



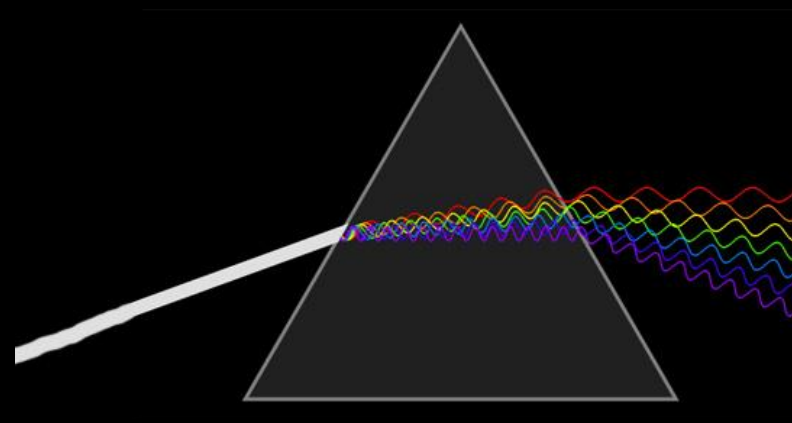
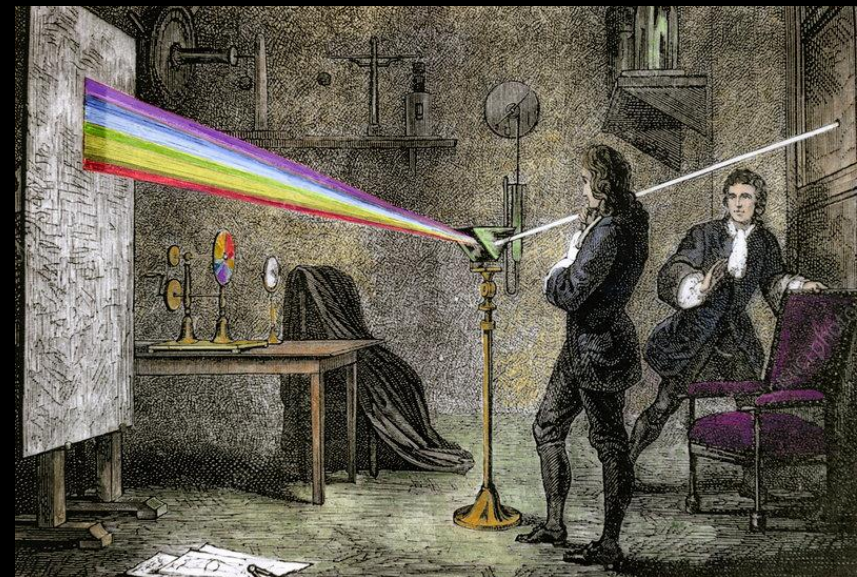
# Light 光现象

(Geometrical Optics

几何光学)

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2022-06-19

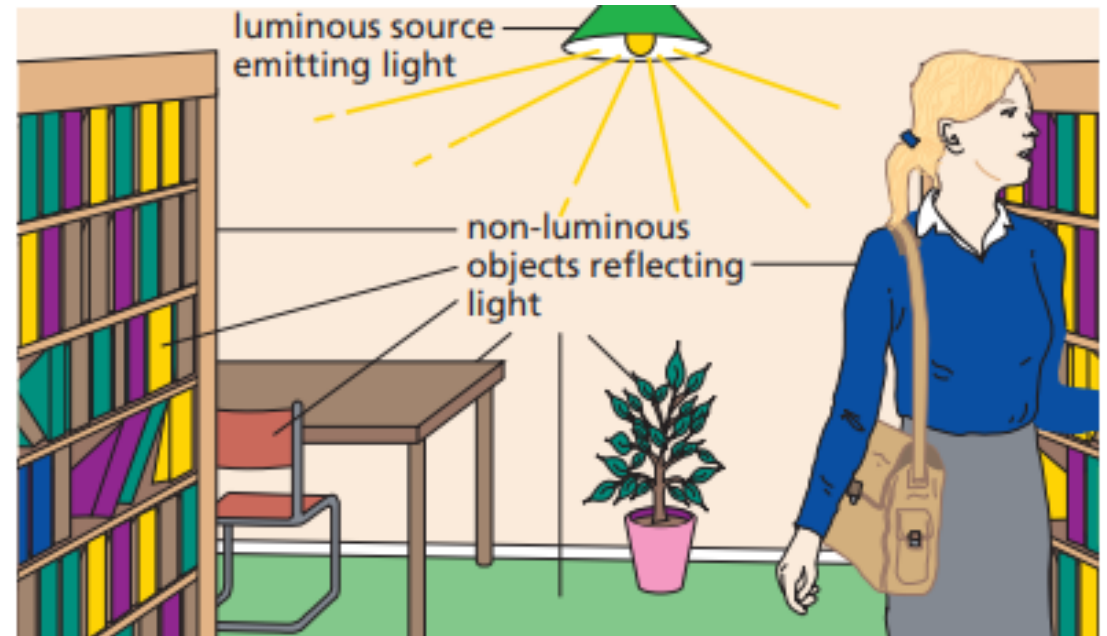


# 1. Light rays ——我们要看见东西，必须有光

- Sources of light
  - **Luminous sources:** objects that make their own light.
  - e.g.: sun, electric lamps, candles, ...
  - Non-luminous objects: reflect light from a luminous source.

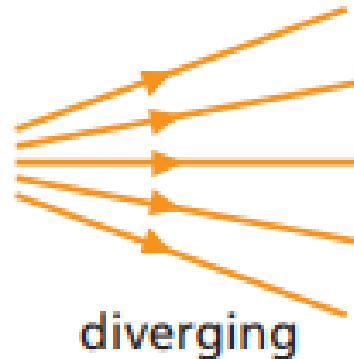
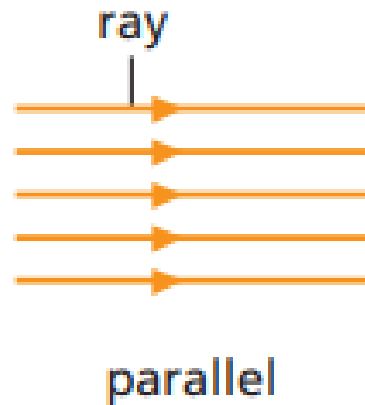
## • 光的来源

- **光源：**能够发光的物体叫光源
- 例：太阳、电灯、电视荧屏等。太阳属于自然光源。



- Rays and beams

- Light travels in straight lines.
- **Ray**: the direction of the path in which light is travelling
- Beam: a stream of light (shown by a number of rays)
- A beam may be **parallel**, **diverging**, or **converging**.

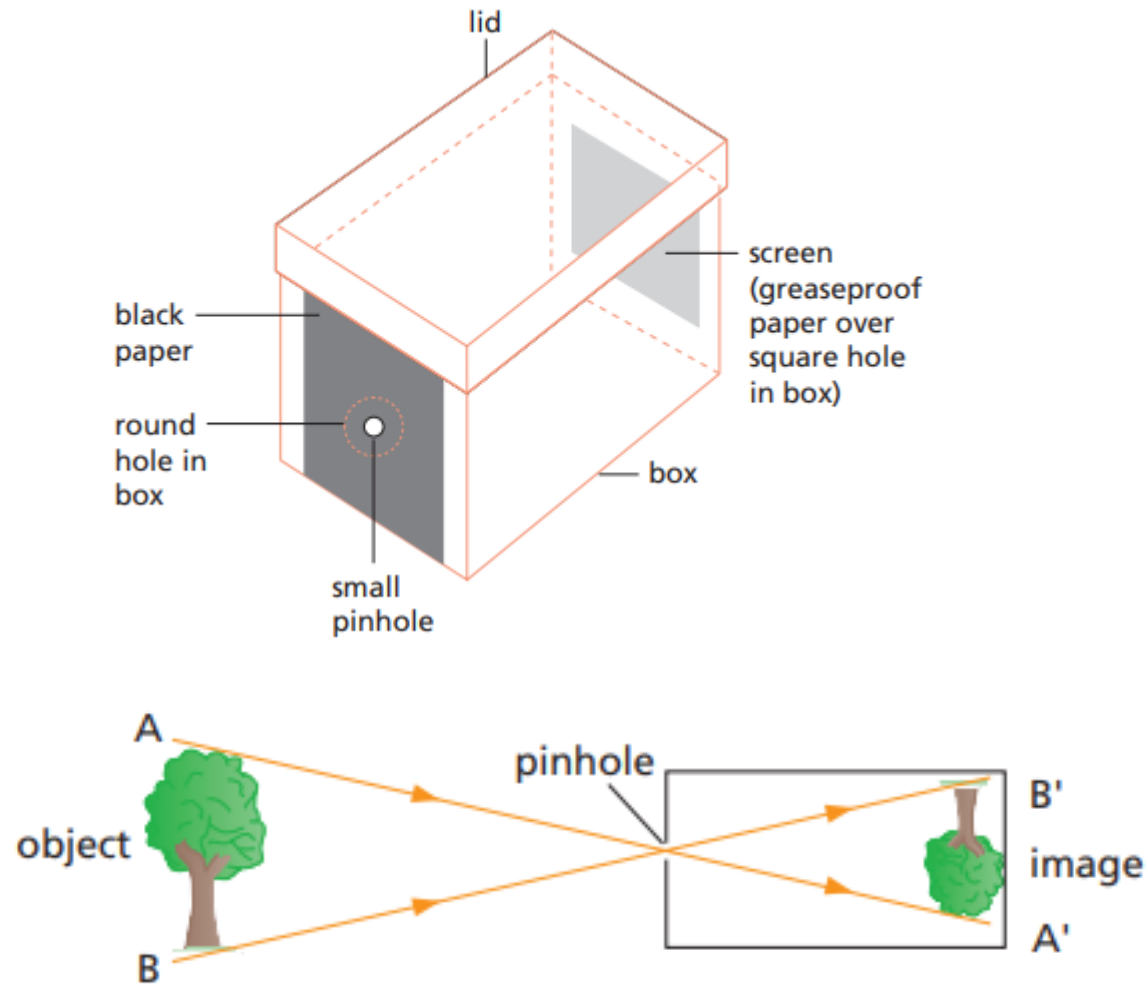


**Figure 26.4** Beams of light

- 光线与光束

- 光在同一种均匀介质中沿直线传播
- **光线**: 画一条直线表示光的传播路径, 直线上的箭头表示传播方向
- 光束: 一组光线
- 分为**平行光束**, **会聚光束**, **发散光束**

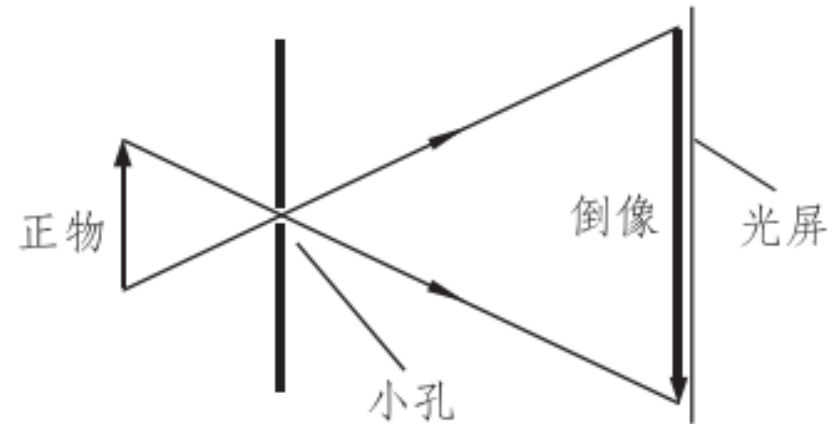
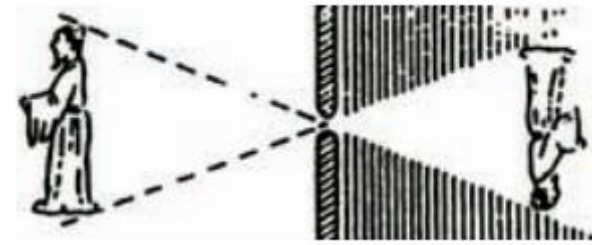
- The pinhole camera



**Figure 26.6** Forming an image in a pinhole camera

- 小孔成像

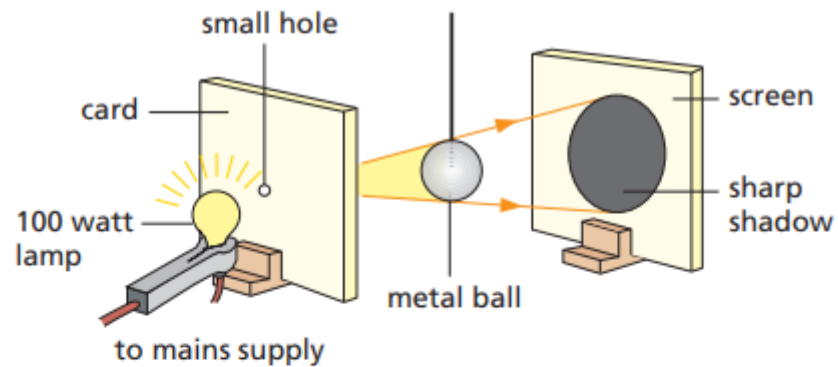
- 《墨经》一书（《墨子》中的一部分）中记载了我国古代用针孔成像的光学实验：



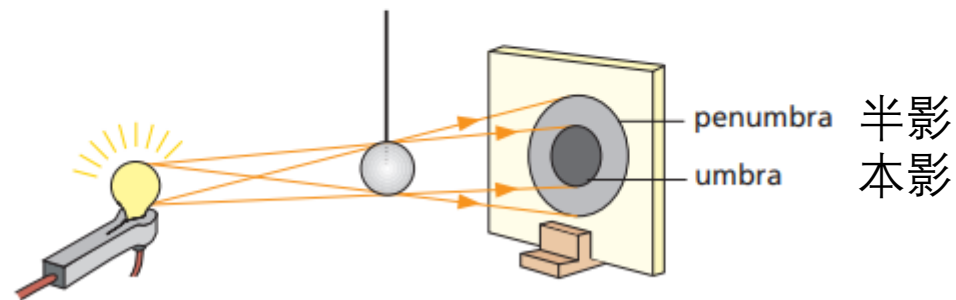
- Shadows

- **Shadows** are formed because:

1. **Opaque** objects do not allow light to pass through them
2. Light travels in straight lines



a With a point source



b With an extended source

Figure 26.7 Forming a shadow

非点光源!

