

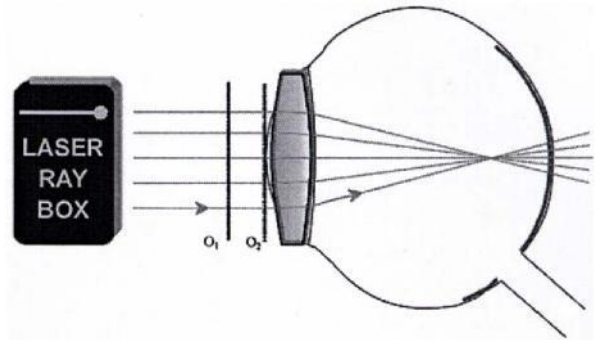
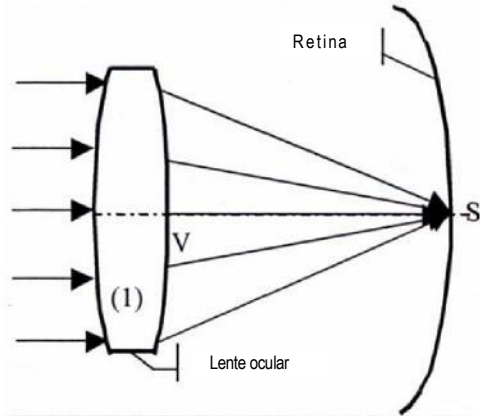
Se habla de lentes gruesas cuando el espesor de éstas no es despreciable. Durante la definición de la distancia focal, se debe tomar en cuenta la distancia entre ambos planos principales H y H' .



E22a Modelo del ojo humano

(U17300, lámina A)

Los rayos de luz paralelos al eje óptico se desvían por la acción de la lente ocular y se encuentran en un punto de la retina. Emplazar la lente ocular (1) directamente detrás de la línea O₂.



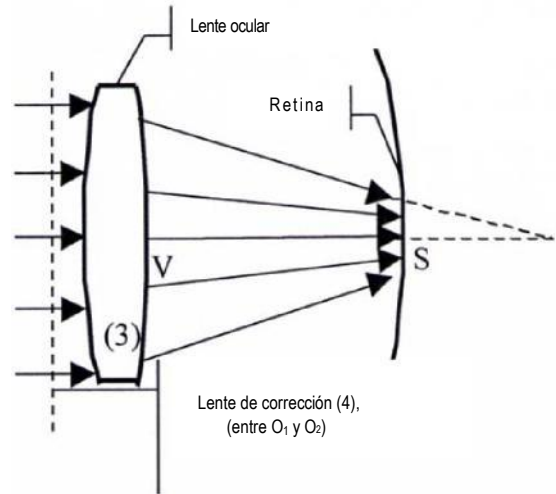
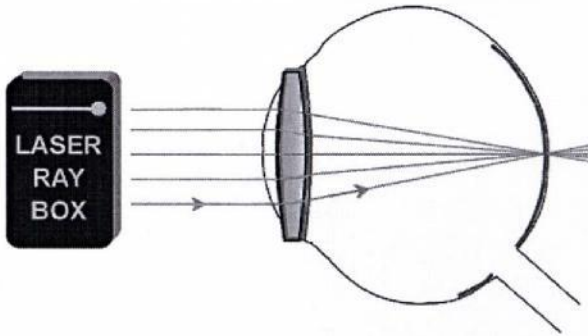
E22c Modelo del ojo humano, presbicia

(U17300, lámina A)

Los rayos de luz paralelos al eje óptico se desvían por la acción de la lente ocular y se encuentran en un punto situado detrás de la retina. La lente de corrección es una lente convergente. Para la distancia focal f del sistema de lentes es válido:

$$= f \frac{1}{\frac{1}{f_1} + \frac{1}{f_2}}$$

en donde f_1 es la distancia focal de la lente ocular y f_2 la de la lente de corrección.

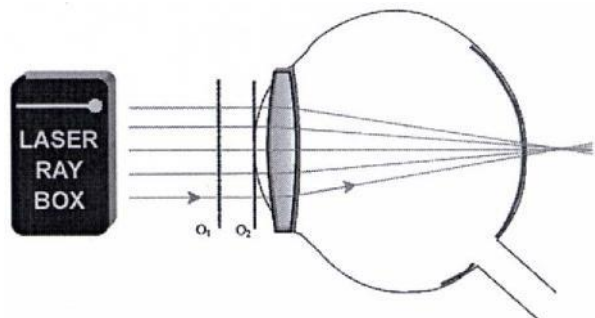
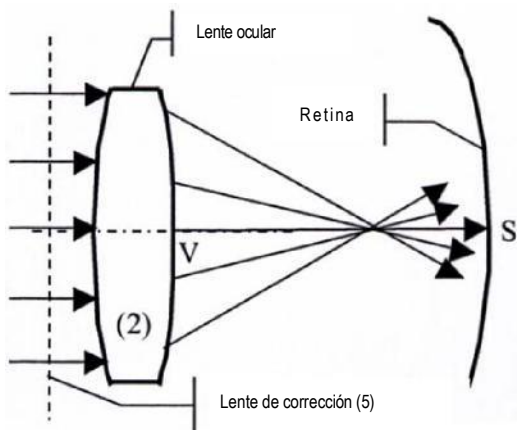


E22b Modelo de ojo humano, miopía

(U17300, lámina A)

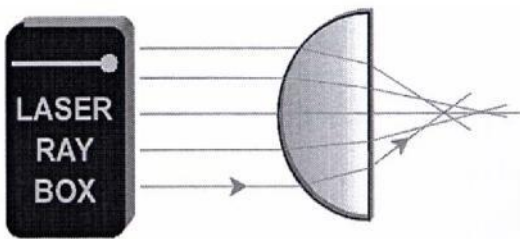
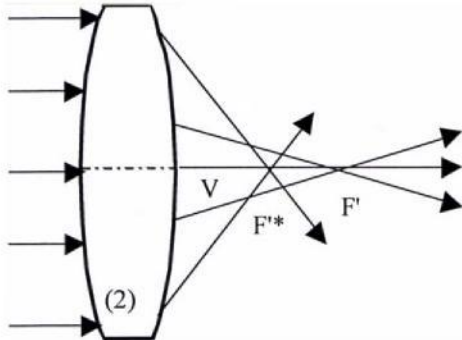
Los rayos de luz paralelos al eje óptico se desvían por la acción de la lente ocular y se encuentran en un punto situado delante de la retina.

Emplazar la lente ocular (2) directamente detrás de la línea O₂ y la lente de corrección (5) entre las líneas O₁ y O₂.



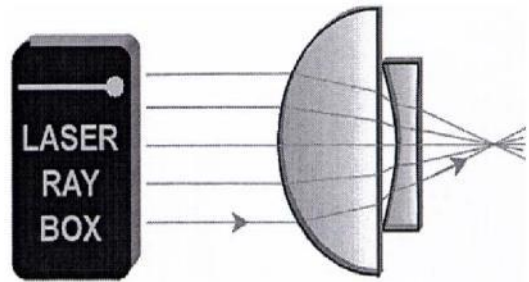
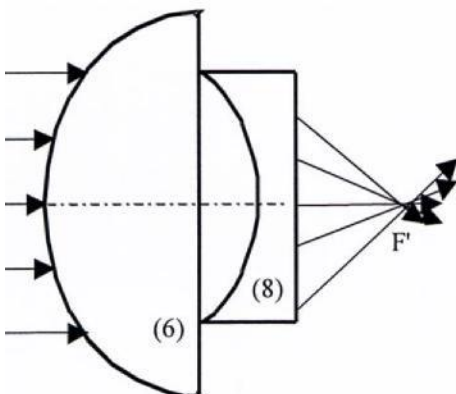
E23a Corrección de la aberración esférica por disminución del diámetro del haz de rayos
(U17300/U17301)

La aberración esférica de una lente se puede reducir disminuyendo el diámetro del haz de rayos que atraviesa la lente. Para ello se suprimen los rayos externos.



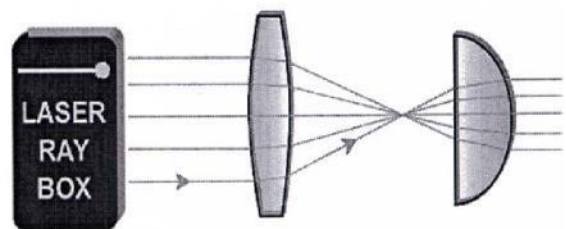
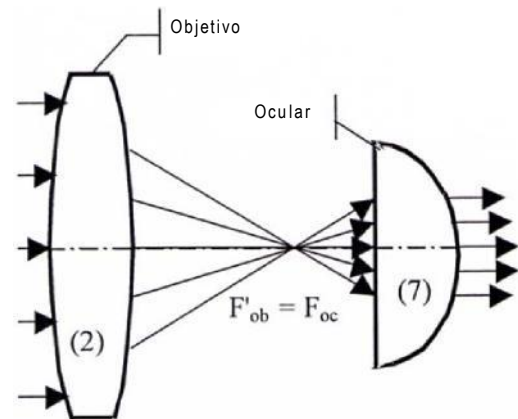
E23b Corrección de la aberración esférica por medio de una combinación de lentes
(U17300, lámina E)

La aberración esférica de las lentes convergentes y divergentes tienen un efecto inverso. El error se puede corregir por medio de una combinación de lentes. La aberración $\Delta f = f_1 - f_2$ se define como la diferencia entre la distancia focal f_1 de los rayos externos y f_2 de los rayos internos. En el caso de las lentes convergentes, la aberración tiene signo positivo, mientras que en las divergentes el signo es negativo.



E24a Telescopio según Kepler
(U17300, lámina D)

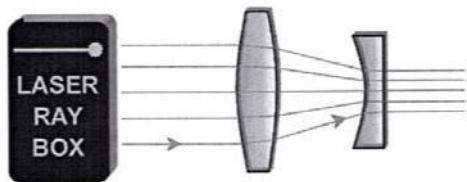
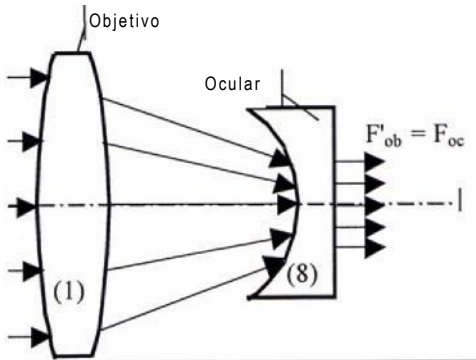
En el telescopio de Kepler, el objetivo genera una imagen real reducida del objeto observado, la cual se ve ampliada por el ocular como si se tratara de una lupa. Se obtiene una imagen invertida enormemente ampliada (tanto las partes superior e inferior, así como la derecha e izquierda se encuentran permutadas). Este hecho se puede demostrar suprimiendo uno de los rayos de luz externos. Si el rayo superior incidente se suprime, desaparece el rayo inferior de salida.



E24b Telescopio según Galilei

(U17300, lámina C)

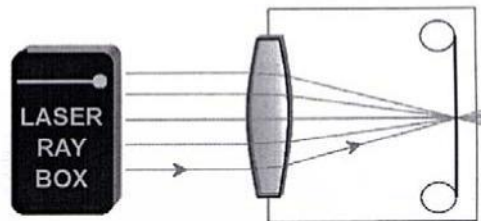
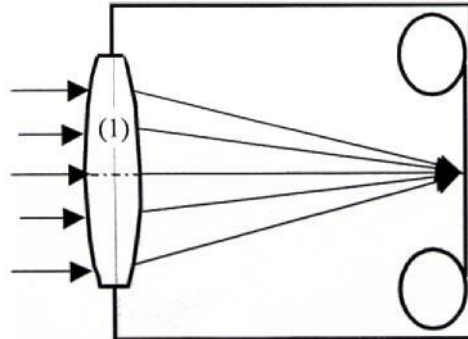
En el telescopio de Galilei, los rayos provenientes del objetivo pasan por una lente divergente antes de arribar al punto focal. Los rayos llegan al ojo en forma de rayos paralelos. La imagen del objeto está ampliada, derecha y no invertida.



E25 Cámara

(U17300, lámina B)

La lente de una cámara es una lente convergente. Refleja un objeto en una imagen real, volteada de cabeza, en la película que se encuentra en la parte posterior de la cámara.



1003049 Kit de ótica laser de demonstração (U17300) e 1003050 kit complementar (U17301)

Manual de instruções

1/05 ALF

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Kit de ótica laser de demonstração U17300 / 1003049
 Kit complementar U17301 / 1003050

A coluna "Kit de aparelhos" indica o kit de aparelhos necessário para cada experiência, U17300, U17301 ou ambos.

Introdução

O kit de ótica laser de demonstração permite uma montagem simples e clara das experiências para a representação dos fundamentos da ótica geométrica assim como do modo de funcionamento de diversos aparelhos óticos. Um laser diodo de 5 feixes U17302 serve de fonte luminosa.

Neste manual de instruções encontram-se descritas numerosas experiências fundamentais com os elementos óticos de ambos kits, U17300 e U17301. Cada descrição de experiência está composta por três partes:

1. Uma descrição simples da experiência
2. Uma representação gráfica da experiência
3. Uma representação da montagem da experiência

Debaixo de cada título encontra-se indicado entre parênteses com qual kit de aparelhos a experiência pode ser executada, U17300, U17301 ou U17300/U17301. A mesma informação encontra-se também na última coluna do índice de conteúdo.

Um elemento constituinte fundamental das monta-

gens de experiências é o laser diodo U17302. Cinco diodos laser produzem cinco raios luminosos paralelos. O número de feixes produzidos pode ser escolhido. Para tal, coloca-se a placa de metal com perfurações incluída no fornecimento na frente do diodo laser. Ao utilizar o laser deve-se evitar o contato direto do olho com o feixe do laser.

Fornecimento

Kit de ótica laser de demonstração U17300

- 1 Lente bicôncava
- 2 Lente biconvexa
- 3 Lente biconvexa
- 4 Lente biconvexa
- 5 Lente biconvexa
- 6 Lente plano côncava pequena
- 7 Lente plano convexa pequena
- 8 Lente plano convexa grande
- 9 Espelho, côncavo
- 10 Espelho, convexo

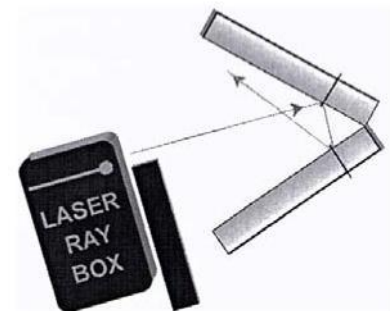
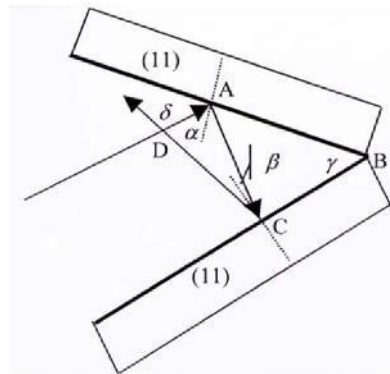
- 11 Espelho plano
- 12 Placa plano paralela
- 13 Prisma
- 14 Conductor de luz

Transparências

- A Modelo de olho
- B Câmera
- C Telescópio segundo Galileu
- D Telescópio segundo Kepler
- E Aberração esférica
- F Escala angular de 360°

Kit complementar U17301

- 21 Lente de ar bicôncava
- 22 Lente bicôncava
- 23 Lente de ar biconvexa
- 24 Lente biconvexa
- 25 Prisma de ar
- 26 Prisma equilátero
- 27 2 prismas retangulares
- 28 Placa plano paralela, quadrada
- 29 2 placas plano paralelas, retangular
- 11 2 espelhos planos

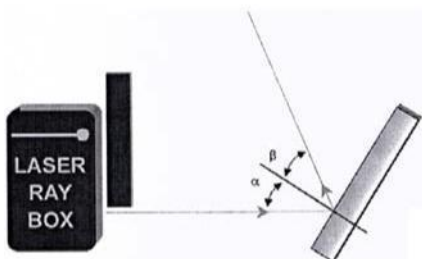
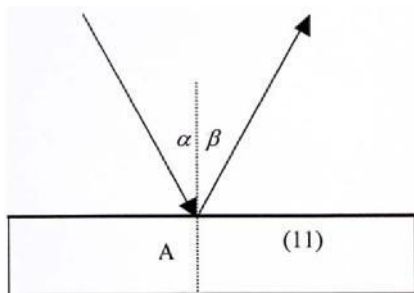


E1 Reflexão no espelho

(U17300/U17301)

Representação da lei dos reflexos. Um raio luminoso que incide na superfície espelhada plana com um ângulo de incidência α , será refletido com o ângulo β $\alpha = \beta$

Ambos ângulos são medidos em relação à normal da superfície.



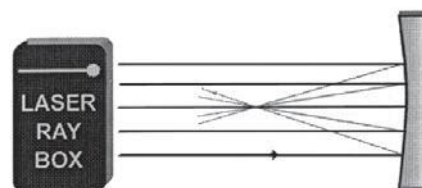
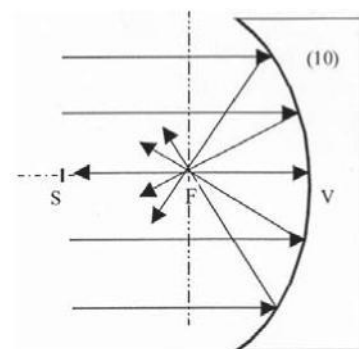
E3a Reflexão em espelhos côncavos – raios paralelos ao eixo ótico

(U17300)

A distância focal f de um espelho côncavo é determinada pelo comprimento do percurso VF . O raio de curvatura pode ser calculado com a fórmula

$$r = 2f$$

O percurso VS é duas vezes mais longo que VF .