- 影子

- 成因：由于光的直线传播，当光遇到不透明物体时，会形成影子



图 8-5 北京故宫的日晷

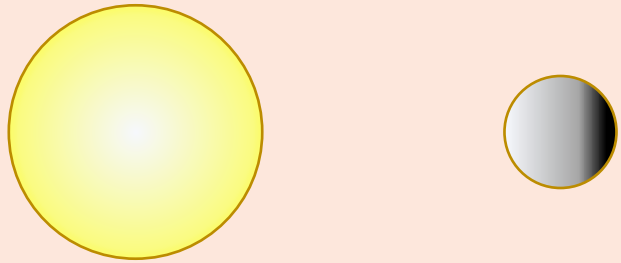
- 光速 Speed of light:

- $3 \times 10^8$  m/s (真空 in vacuum)
  - 光速是一个定值 The speed of light has a definite value

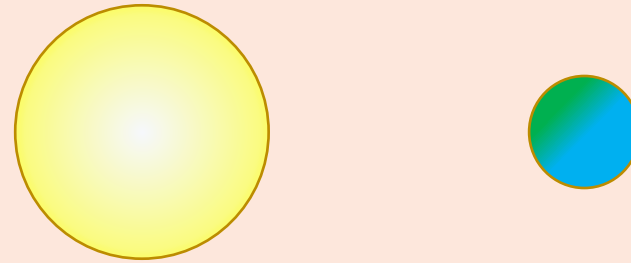


例：画示意图：

- 日食 solar eclipses



- 月食 lunar eclipses



- 例

3 In Figure 26.8 the completely dark region on the screen is  
A PQ    B PR    C QR    D QS    E RS

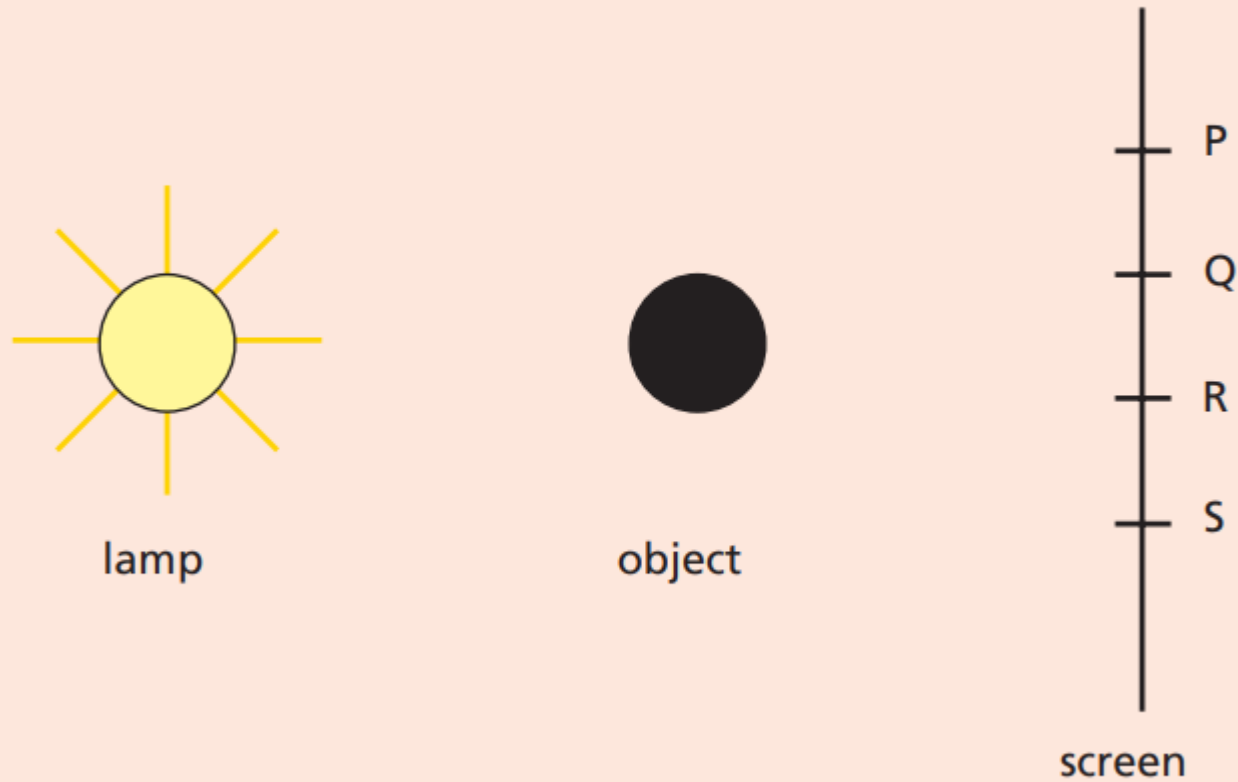


Figure 26.8

## 实践作业：

- 动手制作一个小孔成像装置。用一个带有小孔的不透光的東西（戳孔的纸板，或用两手的手指摆出一个小孔），用白色A4纸或白色墙面做光屏。
  - 在中午或傍晚的太阳下观察屏上太阳的像；
  - 手机做物体，观察屏幕的像。
  - 用透光的纸画一个图案，在光源照射下，观察成像
- 做如下变化，观察像的形状、大小、亮度等等的变化：
  - 改变孔的大小和形状（圆形、方形、长条形、五角星等等）；
  - 改变光源或物体到孔的距离，孔到屏的距离
- 记录你得到的实验结论
- 注意在实验中控制变量——每次只改变一个量，其他保持不变



## 2. Reflection of light 光的反射

- normal,
- Incident ray & Reflected ray
- angle of incidence  $i$  & angle of reflection  $r$
- BV1qR4y1V7xC?p=1

- 法线
- 入射光线、反射光线
- 入射角、反射角

- 实验：探究光的反射规律

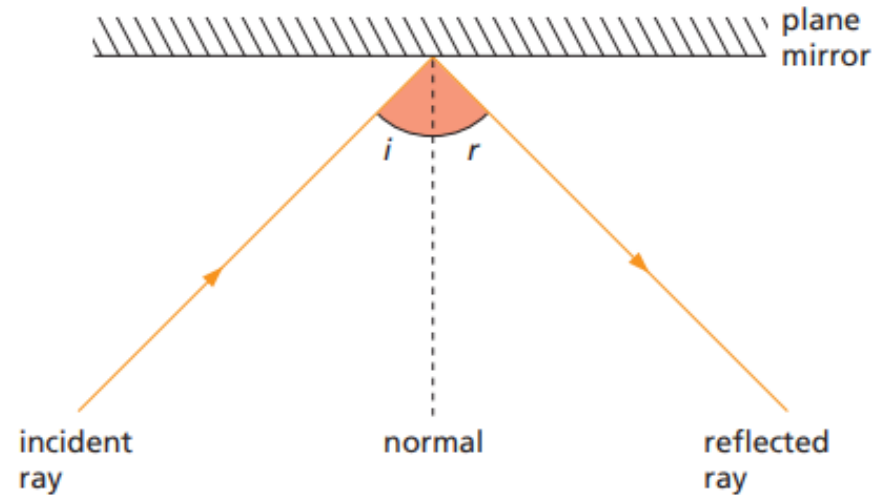


Figure 27.1 Reflection of light by a plane mirror

The **law of reflection** states:

- The angle of incidence equals the angle of reflection.

The incident ray, the reflected ray and the normal all lie in the same plane.

反射定律：

- 光在发生反射时，反射光线、入射光线与法线在同一平面内；
- 反射光线和入射光线分别位于法线两侧；
- 反射角等于入射角。

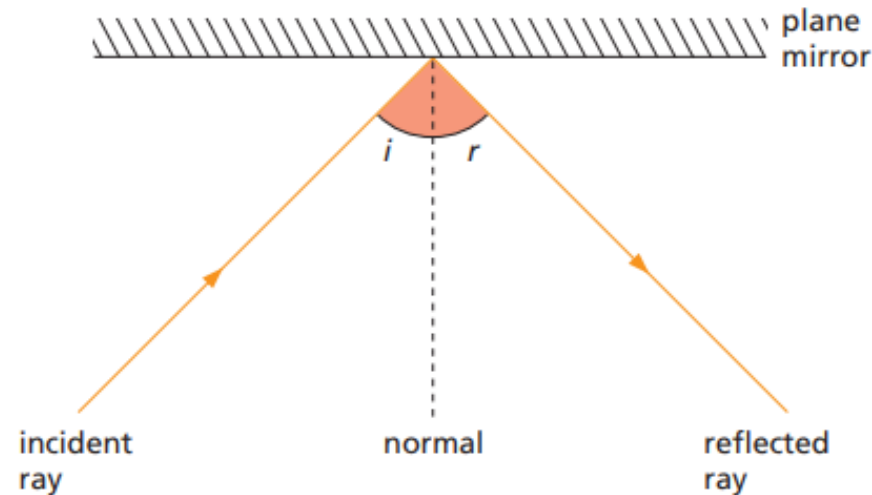


Figure 27.1 Reflection of light by a plane mirror

### 3. Plane mirror 平面镜

- BV1qR4y1V7xC?p=3
- The image in a plane mirror is
  - **as far** behind the mirror as the object is in front, with the line joining the object and image being **perpendicular** to the mirror,
  - the **same size** as the object,
  - virtual,
  - laterally inverted.
- 实验：探究平面镜成像的特点
- 平面镜成像的特点是：
  - 像与物到镜面的距离都相等，  
像与物的连线与镜面垂直，
  - 像与物大小相同，
  - 左右相反，上下相同/  
是正立的虚像

- **Real image:** can be produced on a screen. E.g.: pinhole camera
- **Virtual image:** cannot be formed on a screen
- **Lateral inversion:** In a mirror image, left and right are interchanged and the image appears to be laterally inverted.

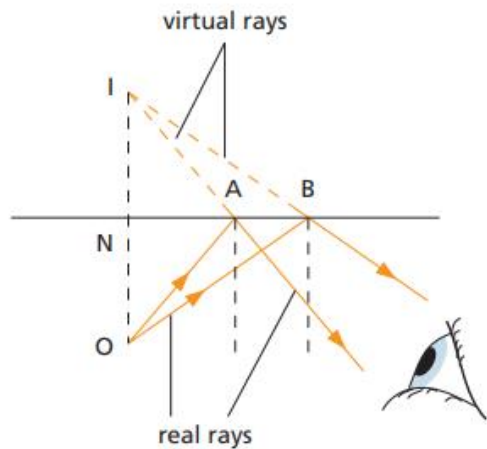
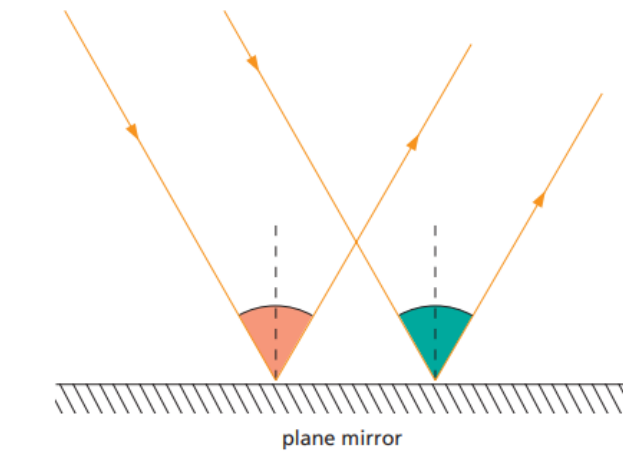


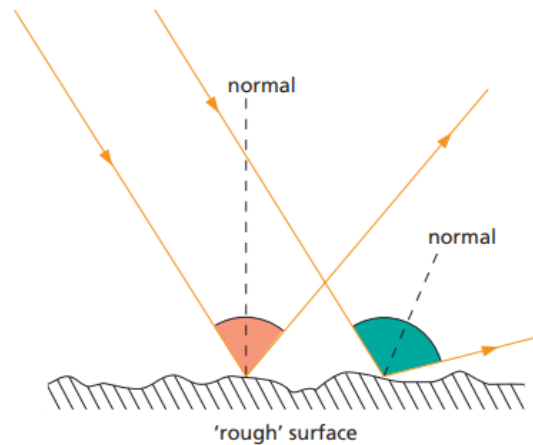
Figure 28.2 A plane mirror forms a virtual image.

- **实像:** 能够呈现在光屏上的像。也可以用眼睛直接观察。
- **虚像:** 只能用眼睛观察, 不能用光屏接收。如: 平面镜成像
- **横向翻转:** 平面镜成像时, 像与物大小相等, 到镜面距离相等; 像与物的连线垂直于平面镜, 像与物左右翻转。
- 物距object distance:  $ON$
- 相距image distance:  $IN$