E2 Reflexão em dois espelhos planos

(U17301)

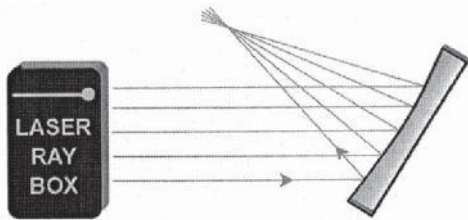
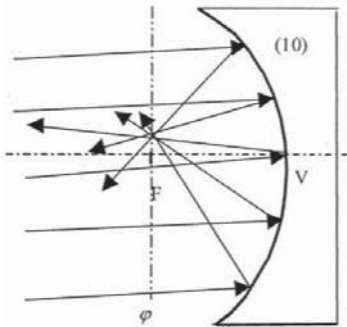
Demonstração da relação:

$$\theta = 2\phi$$

sendo que o ângulo θ é formado pelo raio incidente e o raio refletido e ϕ é o ângulo formado pelas superfícies dos espelhos.

E3b Reflexão em espelhos côncavos – Raios luminosos não paralelos ao eixo óptico (U17300)

O eixo Π perpendicular ao eixo óptico e passa pelo ponto focal. Ele é chamado de plano focal. Os raios incidentes paralelos são refletidos e convergem num ponto no plano focal Π . Se os raios são paralelos ao eixo óptico, então o ponto encontra-se lá e este chama-se ponto focal F.

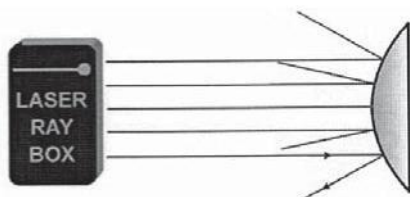
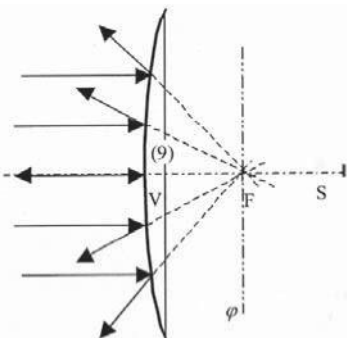


E4a Reflexão em espelhos convexos – Raios luminosos paralelos ao eixo óptico (U17300)

Os raios refletidos parecem ter origem num ponto atrás do espelho. É o chamado ponto focal virtual. O percurso VF determina a distância focal do espelho. O raio de curvatura pode ser calculado com a fórmula

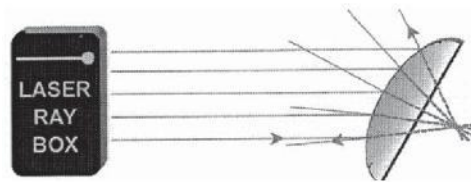
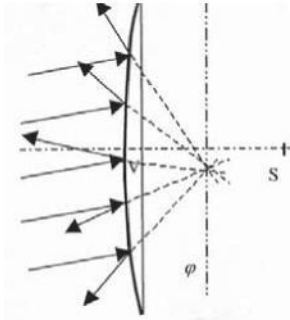
$$f = \frac{r}{2}$$

O percurso VS é duas vezes mais longo que VF.



E4b Reflexão em espelhos convexos – Raios luminosos não paralelos ao eixo óptico (U17300)

O eixo Π perpendicular ao eixo óptico e passa pelo ponto focal. Ele é chamado de plano focal. Se raios paralelos incidem sobre o espelho eles são divergidos de modo que parece que eles têm a sua origem num ponto do plano focal Π atrás do espelho.

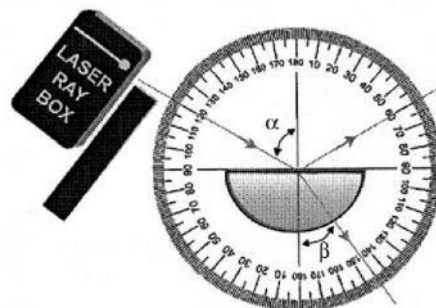
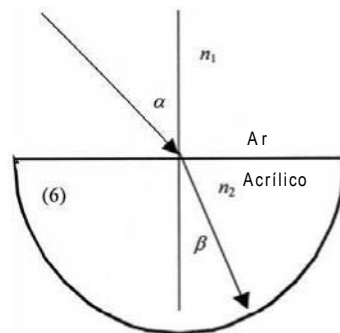


E5a Refração de um raio luminoso ao passar do ar para o acrílico (U17300, transparência F)

Na passagem de um raio luminoso de um meio com o índice de refração n_1 para um meio com índice de refração n_2 , a sua mudança de direção é determinada pela Lei da refração de Snellius:

$$n_1 \sin \alpha = n_2 \sin \beta$$

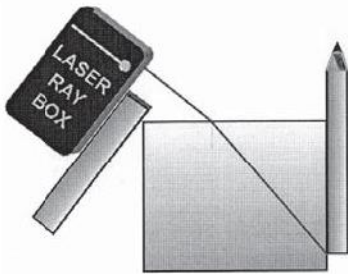
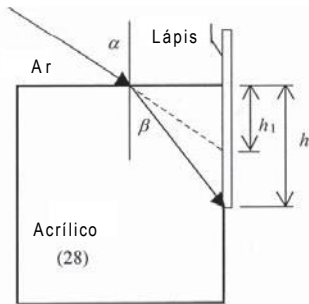
α é o ângulo de incidência no meio n_1 e β é o ângulo de refração no meio n_2 .



E5b Profundidade aparente de um objeto

(U17301)

Montagem da experiência para a observação da profundidade aparente de um objeto na água ou por trás de acrílico visto pelo ar.



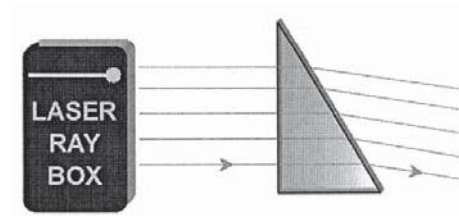
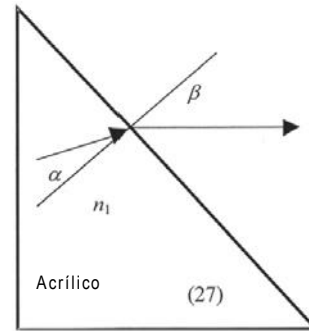
E6b Refração num prisma de acrílico

(U17300/U17301)

Na passagem de um raio luminoso do acrílico para o ar, a Lei de Snellius pode ser escrita da seguinte forma:

$$n_1 \sin \alpha = \sin \beta$$

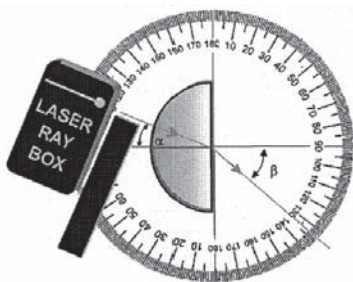
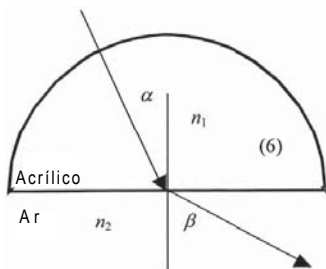
Índice de refração do ar $n_2 = 1$.



E6a Refração de um raio luminoso ao passar do acrílico para o ar

(U17300, transparência F)

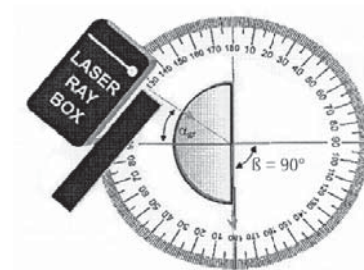
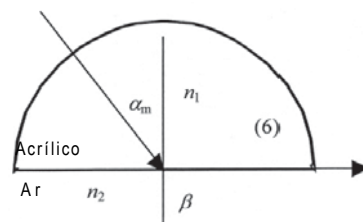
O ângulo de refração β é maior do que o ângulo de incidência α . O raio é refratado para além da normal à superfície.



E6c Ângulo crítico, reflexão total

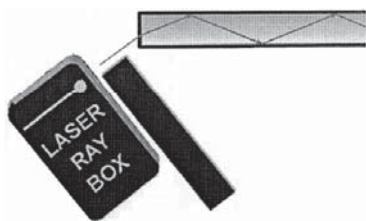
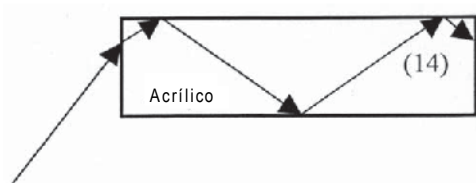
(U17300, transparência F)

Quanto maior é o ângulo de incidência, maior será o ângulo de refração. Se $n_1 < n_2$, então existe um ângulo crítico α_c . O raio refratado encontra-se então na superfície de separação entre dois meios. Caso o ângulo de incidência for maior que o ângulo crítico não há mais refração e a totalidade da luz é refletida. Neste caso fala-se de reflexão total.