- **Specular** reflection 镜面反射
- **Diffuse** reflection 漫反射

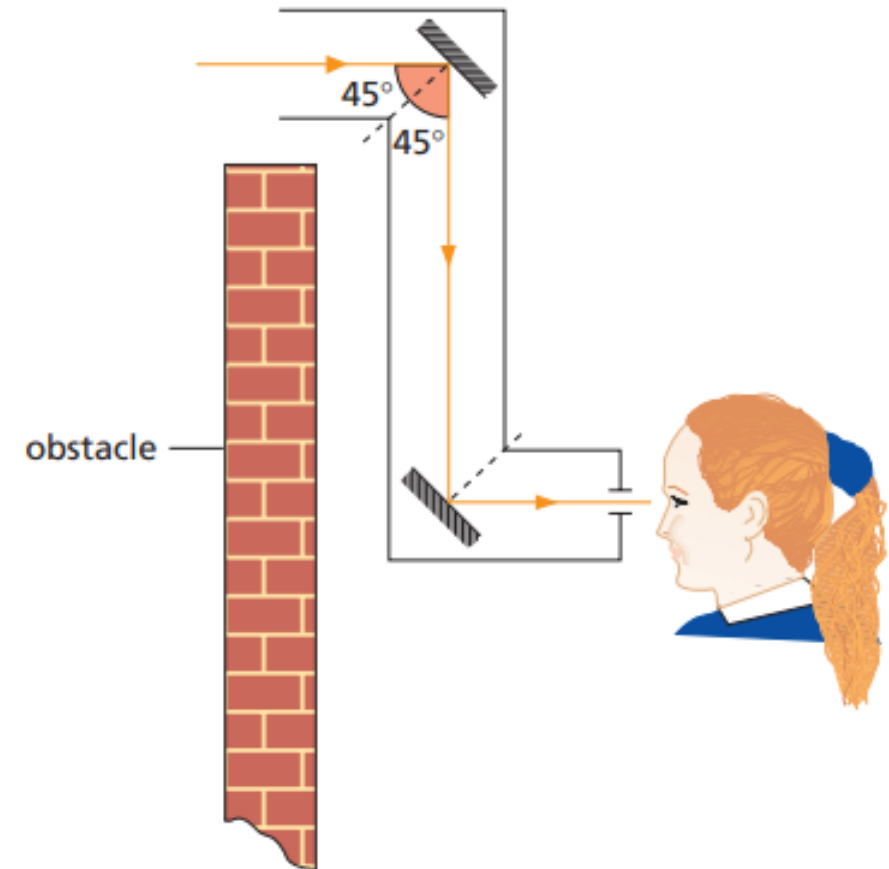


a Regular reflection

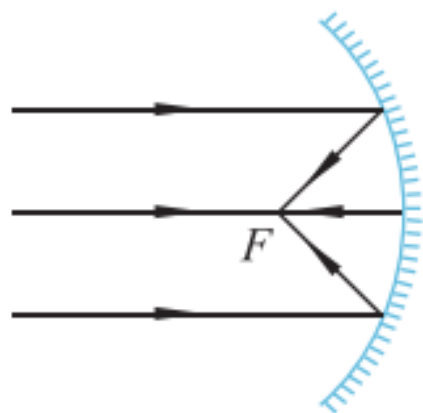


b Diffuse reflection

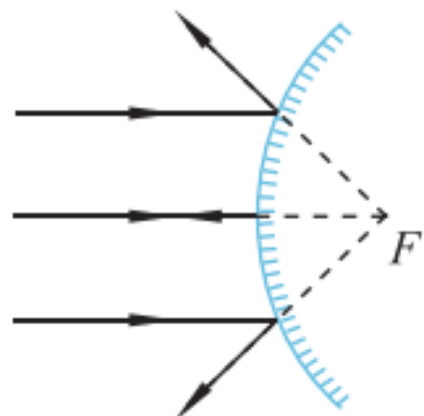
- **Periscope** 潜望镜



- 球面镜 Spherical mirror:
  - 凸面镜与凹面镜 concave and convex mirror



凹面镜



凸面镜

- 应用



图 8-24 凹面镜的应用

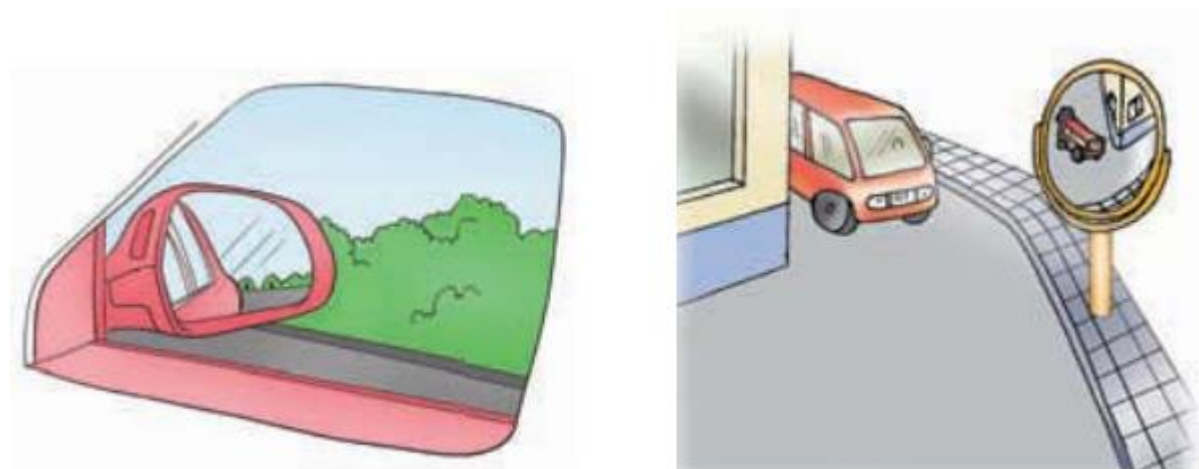


图 8-25 凸面镜的应用



• 例

- 1 In Figure 28.6 at which of the points A to E will the observer see the image in the plane mirror of the object?

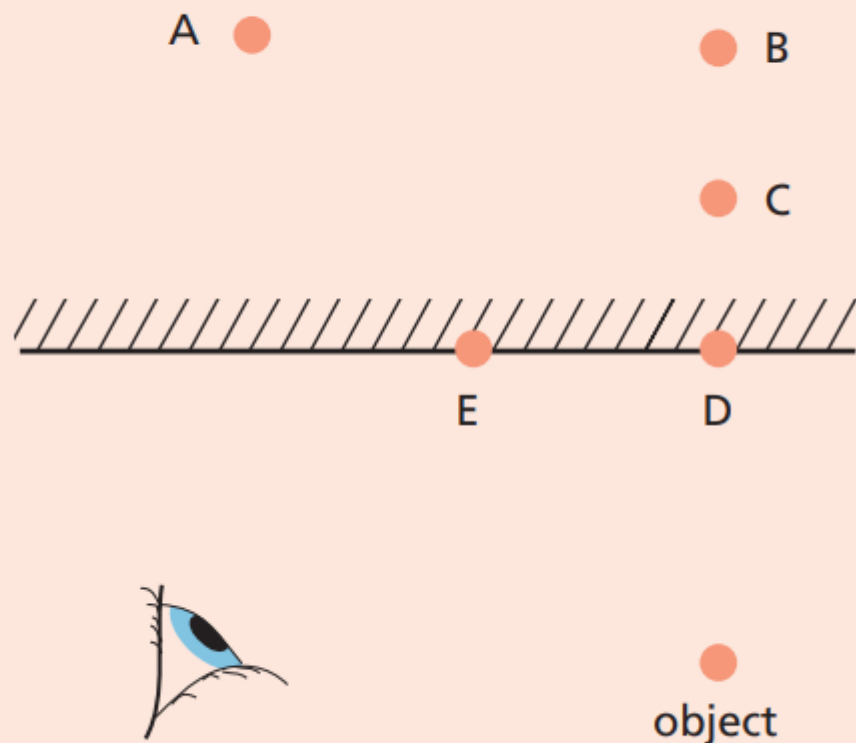


Figure 28.6

- 2 A ray of light strikes a plane mirror at an angle of incidence of  $60^\circ$ , is reflected from the mirror and then strikes a second plane mirror placed so that the angle between the mirrors is  $45^\circ$ . The angle of reflection at the second mirror, in degrees, is  
**A** 15      **B** 25      **C** 45      **D** 65      **E** 75
- 3 A girl stands 5 m away from a large plane mirror. How far must she walk to be 2 m away from her image?
- 4 The image in a plane mirror is  
**A** upright, real and larger  
**B** upright, virtual and the same size  
**C** inverted, real and smaller  
**D** inverted, virtual and the same size  
**E** inverted, real and larger.

- 例

- 一束光线竖直入射到水平放置的平面镜上，则反射角的大小是

A.  $0^\circ$                       B.  $45^\circ$                       C.  $90^\circ$                       D.  $180^\circ$

- 以下属于漫反射的是

A. 在黑暗中看不见东西                      B. 能清楚看到黑板上写的粉笔字  
C. 在穿衣镜前看到自己的像                      D. 在水中看到月亮的倒影

- 人从远处走进一直立的穿衣镜的过程中，他在镜中的像的大小将

A. 逐渐变大              B. 逐渐变小              C. 不变                      D. 无法判定

- 一个人在水平地面上以速度 $v_1=10\text{m/s}$ 向右移动。前方同一平面上有竖立的平面镜，镜面与人与镜子连线垂直，镜子以 $v_2=5\text{m/s}$ 相对人向左移动。平面镜中人的像的运动速度是\_\_\_\_\_m/s，方向\_\_\_\_\_。

## 4. Refraction of light 光的折射

- The bending of light when it passes from one material (called a medium) to another is called **refraction**

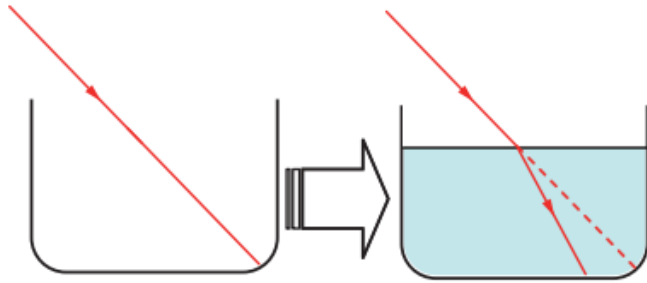
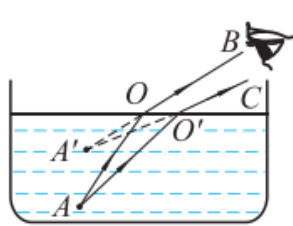


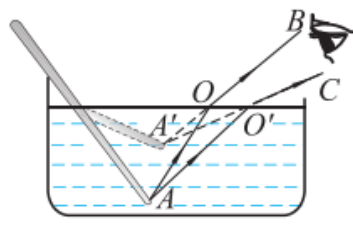
图 8-27 光的折射现象



甲



乙



丙

- 光从一种介质斜射入另一种介质时，传播方向发生了变化，这种现象叫做光的**折射**。

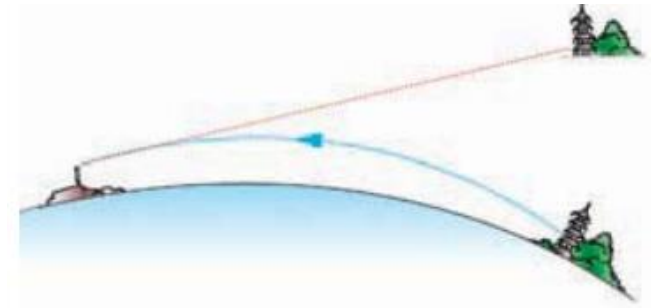
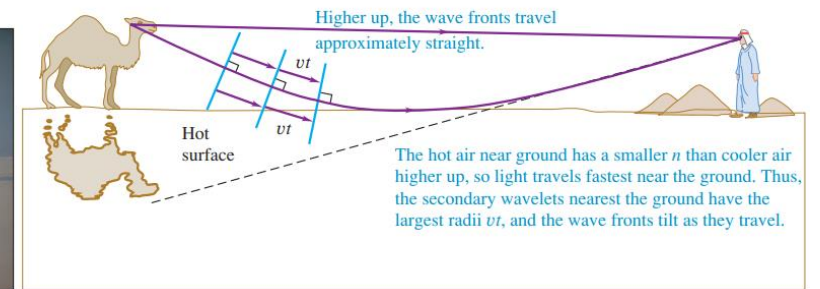


图 8-31 海市蜃楼

33.37 How mirages are formed.



- Facts about refraction
  - A ray of light is **bent towards** the normal when it enters an optically denser medium at an angle, e.g. from air to glass
  - A ray of light is **bent away** from the normal when it enters an optically less dense medium, e.g. from glass to air
  - A ray emerging from a parallel-sided block is **parallel** to the ray entering, but **displaced sideways**
  - A ray travelling along the normal direction at a boundary is **not refracted**.

• BV1qR4y1V7xC?p=19

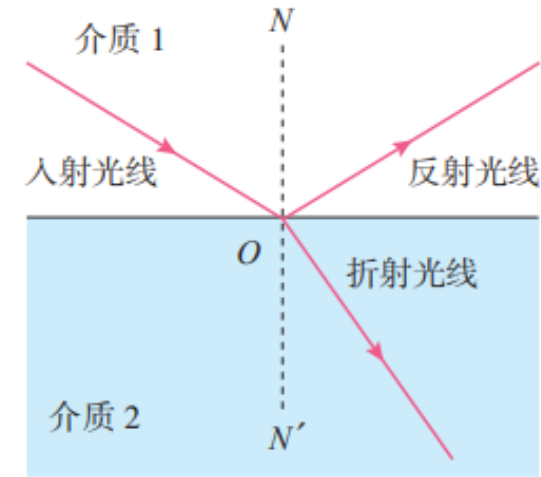
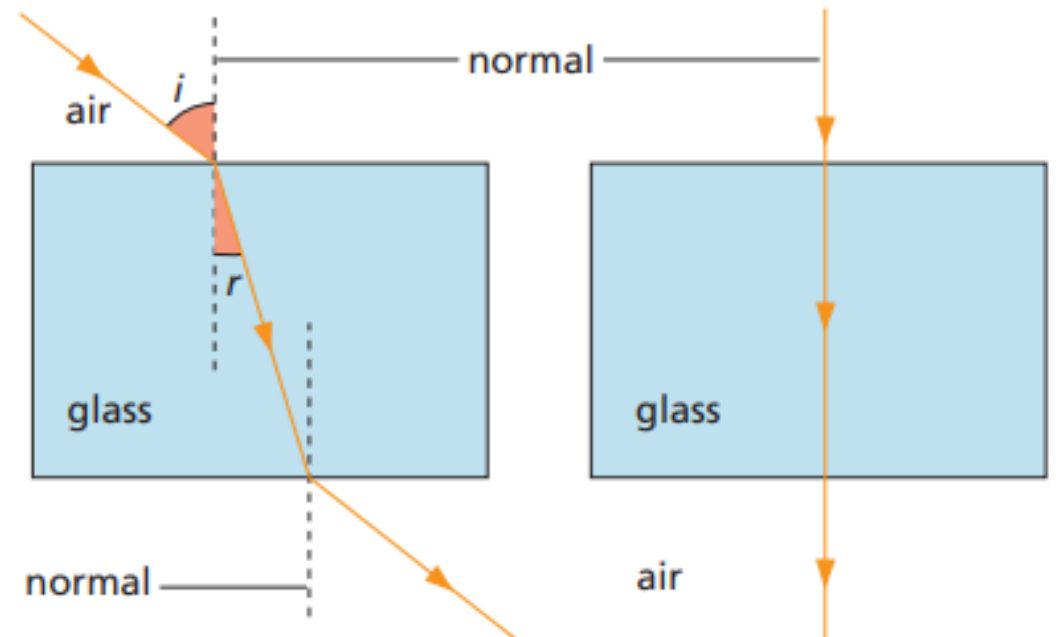
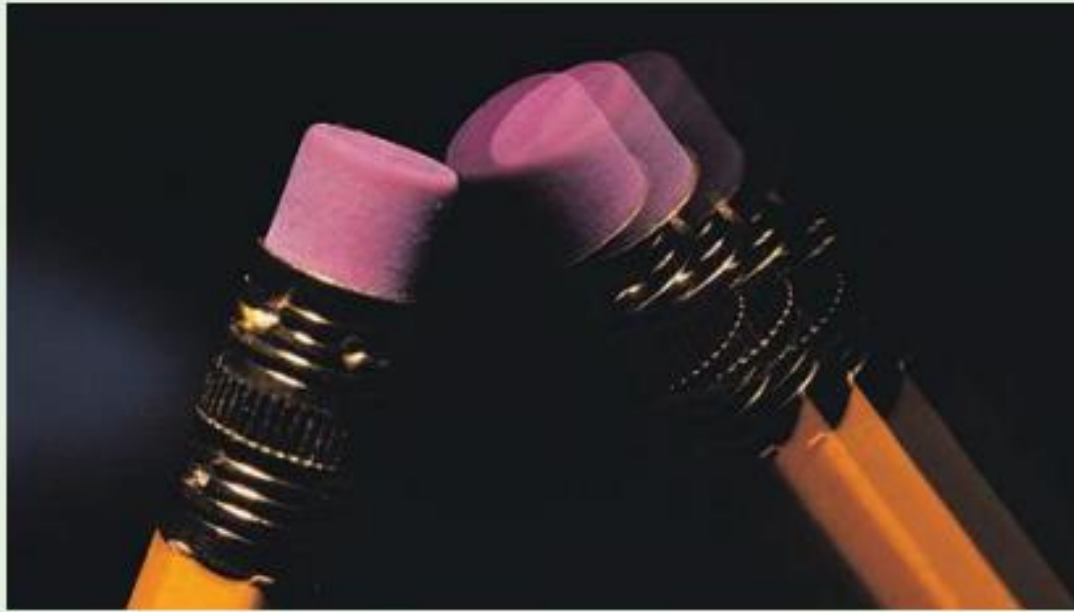


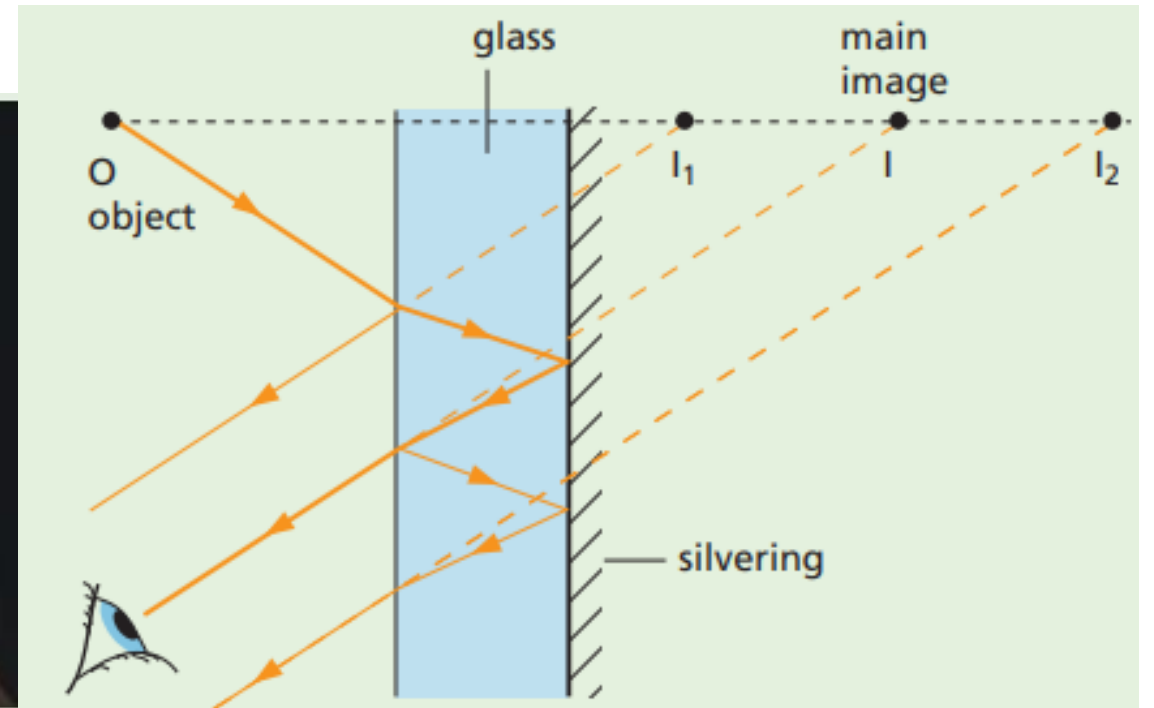
图 4.1-1 光的反射和折射同时发生



- 例: Multiple images in a mirror



**Figure 30.3b** The multiple images in a mirror cause blurring.



**Figure 30.3a** Multiple reflections in a mirror

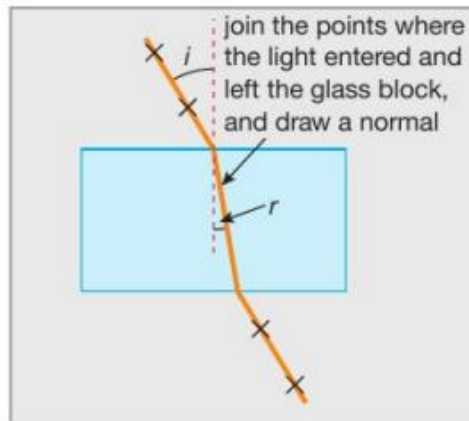
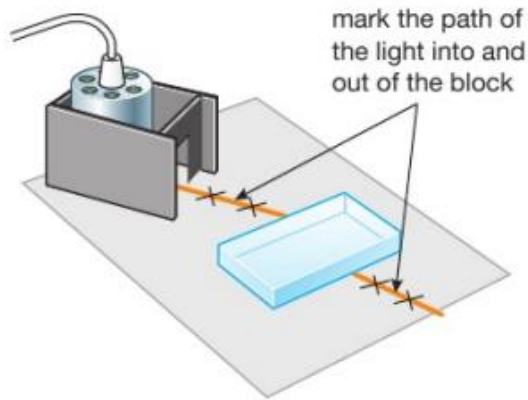
- Law of refraction (**Snell's law**):
  - Incident ray, reflected ray, refracted ray and the normal of the system lie in the same plane.
  - There is a constant relation between the angle of incident ray and angle of refracted ray,
$$\frac{\sin i}{\sin r} = n$$
    - i - **angle of incidence**
    - r - **angle of refraction**
    - n - **refractive index**

- 折射定律:
  - 折射光线与入射光线、法线处在同一平面内，折射光线与入射光线分别位于法线的两侧；
  - 入射角的正弦与折射角的正弦成正比，即
$$\frac{\sin i}{\sin r} = n$$
    - i-**入射角**
    - r-**折射角**
    - n-**折射率**



- (Absolute) refractive index is defined as  

$$n = \frac{\text{speed of light in vacuum, } c}{\text{speed of light in medium, } v}$$



▲ Figure 12.9 How to investigate refraction using a rectangular glass block

- (绝对) 折射率  

$$n = \frac{c}{v}$$

- 实验：测量玻璃的折射率

- 数据处理：

<https://www.bilibili.com/video/BV1YJ411B7W8>

表 几种介质的折射率 ( $\lambda = 589.3 \text{ nm}$   $t = 20^\circ \text{C}$ )

介质	折射率	介质	折射率
金刚石	2.42	氯化钠	1.54
二硫化碳	1.63	酒精	1.36
玻璃	1.5 ~ 1.8	水	1.33
水晶	1.55	空气	1.000 28

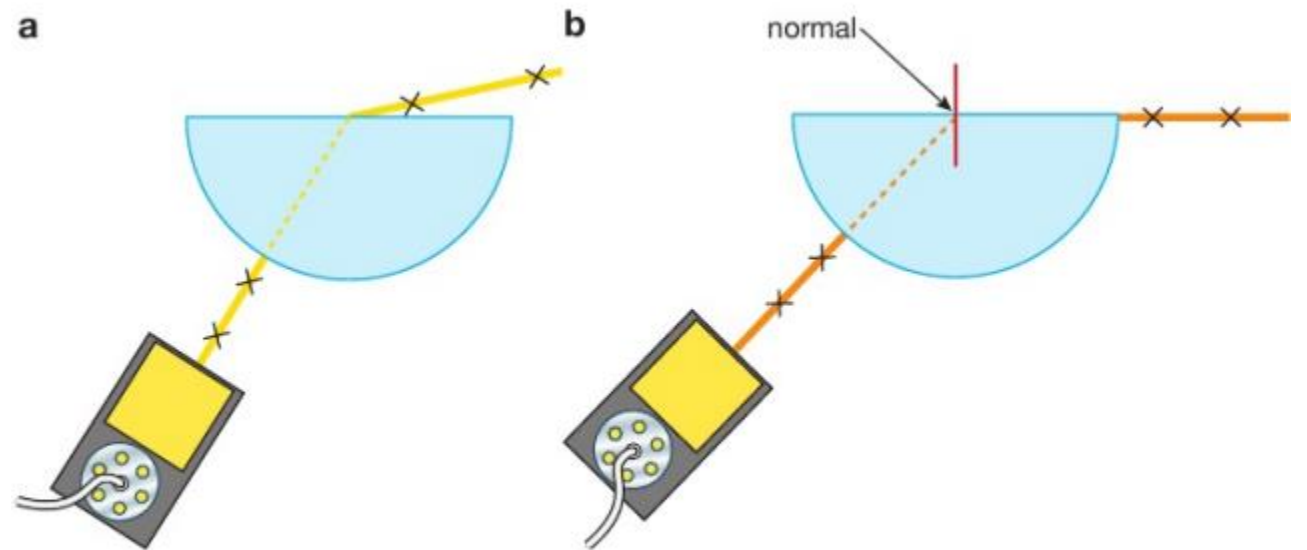
- **Total internal reflection**

- At a certain angle of incidence, called the **critical angle**,  $C$ , the angle of refraction is  $90^\circ$ . For angles of incidence greater than  $C$ , the refracted ray disappears and all the incident light is reflected inside the denser medium. The light does not cross the boundary and is said to undergo **total internal reflection**.

$$\sin C = \frac{1}{n}$$

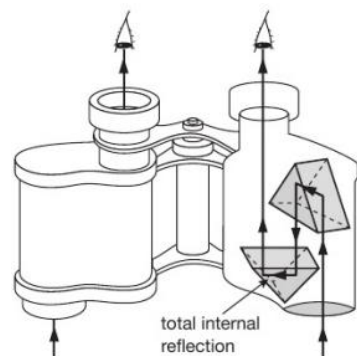
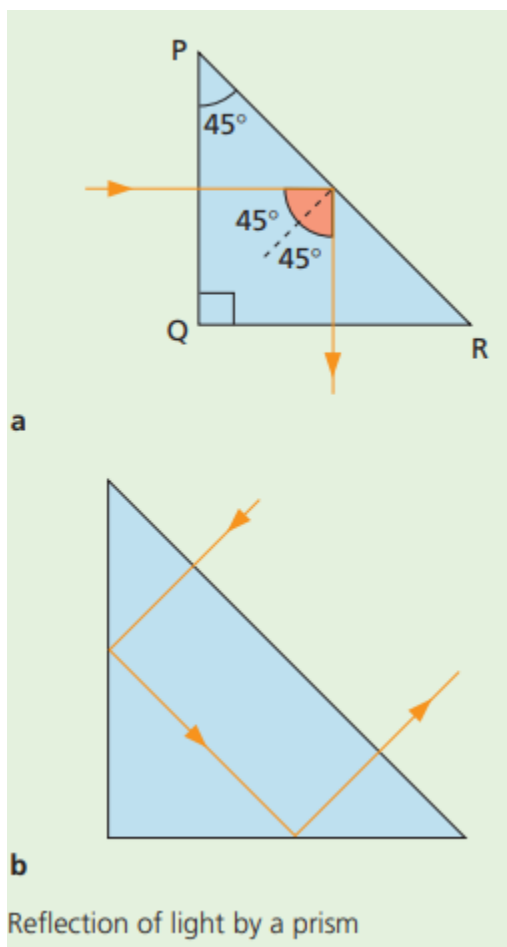
- **全反射与临界角：**

- 当光从光密介质射入光疏介质时，如果入射角等于或大于临界角，就会发生全反射现象。
- 实验： Critical angle of glass

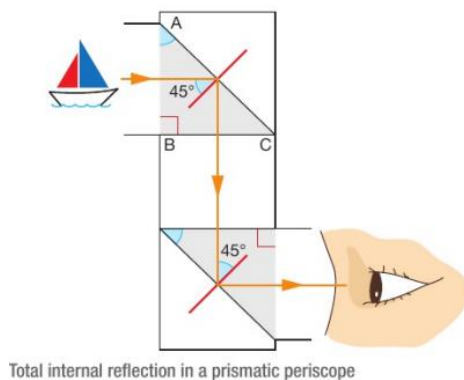


▲ Figure 12.12 a A semi-circular glass block used to demonstrate total internal reflection b Light striking the edge of the glass block at the critical angle

- Totally reflecting prisms 全反射棱镜：
  - 等腰直角三角形



▲ Figure 12.18 Total internal reflection inside binoculars



- Optical fibres 光导纤维

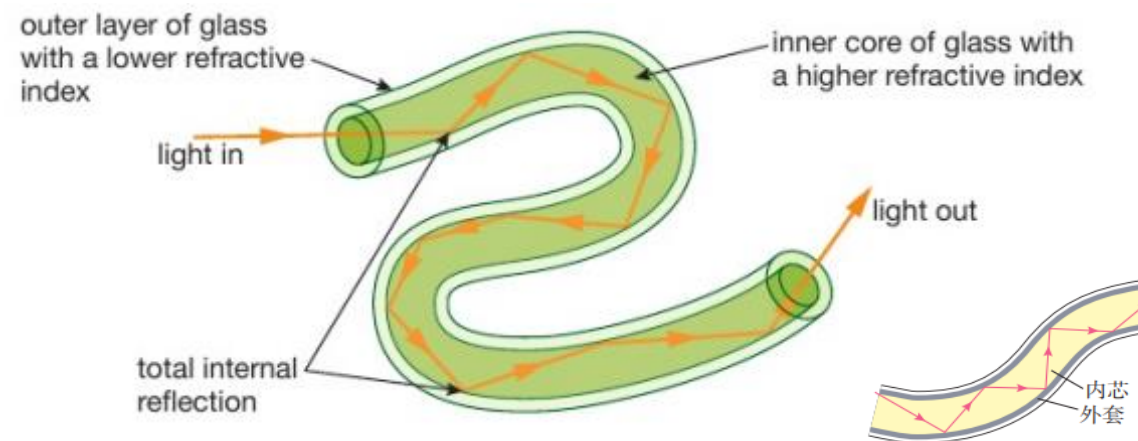
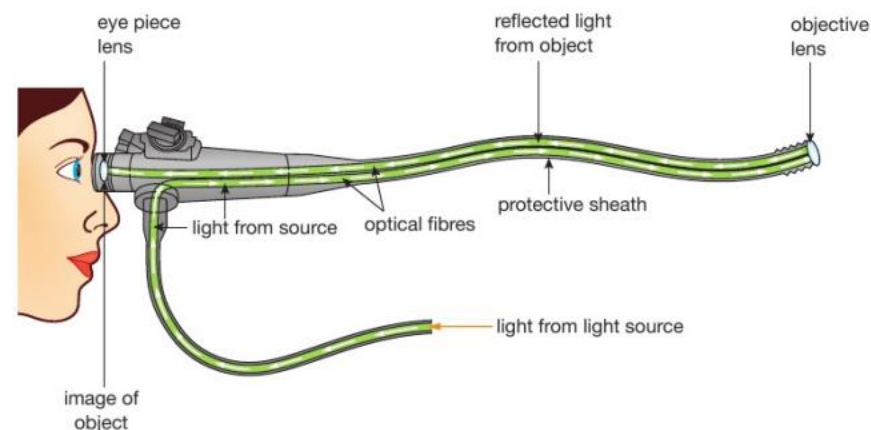


图 4.2-7

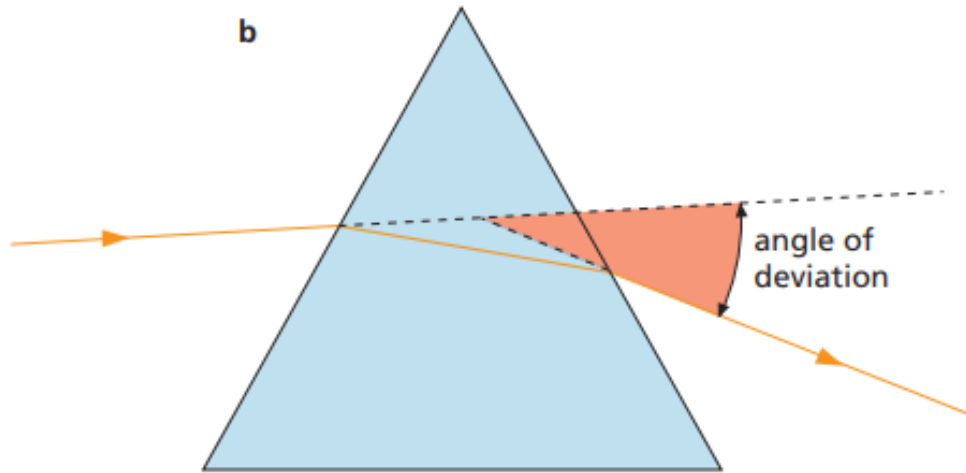
- 应用：
  - Telecommunications: 光纤入户
  - Endoscope 内窥镜



▲ Figure 12.22 Optical fibres are used in endoscopes to see inside the body.