E6d Reflexão total – Propagação da luz em condutores de luz (U17300)

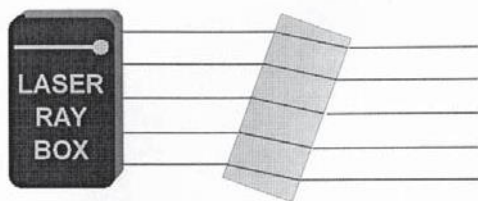
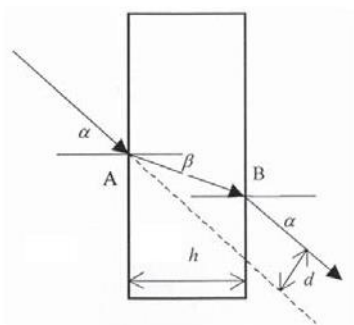
A luz se propaga num condutor de luz graças à reflexão total. O parâmetro, a abertura numérica, determina qual é o ângulo que não deve ser ultrapassado. Ele corresponde ao seno do ângulo de entrada máximo da luz. Também determina-se o menor rádio, quando o condutor é dobrado, por esse parâmetro. Ele não deve ser ultrapassado quando o condutor de luz for instalado.



E7 Deslocamento de um raio luminoso, placa de acrílico plano paralela (U17300/U17301)

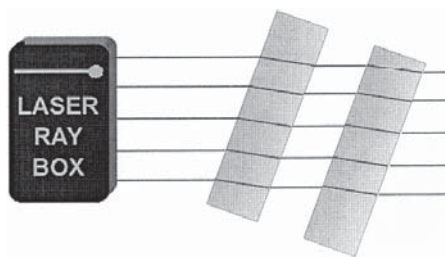
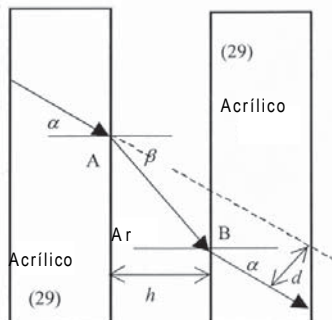
Quando um raio luminoso atravessa uma placa plano paralela, a sua direção não é alterada. O raio emergente é deslocado num valor d . Para uma placa de espessura h resulta para d :

$$d = h \frac{\sin(\alpha - \beta)}{\cos \beta}$$



E8 Deslocamento de um raio luminoso, ar entre duas placas de acrílico plano paralelas (U17301)

Neste caso ocorre um deslocamento entre o raio incidente e o raio emergente. Porém, o deslocamento ocorre no sentido contrário do deslocamento com a placa de acrílico.



E9a Desvio de um raio luminoso através de um prisma de acrílico (U17300/U17301)

Um raio luminoso incidente num prisma de acrílico no ponto A é refratado em direção à normal da superfície. No ponto de saída B a refração ocorre para fora da normal da superfície. A soma de todos os ângulos de refração resulta no ângulo de desvio δ . Este é o ângulo formado pelo raio luminoso incidente e o raio luminoso emergente.

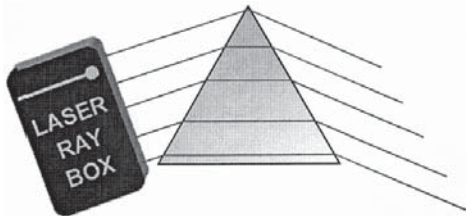
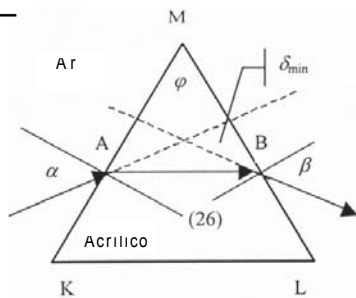
Ar Acrílico



E9b Desvio mínimo através de um prisma de acrílico
(U17300/U17301)

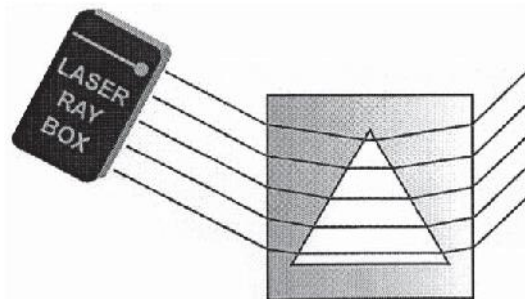
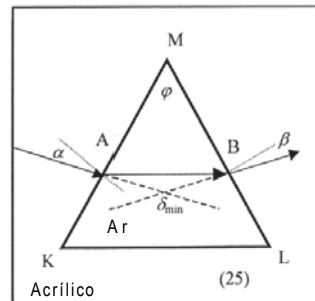
Pode ser demonstrado que o ângulo de incidência α , no caso do ângulo mínimo de desvio $\delta_{\min}^{\text{TM}}$, é igual ao ângulo de saída β . O raio refratado atravessa então o prisma paralelamente ao lado que não é atravessado. Para o índice de refração do prisma é válido:

$$n = \frac{\sin \frac{\alpha + \beta}{2}}{\sin \frac{\varphi}{2}}$$



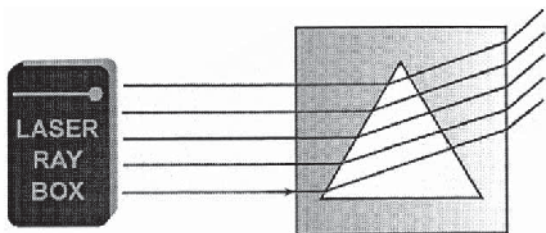
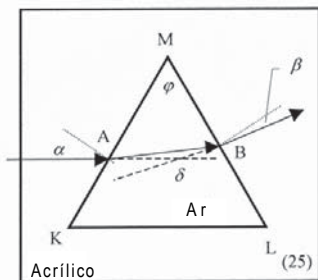
E10b Desvio mínimo através de um prisma de ar
(U17301)

No caso do desvio mínimo $\delta_{\min}^{\text{TM}}$, o ângulo de incidência α é igual ao ângulo de saída β . O raio refratado atravessa o prisma então paralelamente ao lado que não é atravessado. Para o índice de refração do prisma é válido: (veja E9b). A direção do desvio é oposta à do caso do prisma de acrílico.



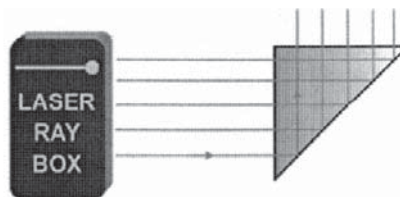
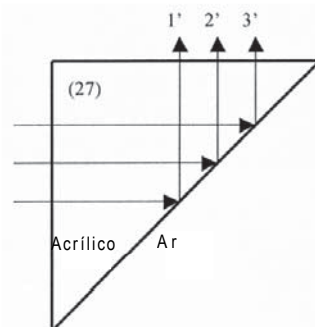
E10a Desvio de um raio luminoso através de um prisma de ar
(U17301)

A luz atravessa a superfície de separação acrílico/ar no ponto A. O raio luminoso é refratado para fora da normal da superfície. No ponto de saída B ele é refratado em direção à normal da superfície. A soma de todos os ângulos de refração resulta no ângulo de desvio δ^{TM} . Este é o ângulo formado pelo raio luminoso incidente e o raio luminoso emergente.



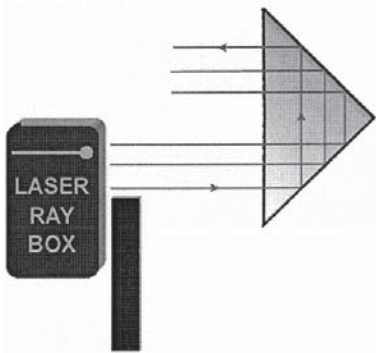
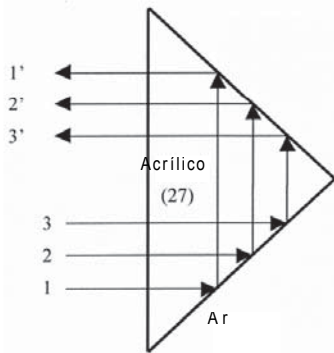
E11a Reflexão numa aresta de um prisma de acrílico
(U17301)

Quando os raios luminosos atingem a aresta, eles são totalmente refletidos. Girando levemente o prisma pode-se observar tanto a refração quanto a reflexão.



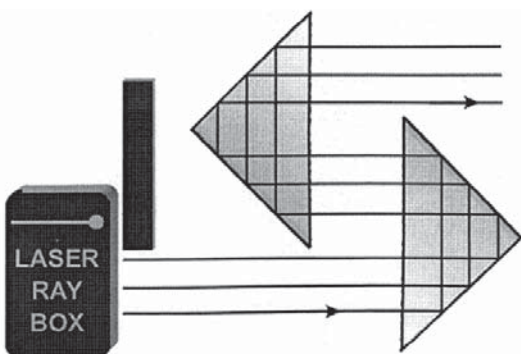
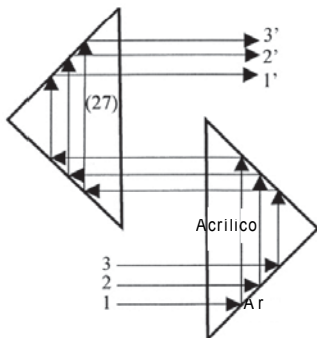
E11b Reflexão em duas arestas de um prisma de acrílico (U17301)

Neste caso encontram-se reunidas as condições para a reflexão total em ambas arestas. Se o raio incidente superior for interrompido, então desaparece o raio emergente inferior. A imagem está invertida em 180°.