- **Dispersion**

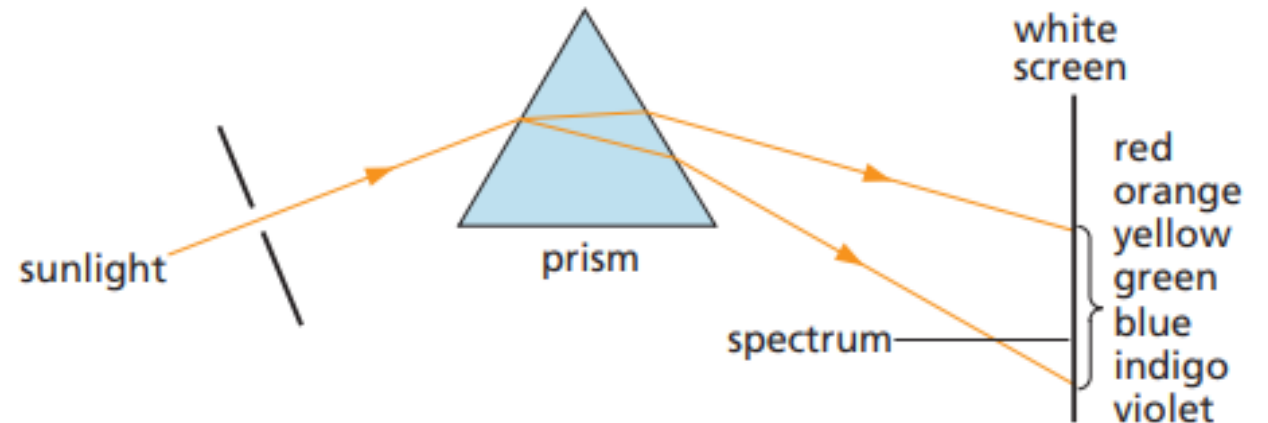
- When sunlight (white light) falls on a triangular glass prism, a band of colours called a **spectrum** is obtained.
  - Red, orange, yellow, green, blue, indigo, violet



- 光的色散：

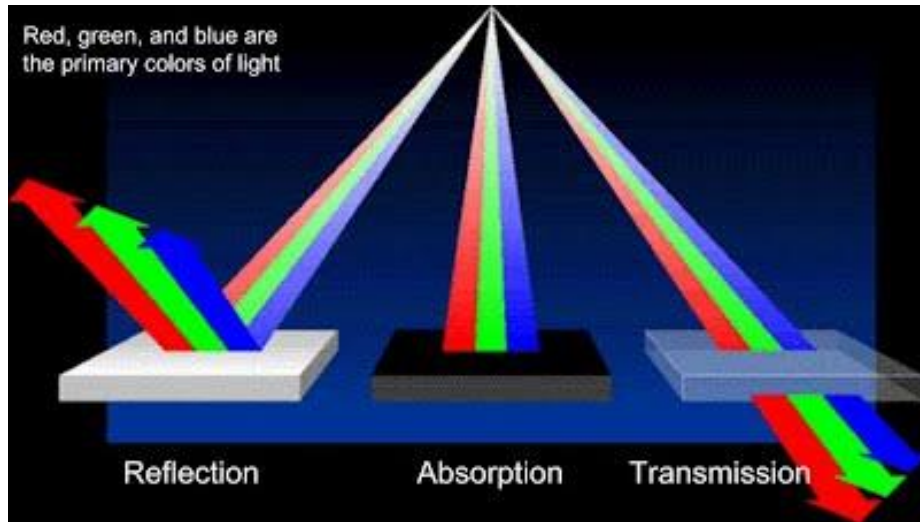
- 光通过三棱镜折射后照射到屏上形成彩色的光带——**光谱**。
- 红、橙、黄、绿、蓝、靛、紫

➤同一种材料（玻璃），对不同频率的波，折射率不同



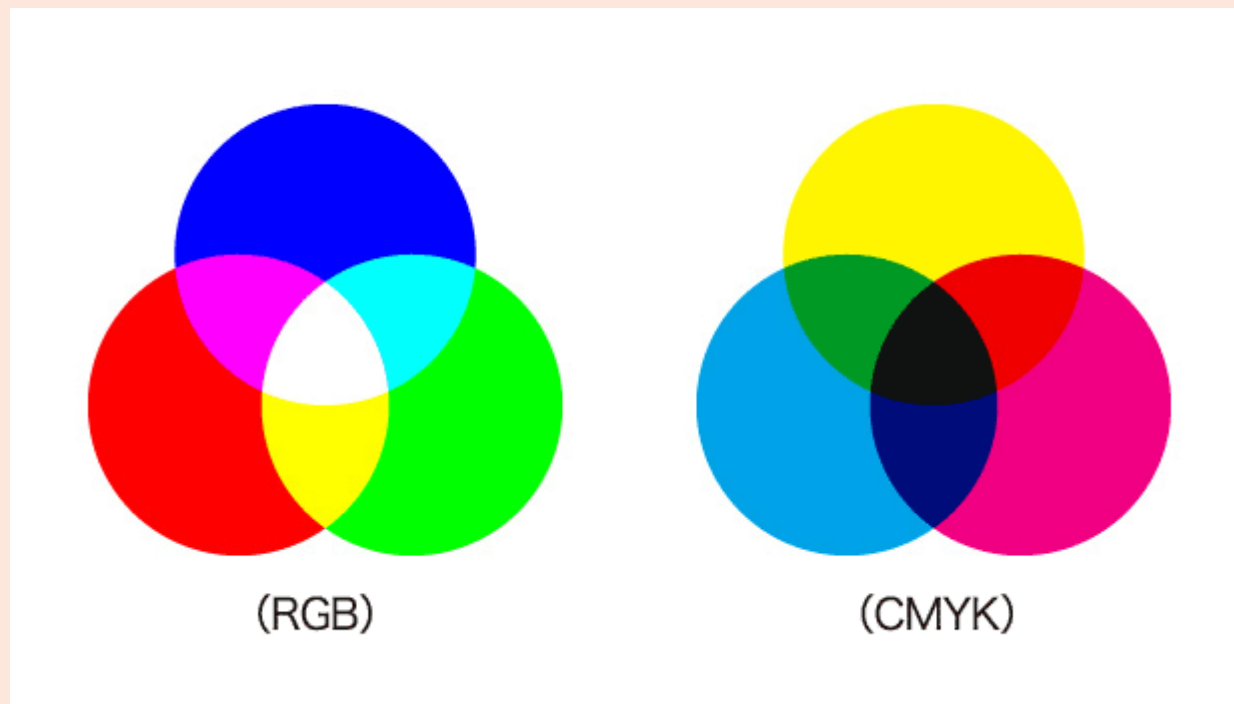
- **Transmission** and **absorption** of light; Colour of objects  
光的透射与吸收、物体的颜色

- Opaque materials absorb or reflect all incident light.
- Translucent materials transmit some, but not all incident light.
- Transparent materials transmit virtually all of the incident light.





- 查阅：光的三原色
  - 思考：物理中光的三原色和美术中颜料三原色有什么区别。





## 补充视频

- BV1dE411c7cV 折射实验(1:54)
  - 问：为什么注水容器是半圆形的semicircular?
- BV1HX4y1u7aX 测玻璃砖折射率实验
- BV1k5411h7vF 测玻璃砖折射率（单位圆法）
- BV1h44y1k7Ch 全反射、光纤
- （BV1NL4y1s7YS 光纤的桥接）
- [Light – GCSE Physics AQA Revision – Stu](#)
- 关于物体颜色，有部分没讲到的



- 例

6 Which diagram in Figure 29.11 shows the ray of light refracted correctly?

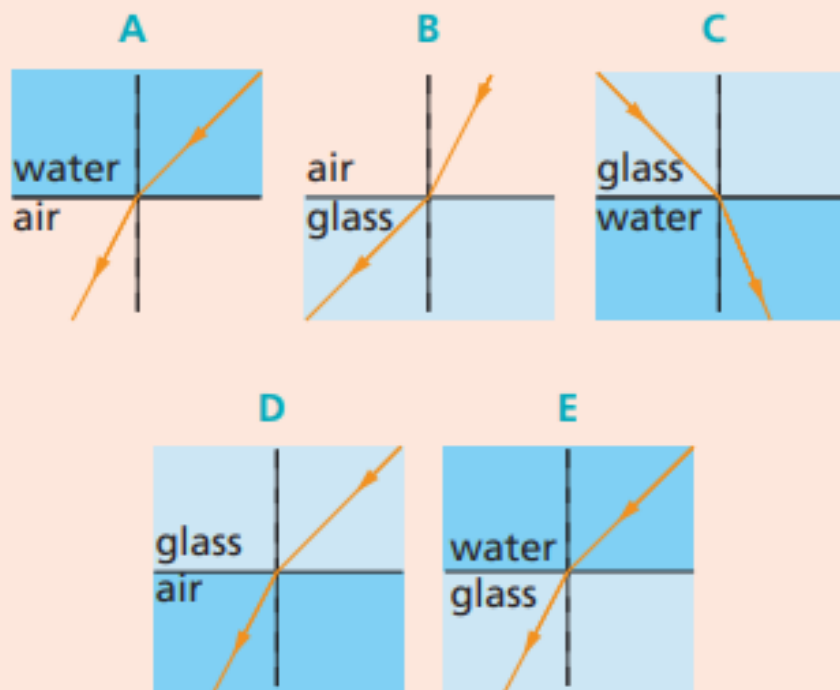


Figure 29.11

5 A beam of white light strikes the face of a prism. Copy Figure 29.10 and draw the path taken by red and blue rays of light as they pass through the prism and on to the screen AB.

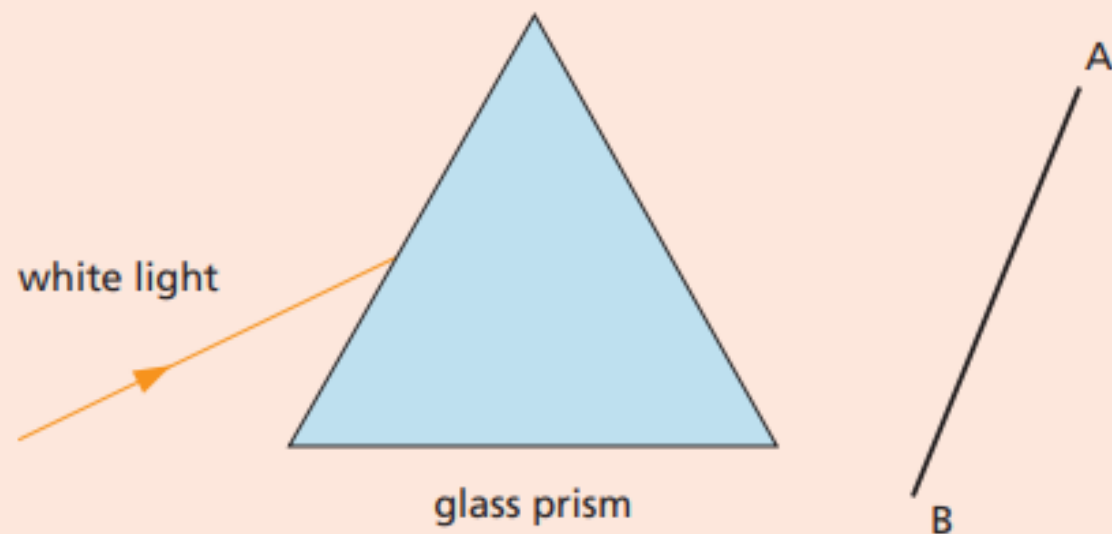


Figure 29.10

- 1 Figure 29.8 shows a ray of light entering a rectangular block of glass.
  - a Copy the diagram and draw the normal at the point of entry.
  - b Sketch the approximate path of the ray through the block and out of the other side.

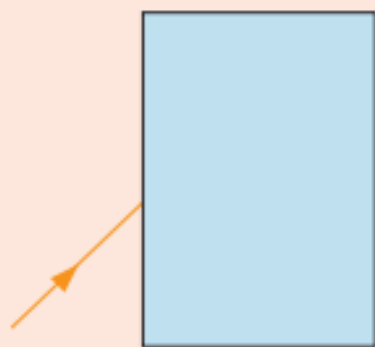


Figure 29.8

- 3 What is the speed of light in a medium of refractive index  $6/5$  if its speed in air is  $300\,000\text{ km/s}$ ?

- 7 Which diagram in Figure 29.12 shows the correct path of the ray through the prism?

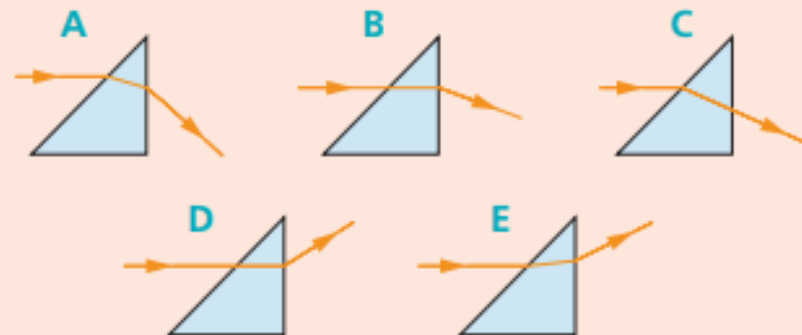


Figure 29.12

- 例

- 人潜到水中看岸边的树木，下列叙述正确的是

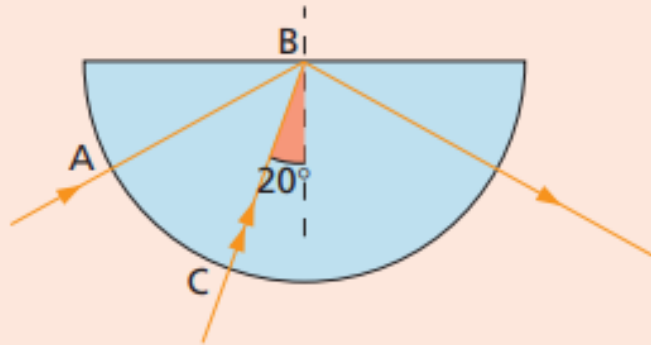
- A. 看到的是树的虚像，且变矮了
    - B. 看到的是树的虚像，且变高了
    - C. 看到的是树的实像，高度不变
    - D. 看到的是树的实像，且变高了

4 Light travels up through a pond of water of critical angle  $49^\circ$ . What happens at the surface if the angle of incidence is: **a**  $30^\circ$ ; **b**  $60^\circ$ ?

5 Calculate the critical angle for water if  $n = \frac{4}{3}$ .

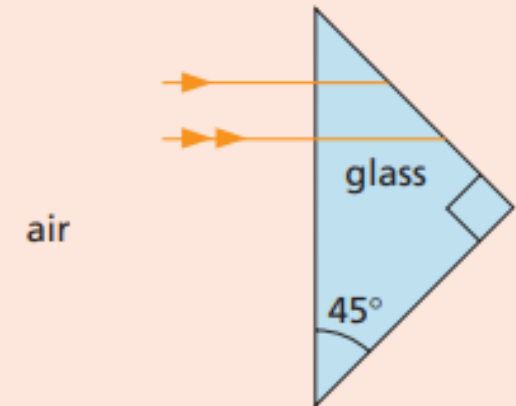
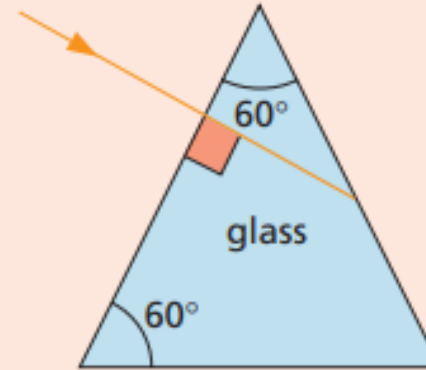
- for glass,  $n = 1.5$

- 1 Figure 30.7 shows rays of light in a semicircular glass block. 2 Copy Figures 30.8a and 30.8b and complete the paths of the rays through the glass prisms.



**Figure 30.7**

- Explain why the ray entering the glass at A is not bent as it enters.
- Explain why the ray AB is reflected at B and not refracted.
- Ray CB does not stop at B. Copy the diagram and draw its approximate path after it leaves B.



**Figure 30.8**



## 5. Lenses 透镜

- Lenses are used in optical instruments such as cameras, spectacles, microscopes and telescopes; they often have spherical surfaces and there are two types.

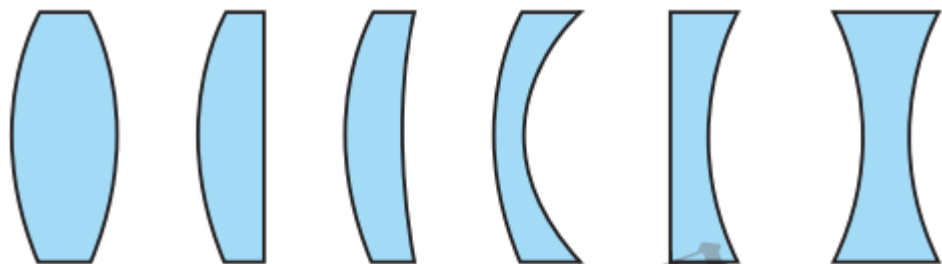


图 8-38 凸透镜与凹透镜



Figure 31.2a A converging lens forms a magnified image of a close object.

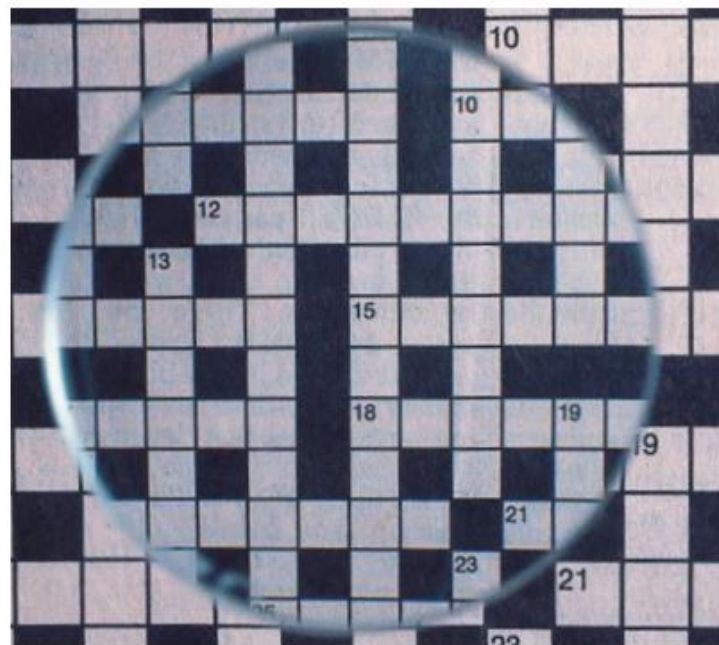
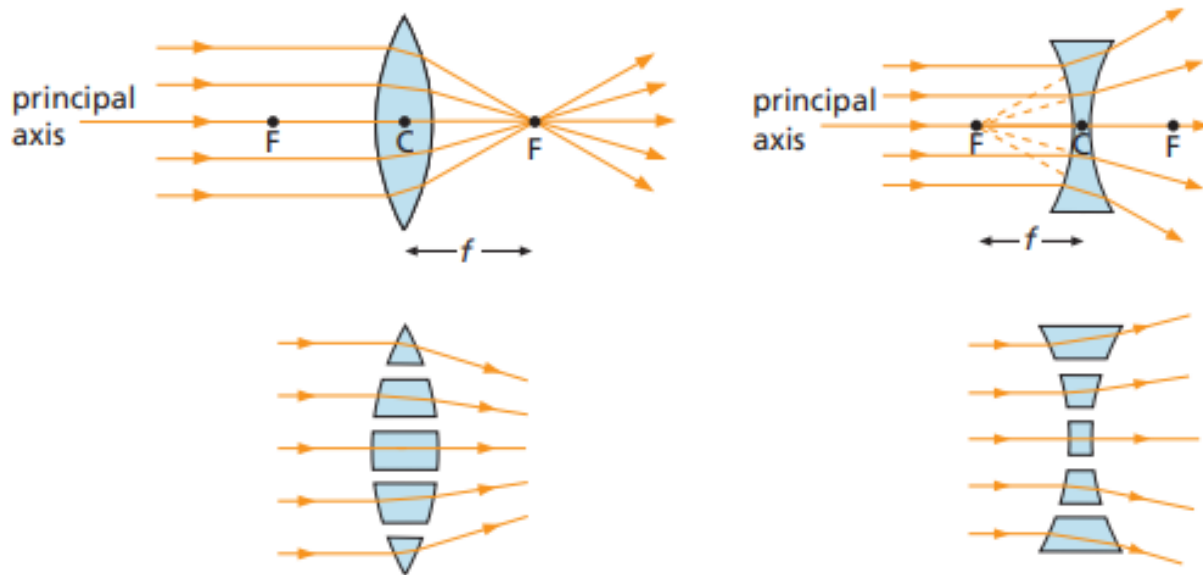


Figure 31.2b A diverging lens always forms a diminished image.



- Converging and diverging lenses  
(convex & concave lenses)  
A converging lens bends light inwards  
A diverging lens spreads light out

- C: optical centre 光心
- F: principal focus 焦点



- 凸透镜与凹透镜  
(会聚透镜、发散透镜)

凸透镜对光线起会聚作用  
凹透镜对光线起发散作用

- principal axis 主轴
- CF: focal length  $f$  焦距

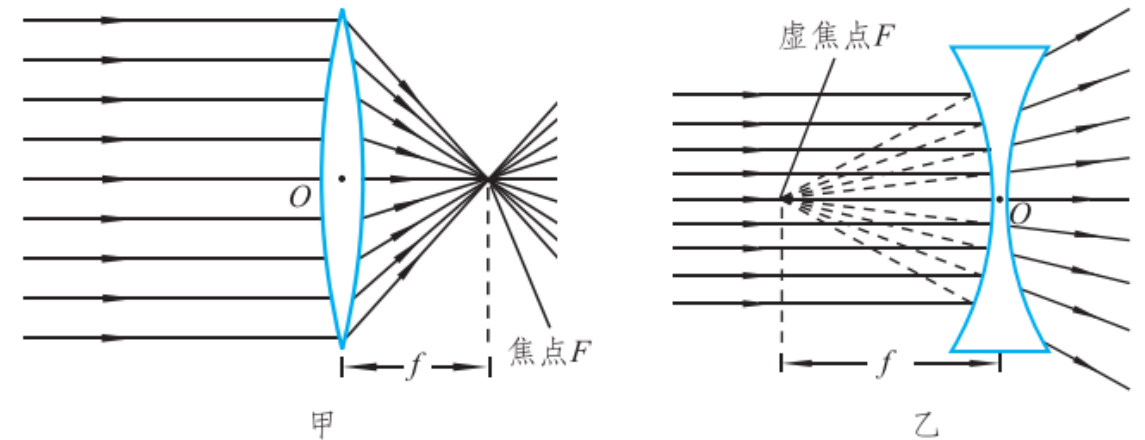


图 8-41

# Images formed by a converging lens

## 探究凸透镜成像规律

- BV1qR4y1V7xC?p=2

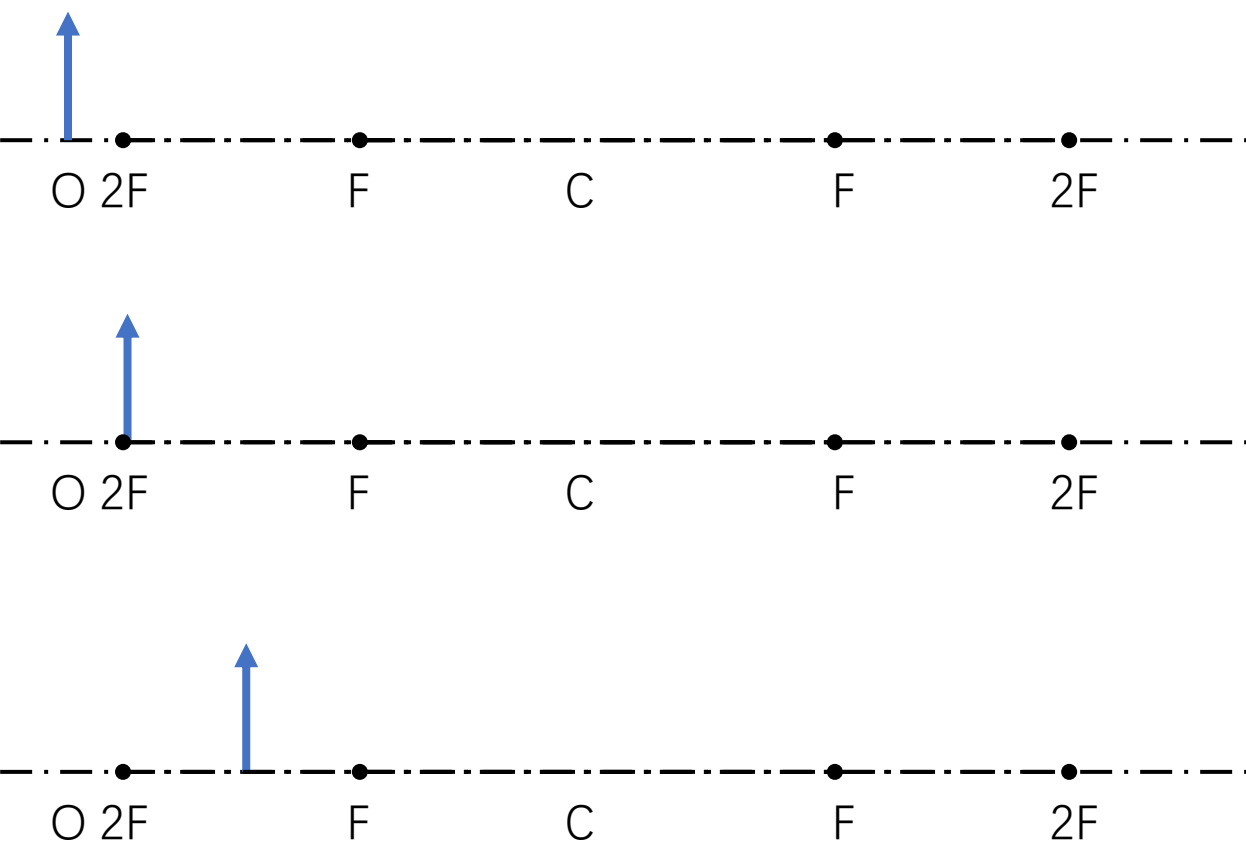


- 实验记录表格:

Object position	Image position	Larger, smaller or same size?	Upright or inverted?	Real or virtual?
beyond 2F				
at 2F				
between 2F and F				
between F and lens				

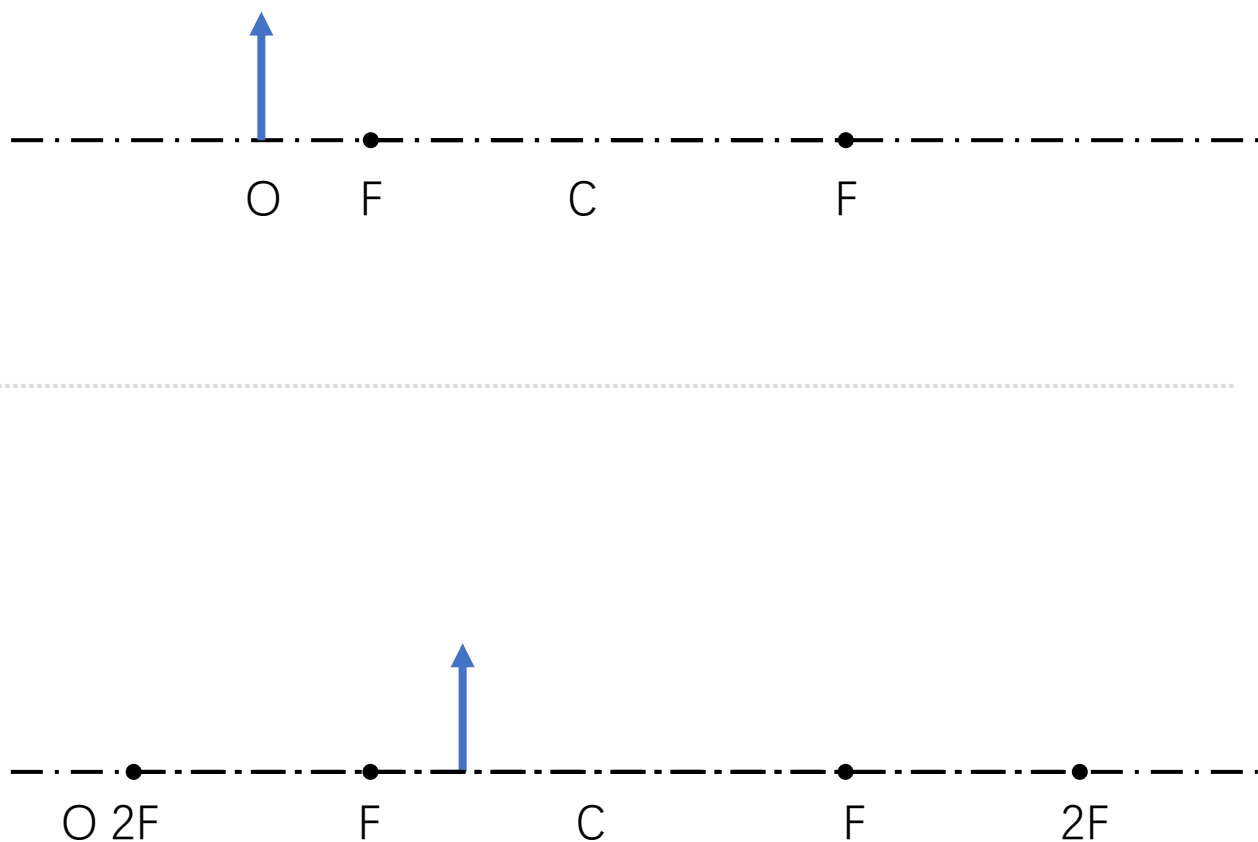
- Ray diagrams
  - To obtain information about the images