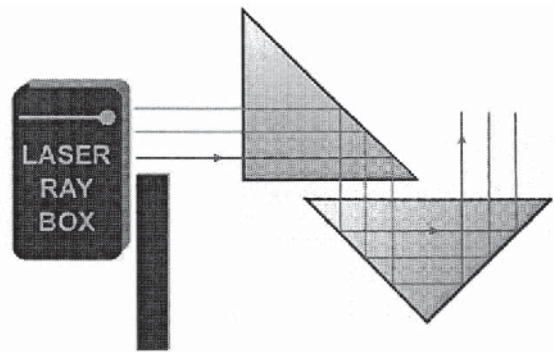
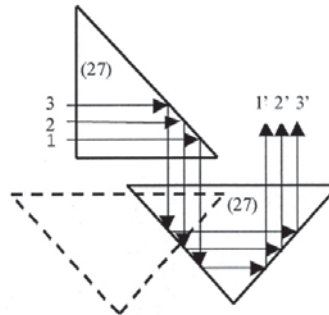
E11c Reflexão em dois prismas de acrílico (U17301)

As condições para a reflexão total estão reunidas em todas as arestas do prisma.



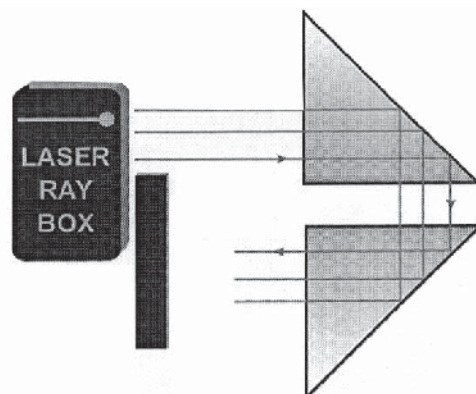
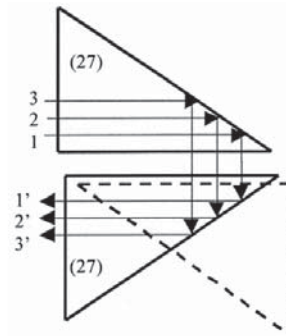
E11d Reflexão em dois prismas de acrílico (U17301)

As condições para a reflexão total estão reunidas em todas as arestas do prisma.

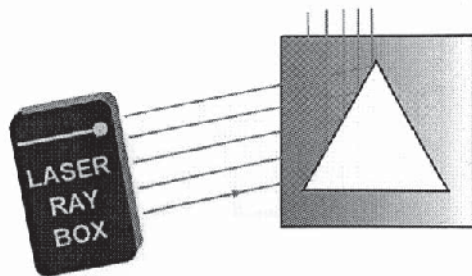
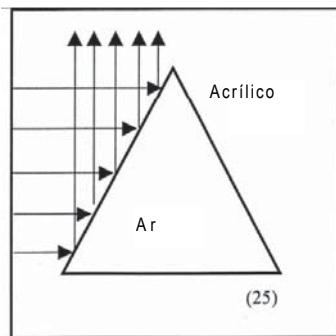


E11e Reflexão em dois prismas de acrílico (U17301)

As condições para a reflexão total estão reunidas em todas as arestas do prisma.

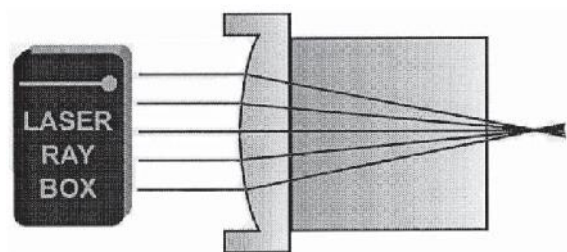
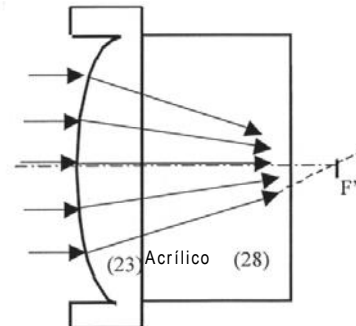


E12 Reflexão num prisma de ar (U17301) Quando o ângulo de incidência dos raios luminosos é menor do que o ângulo crítico (42°), os raios luminosos são refletidos para dentro do acrílico. Se o ângulo é maior, uma parte da luz passa pelo prisma de ar.



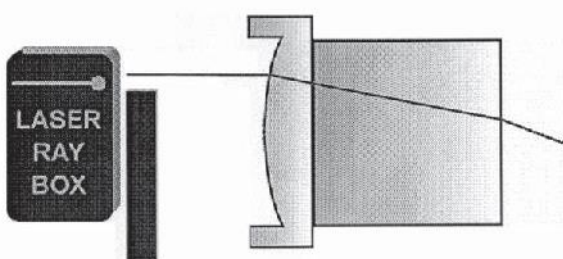
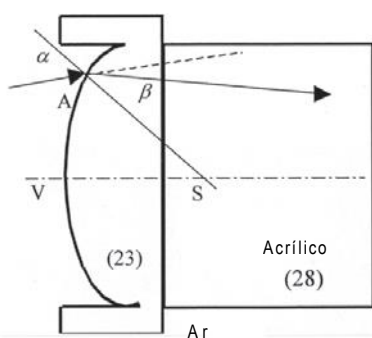
E13b Percurso de um raio luminoso através de uma superfície de separação ar-acrílico convexa (U17301)

Os raios luminosos incidentes são refratados duas vezes e se encontram no ponto F' no eixo óptico, o ponto focal.



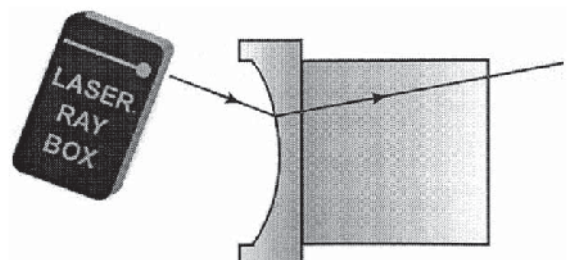
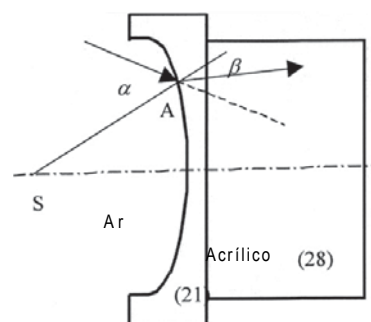
E13a Percurso de um raio luminoso através de uma superfície de separação ar-acrílico convexa (U17301)

Quando um raio luminoso atravessa a superfície de separação ar/acrílico no ponto A ele é refratado em direção à normal da superfície. A normal da superfície é a reta que vai do ponto A ao ponto S centro da curva-tura.



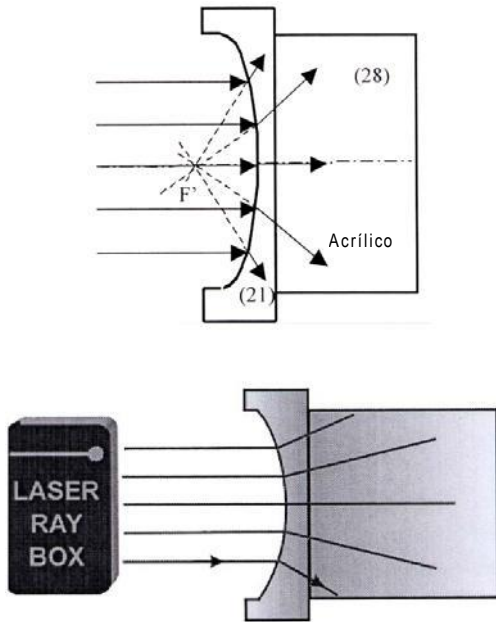
E14a Percurso de um raio luminoso através de uma superfície de separação ar-acrílico côncava (U17301)

Se o raio luminoso atinge a superfície de separação no ponto A, observa-se uma refração em direção à normal da superfície. A normal da superfície é a reta que vai do ponto A ao ponto S centro da curvatura.



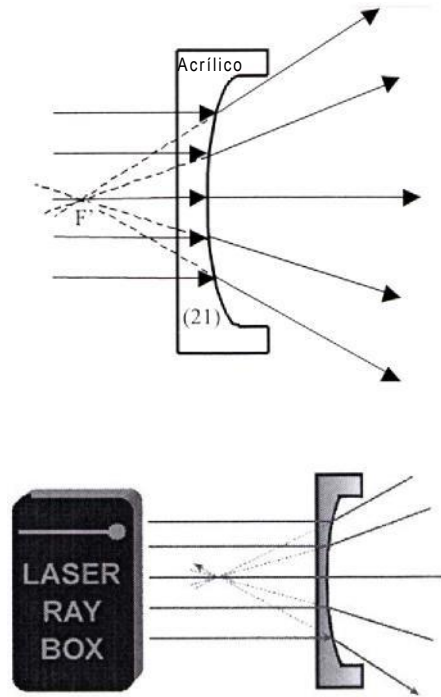
E14b Percurso de um raio luminoso através de uma superfície de separação ar-acrílico côncava (U17301)

Após a passagem pela superfície de separação acrílico/ar o feixe luminoso é refratado de modo divergente. Se os raios refratados fossem prolongados para trás, então eles se encontrariam num ponto no eixo ótico. Esse ponto chama-se ponto focal virtual F' .