- 凸透镜成像光路图，符号



- 光路图
  - 用来分析像的信息：三条线

- 凹透镜成像光路图，符号



- Ray diagrams
  - To obtain information about the images

- 光路图
  - 用来分析像的信息

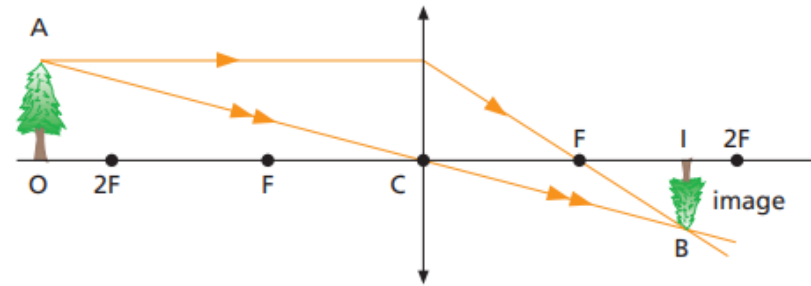


Image is between F and 2F, real, inverted, smaller

Figure 31.5a Object beyond 2F

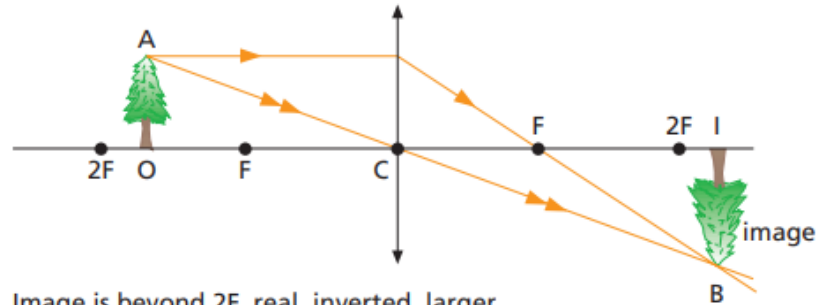


Image is beyond 2F, real, inverted, larger

Figure 31.5b Object at 2F

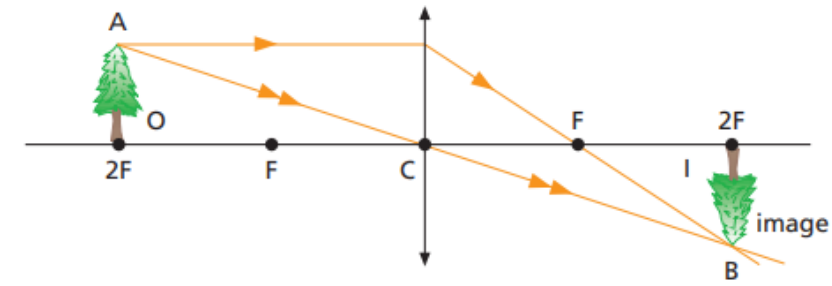


Image is at 2F, real, inverted, same size

Figure 31.5c Object between 2F and F

- Magnifying glass
- 放大镜

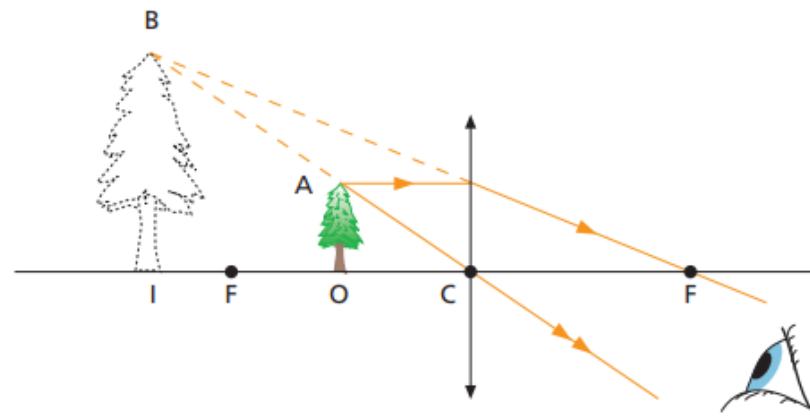


Image is behind object, virtual, erect, larger

Figure 31.5d Object between F and C

- Spectacles, Short sight & Long sight 眼镜、近视与远视

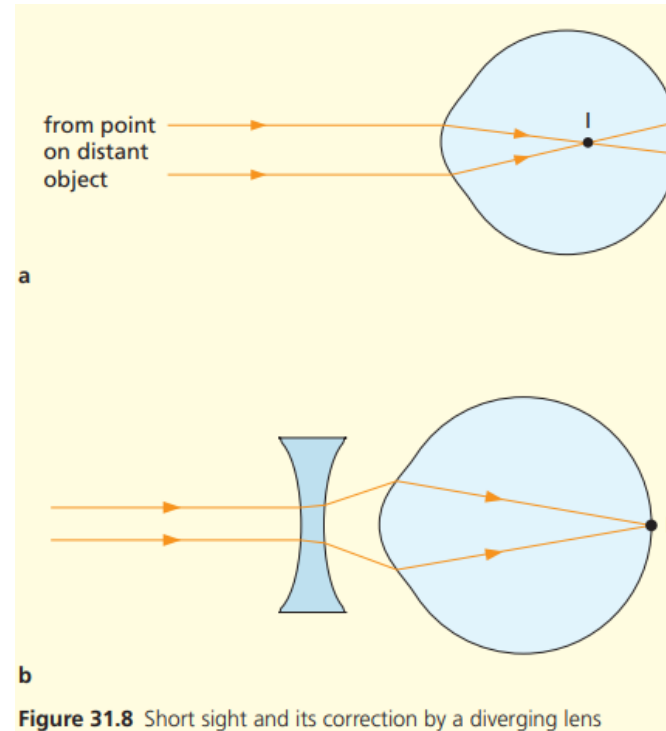
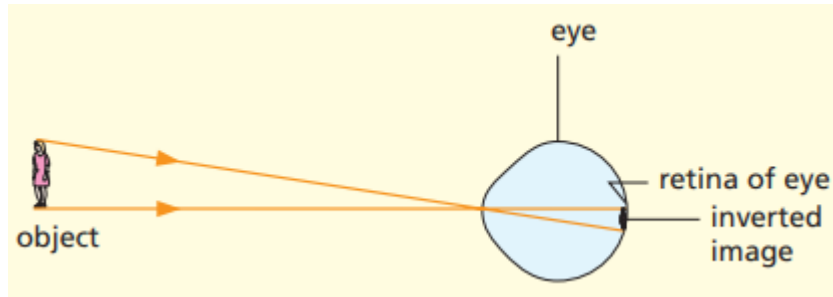


Figure 31.8 Short sight and its correction by a diverging lens

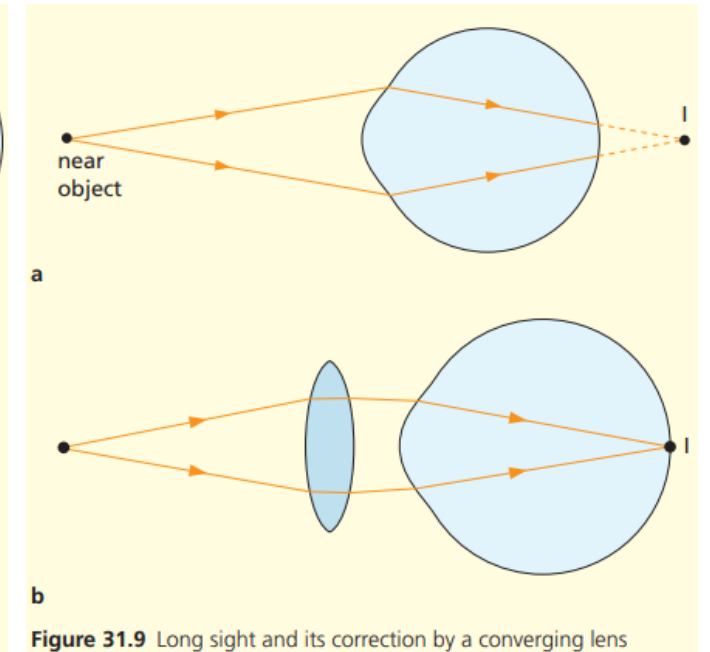


Figure 31.9 Long sight and its correction by a converging lens

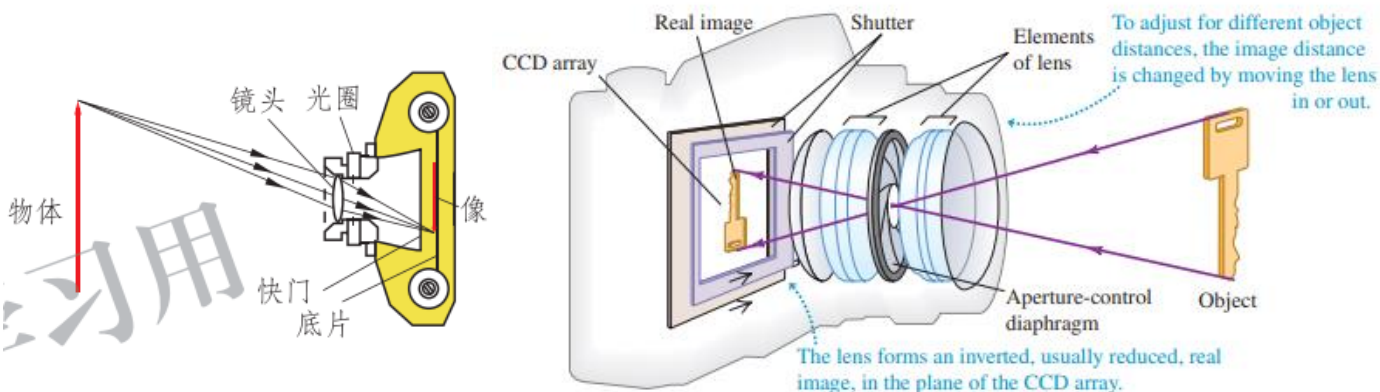
- Power of a lens

$$P = \frac{1}{f},$$

$$\text{眼镜的度数} = \frac{1}{f [\text{in metre}]} \times 100$$

## • 透镜的其他应用:

- 照相机 camera



- 幻灯机与投影仪 projector

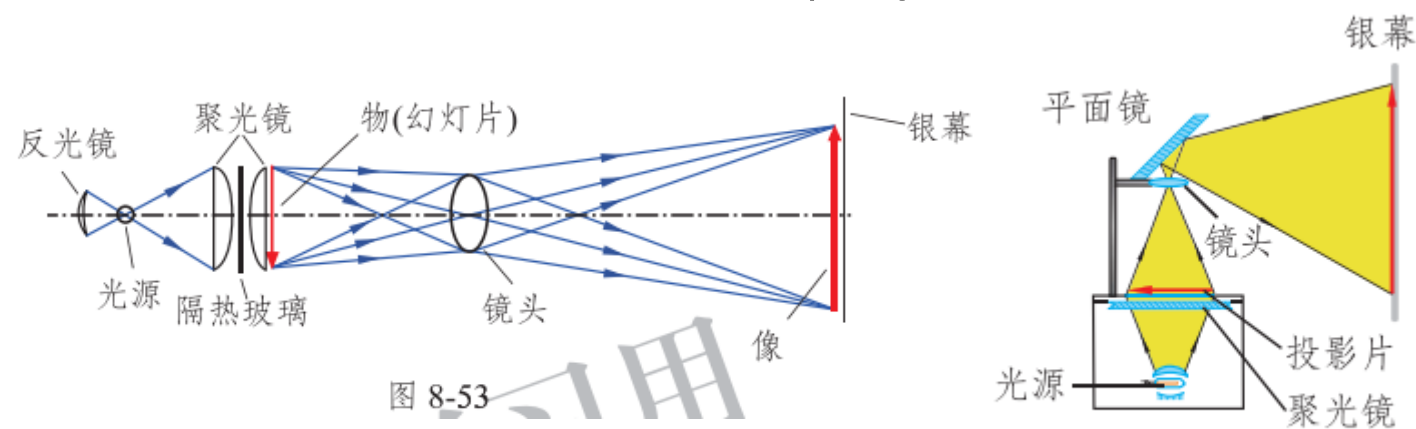


图 8-53

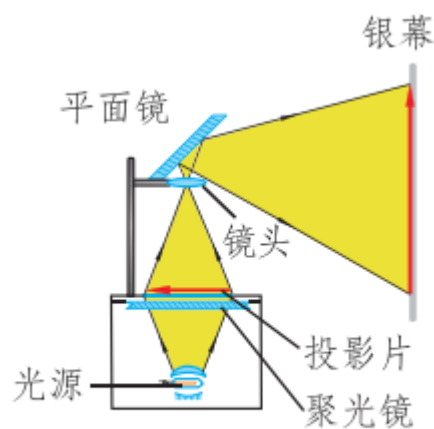
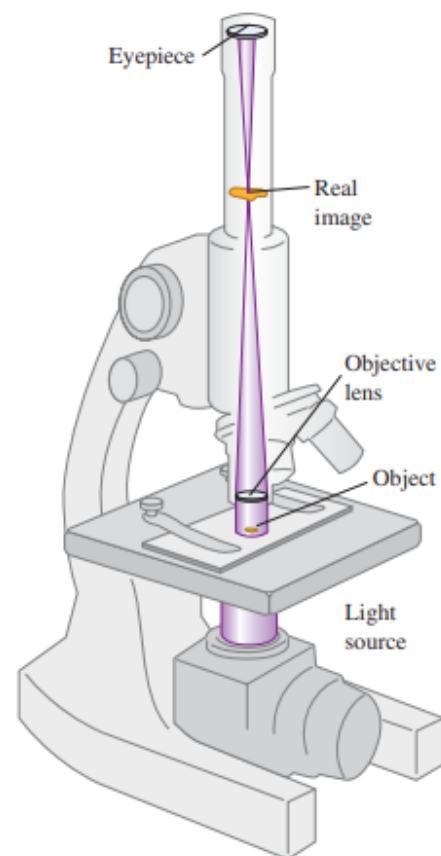


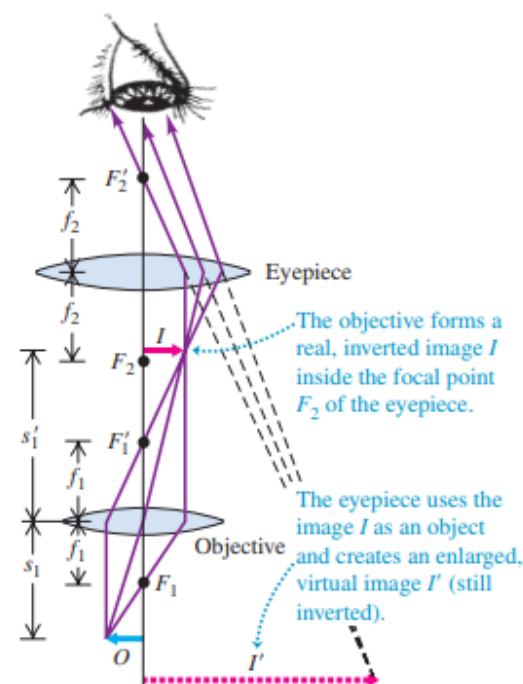
图 8-54

- 显微镜 microscope: 用两个透镜

(a) Elements of a microscope

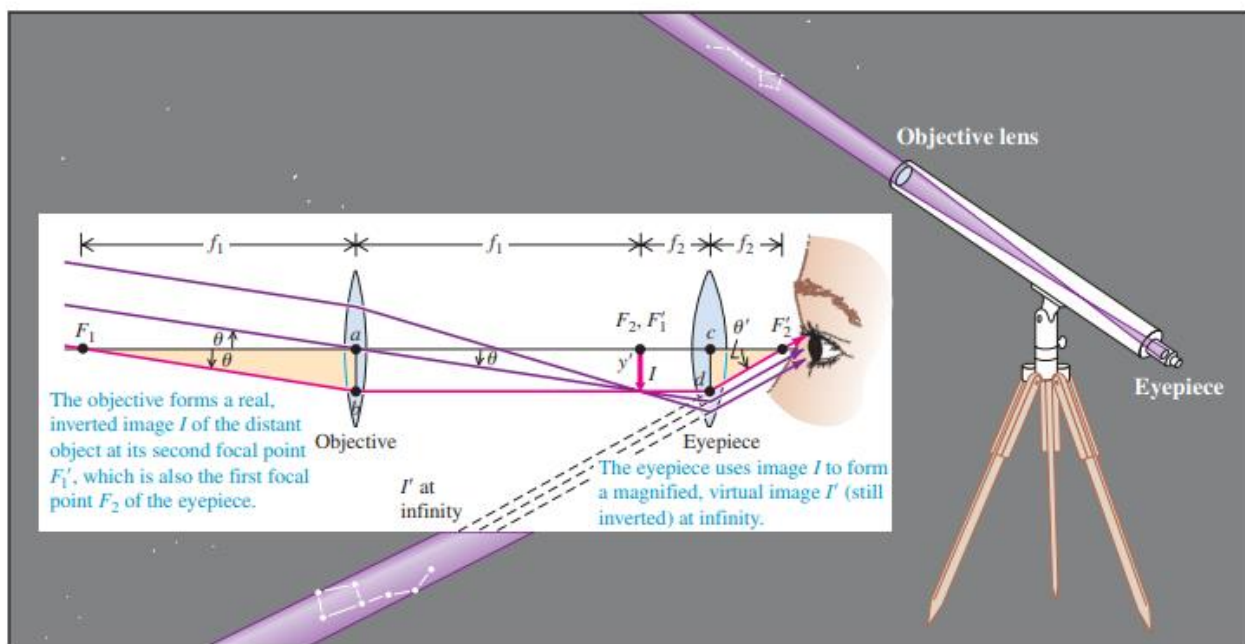


(b) Microscope optics



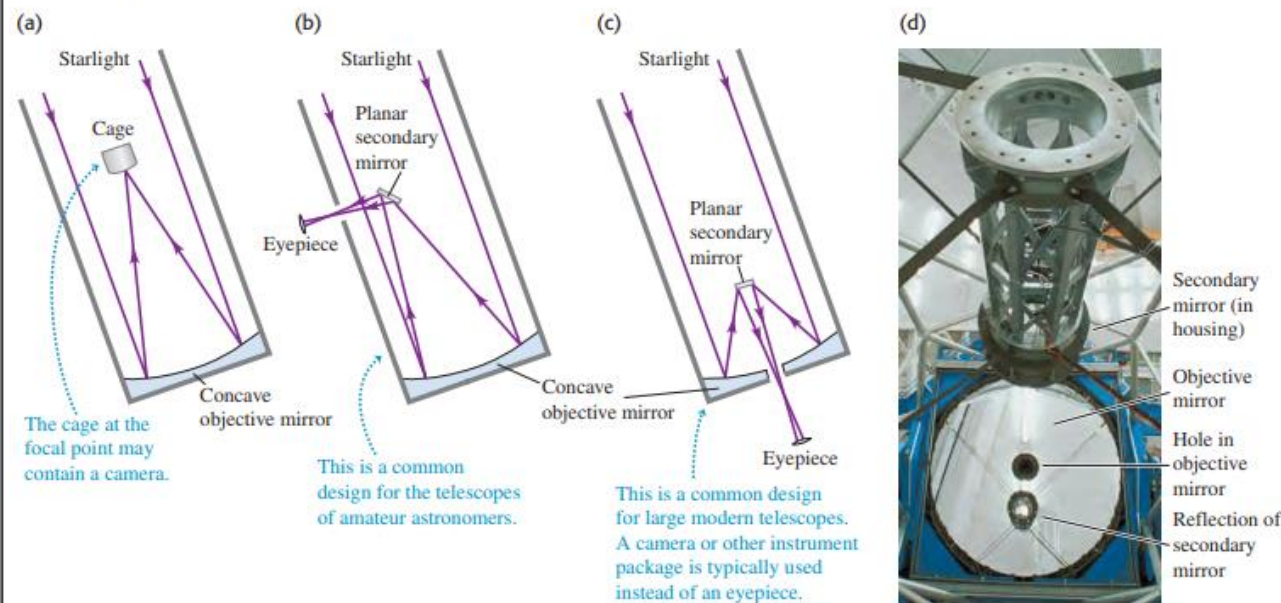
- 透镜的其他应用：
  - 折射式望远镜  
refracting telescope
  - 伽利略式望远镜

34.53 Optical system of an astronomical refracting telescope.



- 反射式望远镜（没用透镜）  
reflecting telescope
- 牛顿式望远镜 BV15T4y1D7EY

34.54 (a), (b), (c) Three designs for reflecting telescopes. (d) This photo shows the interior of the Gemini North telescope, which uses the design shown in (c). The objective mirror is 8 meters in diameter.



- 没有色差； 镜面不吸收光； 短



• 例

2 a What kind of lens is shown in Figure 31.10?

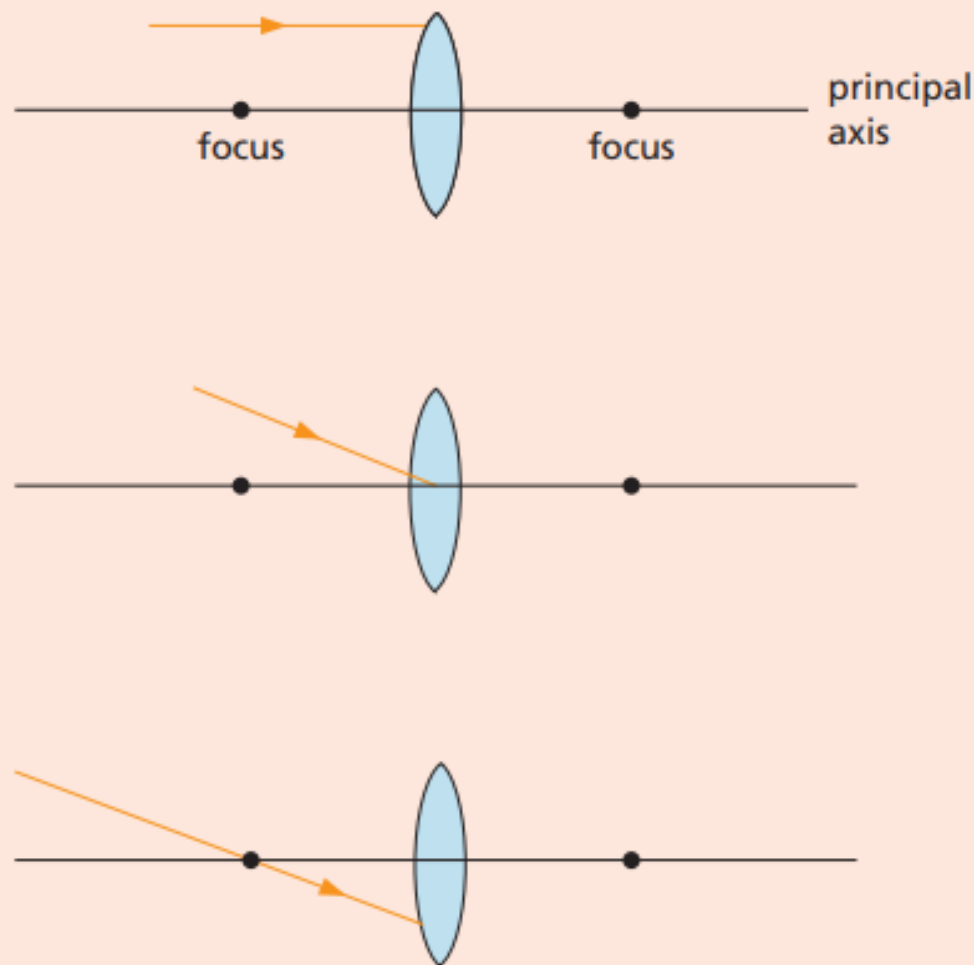


Figure 31.10

b Copy the diagrams and complete them to show the path of the light after passing through the lens.

c Figure 31.11 shows an object AB 6 cm high placed 18 cm in front of a lens of focal length 6 cm. Draw the diagram to scale and, by tracing the paths of rays from A, find the position and size of the image formed.

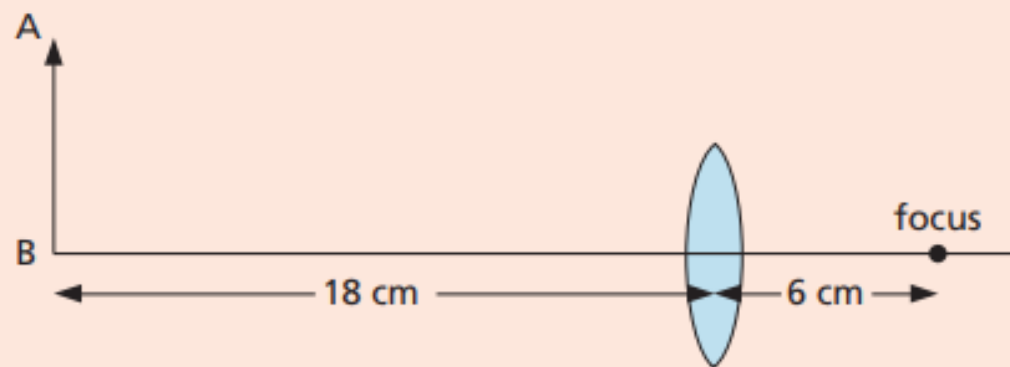


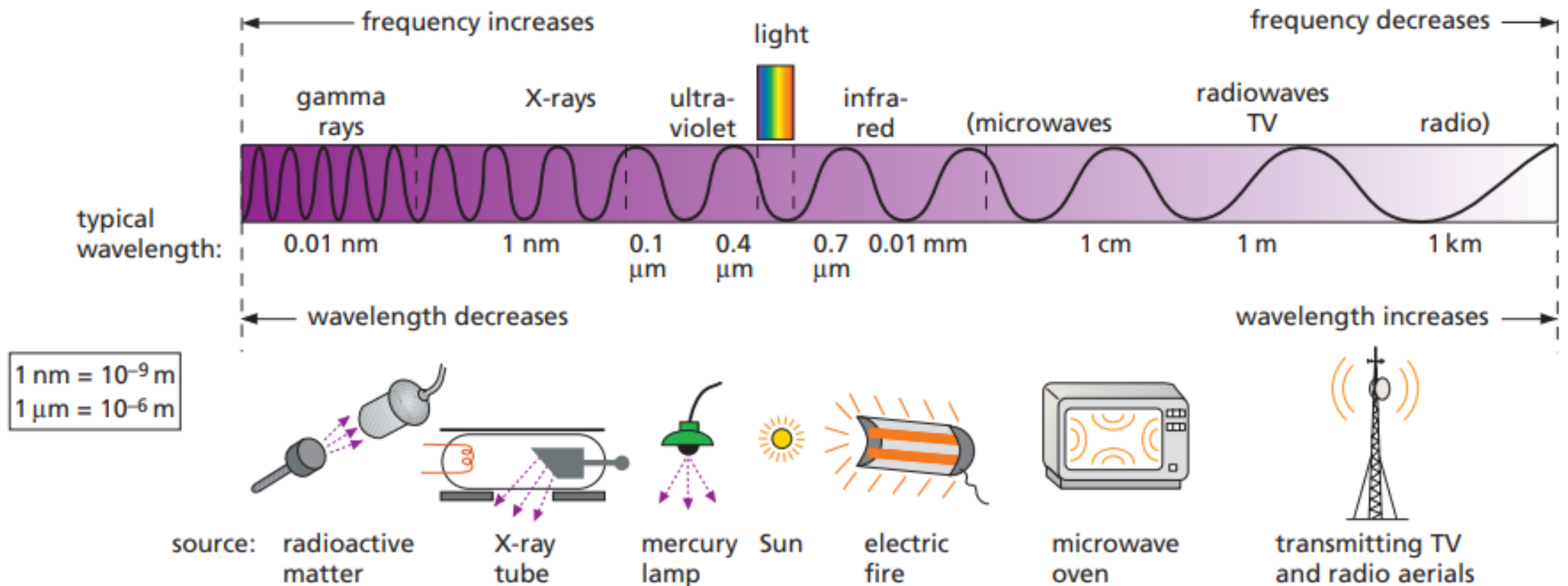
Figure 31.11

- 3 Where must the object be placed for the image formed by a converging lens to be
- a real, inverted and smaller than the object,
  - b real, inverted and same size as the object,
  - c real, inverted and larger than the object,
  - d virtual, upright and larger than the object?

# 总结

知识点	重要的实操实验	成像
光的直线传播 Light travels in straight line		小孔成像 Pinhole camera
光的反射 Reflection of light		平面镜成像 Plane mirror
光的折射 Refraction of light	测量玻璃砖折射率 Measuring the refractive index of a glass block 测量全反射临界角 Find the critical angle for total internal reflection	凸透镜成像 Lenses
光的色散 Dispersion of light		

- The terms light, electromagnetic waves, and radiation all refer to the same physical phenomenon: **electromagnetic energy**
- → **Wave optics 波动光学**



**Figure 32.1** The electromagnetic spectrum and sources of each type of radiation

## 参考教材：

- 北京市物理（八全、九全）北师大版
  - 高中物理人教版（2019版）
  - Cambridge IGCSE Physics 3<sup>rd</sup> ed
  - Pearson Edexcel International GCSE (9-1) Physics
  - AQA GCSE (9-1) Physics
  - Young and Freedman, “University Physics,” 13<sup>th</sup> edition. Pearson Press.
- 
- 部分实验视频由B站BV号给出