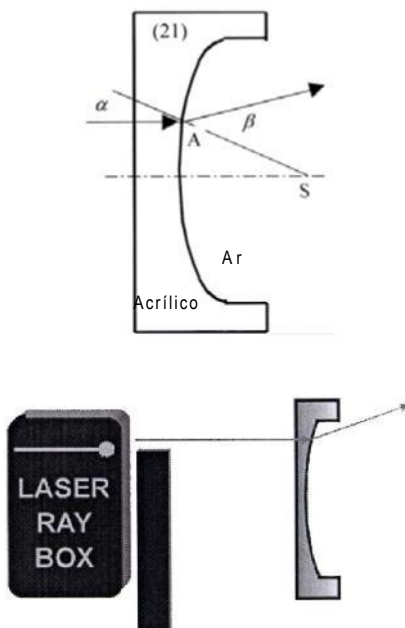
E15b Percurso de um raio luminoso através de uma superfície de separação acrílico-ar convexa (U17301)

Após a passagem pela superfície de separação acrílico/ar o feixe luminoso é refratado de modo divergente. Se os raios refratados fossem prolongados para trás, então eles se encontrariam num ponto no eixo ótico. Esse ponto chama-se ponto focal virtual F' .



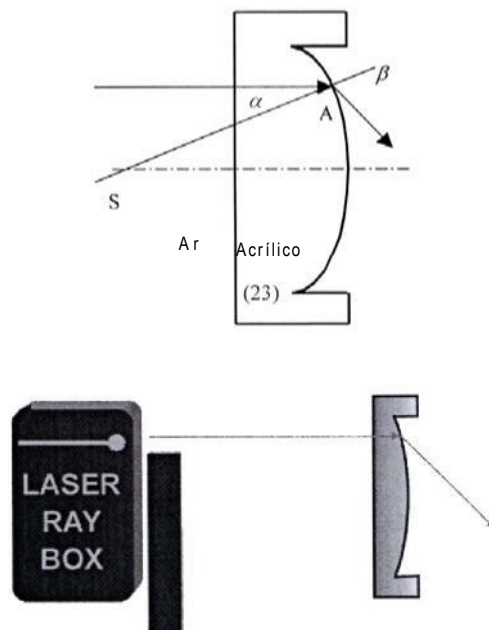
E15a Percurso de um raio luminoso através de uma superfície de separação acrílico-ar convexa (U17301)

Após a passagem do raio luminoso pelo ponto A este é refratado para fora da normal da superfície. A normal da superfície é a reta que vai do ponto A ao ponto S centro da curvatura.



E16a Percurso de um raio luminoso através de uma superfície de separação acrílico-ar côncava (U17301)

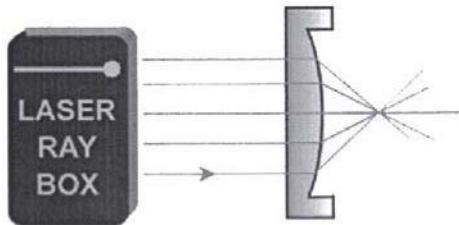
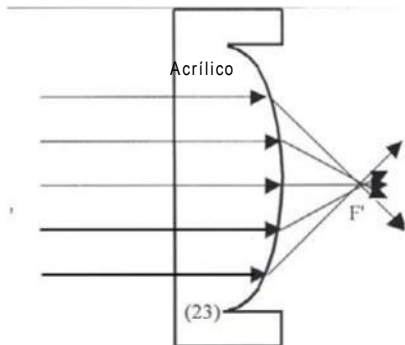
Após a passagem do raio luminoso pelo ponto A este é refratado para fora da normal da superfície. A normal da superfície é a reta que vai do ponto A ao ponto S centro da curvatura.



E16b Percurso de um raio luminoso através de uma superfície de separação acrílico-ar côncava
(U17301)

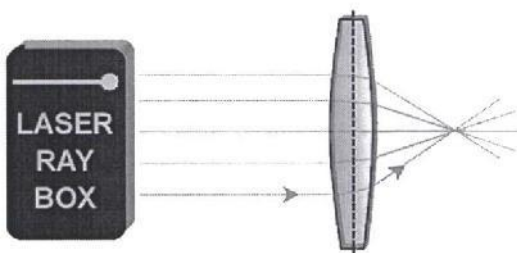
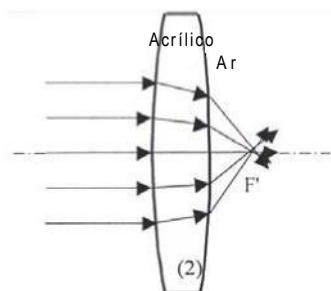
Após a passagem através da superfície de separação o feixe de raios luminosos é convergente. Raios paralelos encontram-se num ponto do eixo óptico, o

Uma lente de acrílico convexa é uma lente convergente e os raios luminosos se encontram no ponto focal F' após atravessar a lente.



ponto focal F' .

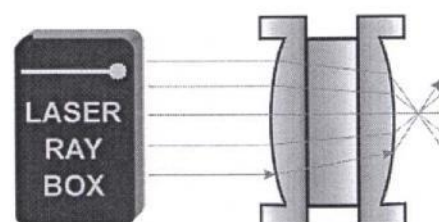
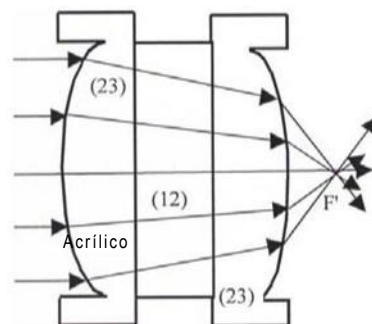
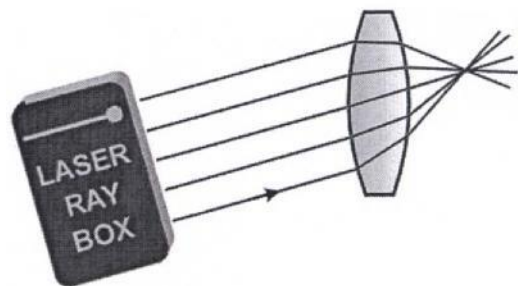
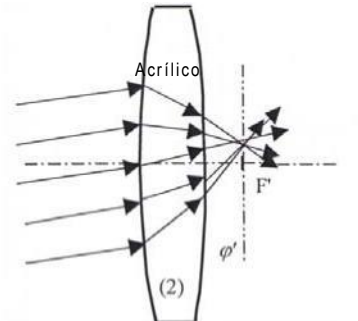
E17a Percurso de raios luminosos através de uma lente de acrílico convexa – Raios luminosos paralelos ao eixo óptico
(U17300/U17301)



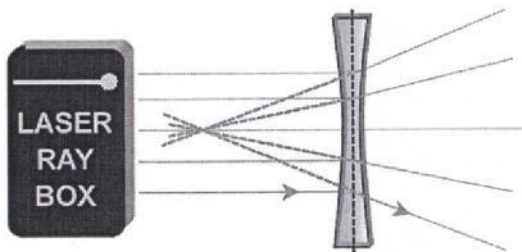
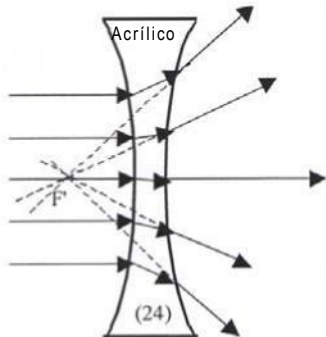
E17b Percurso de raios luminosos através de uma lente de acrílico convexa – Raios luminosos não paralelos ao eixo ótico (U17300/U17301) O eixo Π' perpendicular ao eixo ótico e passa pelo ponto focal F' . Ele é chamado de plano focal. Os raios incidentes são refratados e convergem num ponto no eixo Π' .

E17c Percurso de raios luminosos através de uma lente de acrílico convexa grossa (U17301) Colocando uma placa plano paralela entre duas len-

tes (23) pode-se realizar o modelo de uma lente [grosseira](#). Com a alteração da espessura d da lente também altera-se a distância focal, quanto mais grossa a lente, menor a distância focal. A partir de uma espessura crítica, a lente convergente torna-se uma lente divergente.

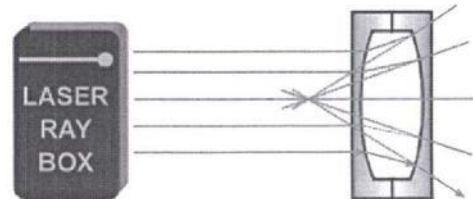
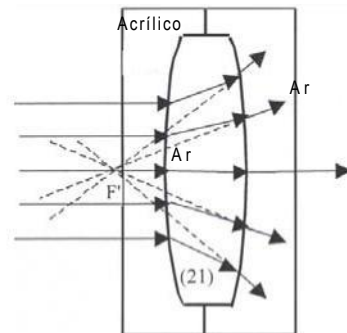


E18a Percurso de raios luminosos através de uma lente de acrílico côncava – Raios luminosos paralelos ao eixo óptico (U17300/U17301) Os raios luminosos são divergentes após a passagem pela lente. Não é projetado um objeto. Se prolongados para trás, os raios se encontram no ponto focal virtual F' .

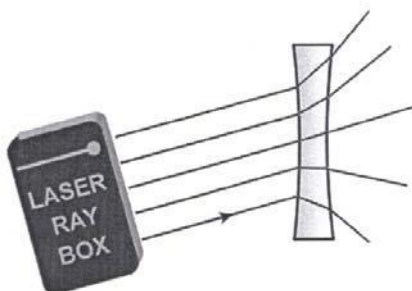
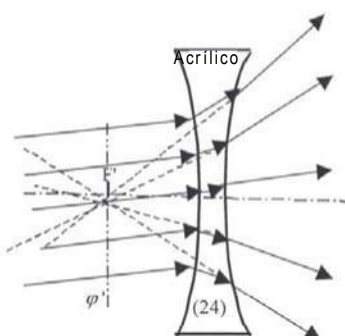


E19a Percurso de raios luminosos através de uma lente de ar convexa – Raios luminosos paralelos ao eixo óptico (U17301)

Os raios luminosos são divergentes após a passagem pela lente. Eles não projetam um objeto. Se prolongados para trás, os raios se encontram no ponto focal virtual F' .

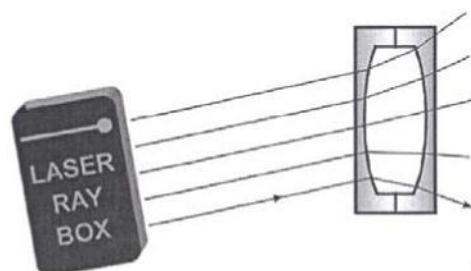
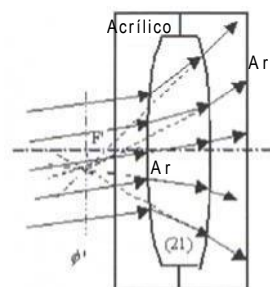


E18b Percurso de raios luminosos através de uma lente de acrílico côncava – Raios luminosos não paralelos ao eixo óptico (U17300/U17301) O eixo Π' perpendicular ao eixo óptico e passa pelo ponto focal virtual F' . Ele é chamado de plano focal. Os prolongamentos dos raios refratados se encontram num ponto no eixo Π' .



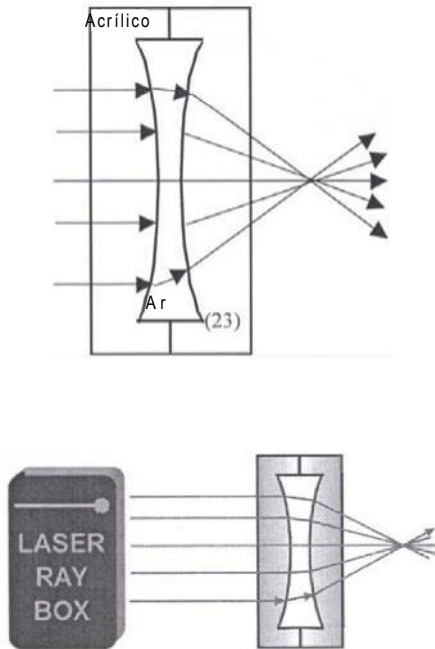
E19b Percurso de raios luminosos através de uma lente de ar convexa – Raios luminosos não paralelos ao eixo óptico (U17301)

O eixo Π' perpendicular ao eixo óptico e passa pelo ponto focal virtual F' . Ele é chamado de plano focal. Os prolongamentos dos raios refratados se encontram num ponto no eixo Π' .



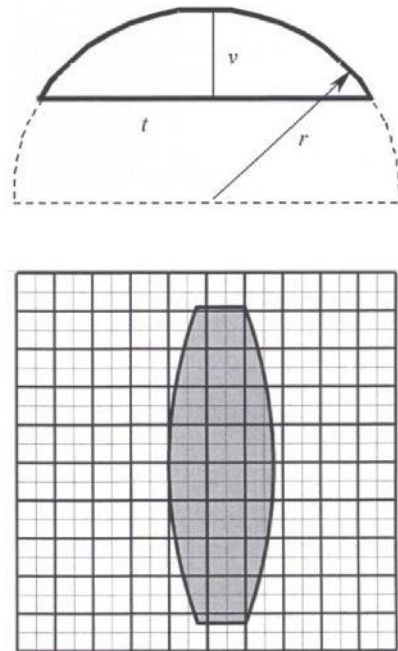
E20a Percurso de raios luminosos através de uma lente de ar côncava – Raios luminosos paralelos ao eixo ótico
(U17301)

Uma lente de ar côncava se comporta como uma lente convergente e os raios refratados se encontram no ponto focal F' após a passagem pela lente.



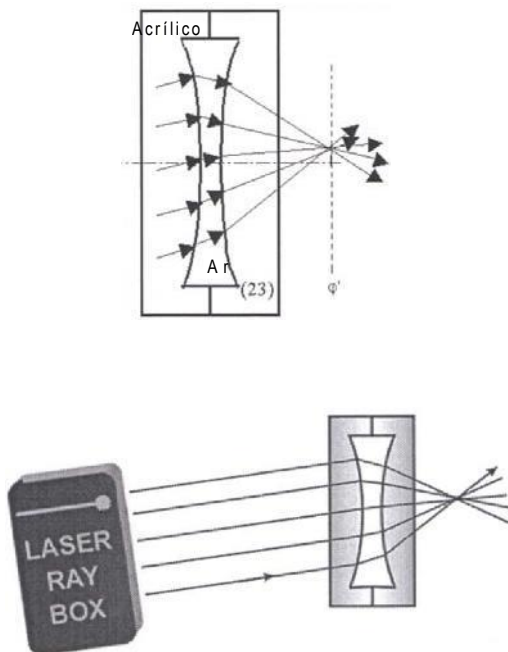
E21a Parâmetros de lentes grossas – Determinação do raio de curvatura
(U17300/U17301)

As lentes do kit de ótica laser possuem uma superfície de refração cilíndrica sobre uma base circular com de curvatura [iguais](#). Com a ajuda de papel milimetrado pode-se determinar esses raios.



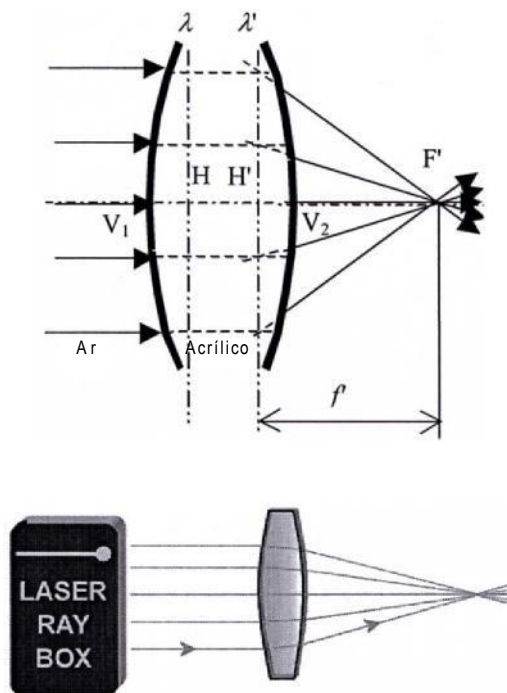
E20b Percurso de raios luminosos através de uma lente de ar côncava – Raios luminosos paralelos ao eixo ótico
(U17301)

O eixo Π' perpendicular ao eixo ótico e passa pelo ponto focal virtual F' . Ele é chamado de plano focal. Os raios refratados se encontram num ponto no eixo Π' .



E21b Parâmetros de lentes grossas – Distância focal
(U17300/U17301)

Lentes grossas são aquelas nas quais a espessura não é desprezível. Ao definir-se a distância focal deve-se levar em consideração a distância entre os dois planos principais H e H' .

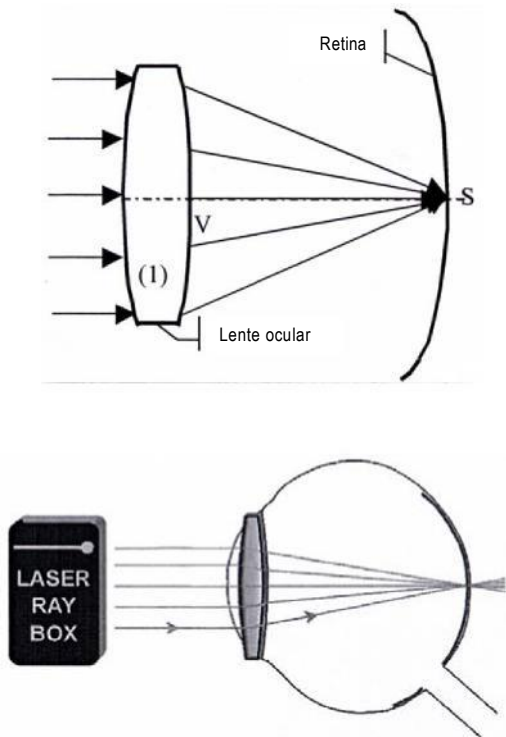


E22a Modelo de olho

(U17300, transparência A)

Raios luminosos paralelos ao eixo ótico são refratados pelo cristalino e se encontram num ponto sobre a retina.

Colocar o cristalino (1) diretamente atrás da linha O_2 .



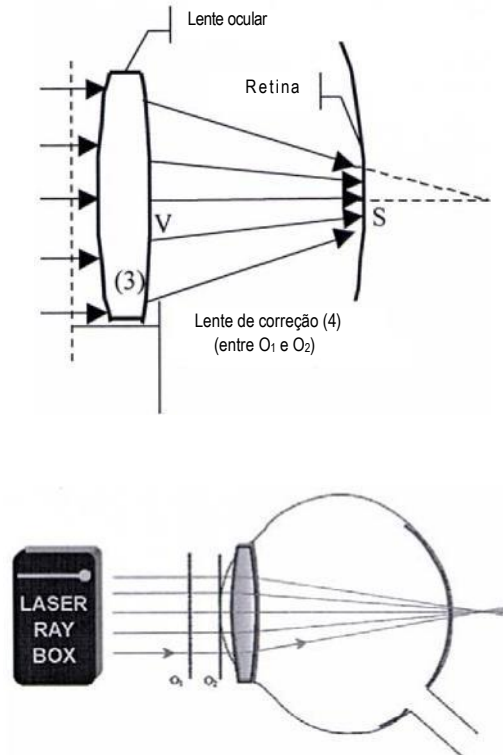
E22c Modelo de olho, hipermetropia

(U17300, transparência A)

Raios luminosos paralelos ao eixo ótico são refratados pelo cristalino e se encontram num ponto atrás da retina. A lente de correção é uma lente convergente. Para a distância focal f' do sistema de lentes vale:

$$f' = \frac{f_1' f_2'}{f_1' + f_2'}$$

sendo que f_1' é a distância focal do cristalino e f_2' é a da lente de correção.

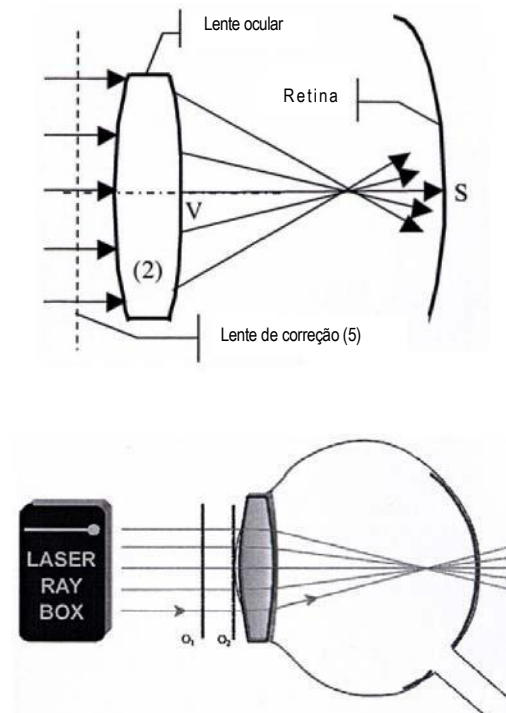


E22b Modelo de olho, miopia

(U17300, transparência A)

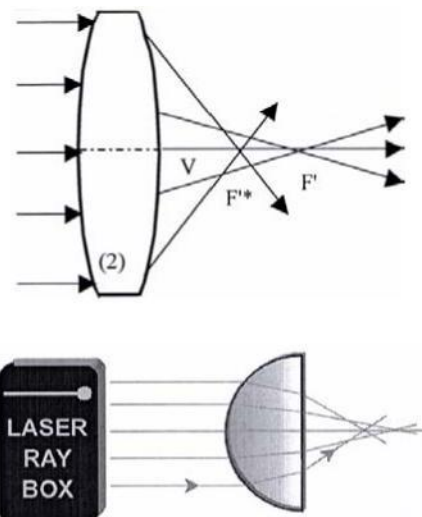
Raios luminosos paralelos ao eixo ótico são refratados pelo cristalino e se encontram num ponto antes da retina.

Colocar o cristalino (2) diretamente atrás da linha O_2 e a lente de correção (5) entre a linha O_1 e O_2 .



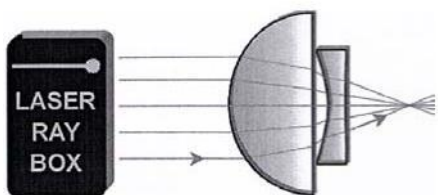
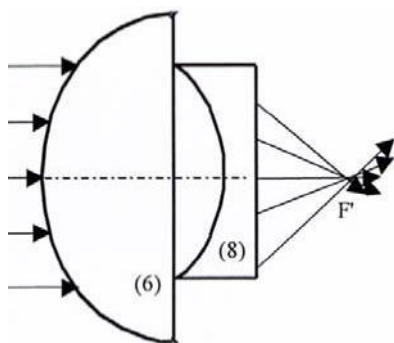
E23a Correção da aberração esférica através da redução do diâmetro do feixe de raios luminosos (U17300/U17301)

A aberração esférica de uma lente pode ser reduzida pela diminuição do diâmetro do feixe de raios luminosos que atravessa a lente. Para tal, utilizar os raios mais exteriores.



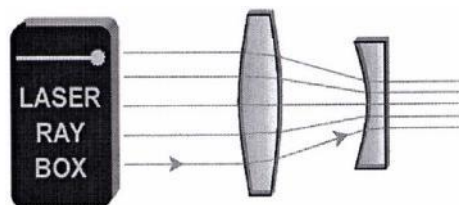
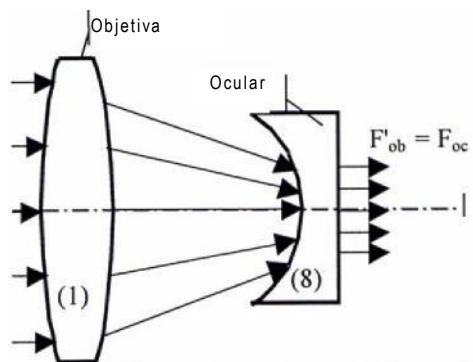
E23b Correção da aberração esférica através de uma combinação de lentes
(U17300, transparência E)

As aberrações esféricas de lentes convergentes e divergentes têm efeitos opostos. Por uma combinação de lentes pode-se corrigir esses erros. A aberração $\Delta f = f_1 - f_2$ é definida como a diferença entre a distância focal f_1 dos raios exteriores e a f_2 dos raios interiores. No caso das lentes convergentes a aberração tem um valor com sinal positivo, no das lentes divergentes com sinal negativo.



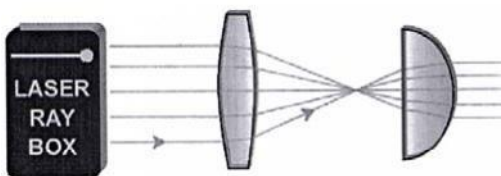
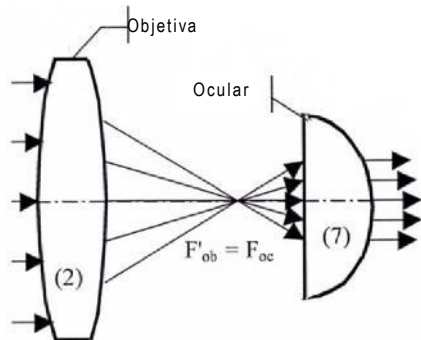
E24b Telescópio segundo Galileu
(U17300, transparência C)

No telescópio de Galileu, os raios que vêm da objetiva encontram uma lente divergente antes de atingir o ponto focal. Os raios chegam aos olhos como raios paralelos. A imagem do objeto é ampliada, de pé e lateralmente correta.



E24a Telescópio segundo Kepler
(U17300, transparência D)

A objetiva no telescópio de Kepler produz uma imagem real reduzida do objeto observado, a qual é ampliada pelo ocular como por uma lupa. Resulta disto uma imagem invertida (acima e abaixo como esquerda e direita estão invertidos) e fortemente ampliada. Para a demonstração desse comportamento apagar um dos raios mais periféricos. Se o raio incidente superior é interrompido, então o raio emergente inferior desaparece.



E25 Câmera
(U17300, transparência B)

A lente da câmera é uma lente convergente. Ela projeta um objeto numa imagem real, de cabeça para baixo, no filme que se encontra na parte traseira da câmera.

