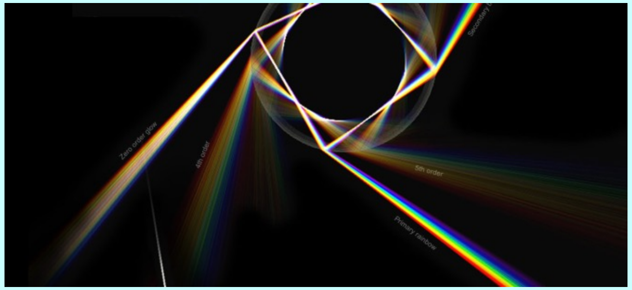
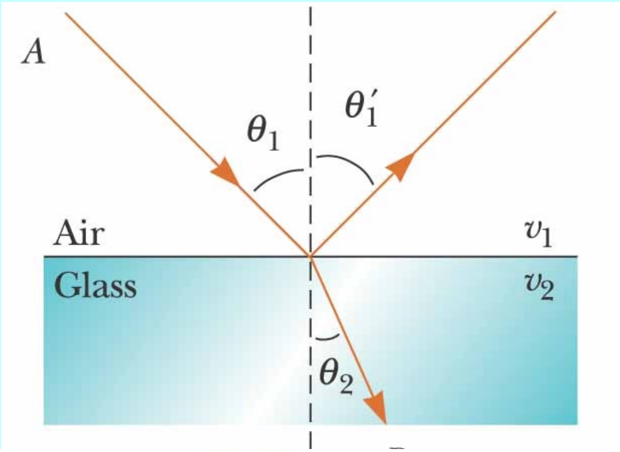
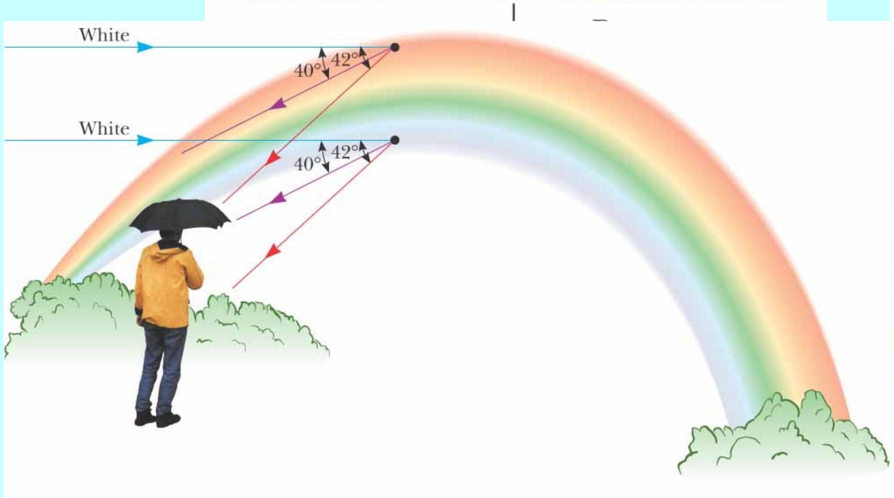
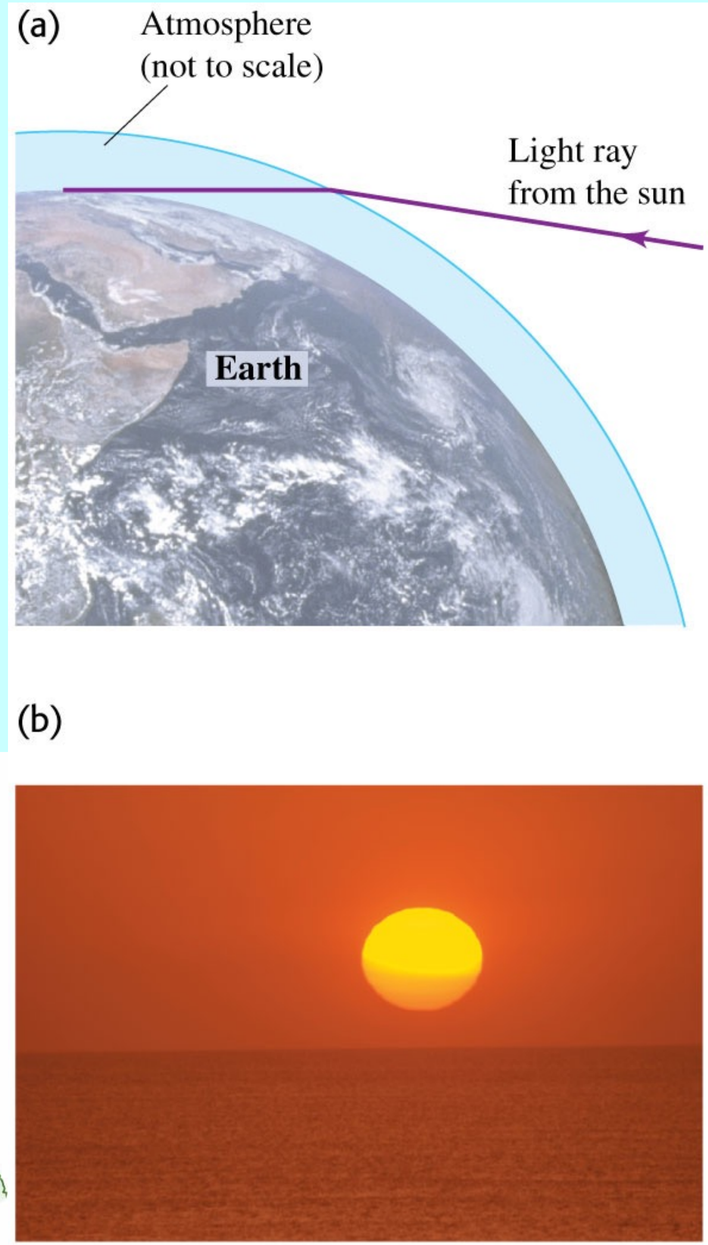
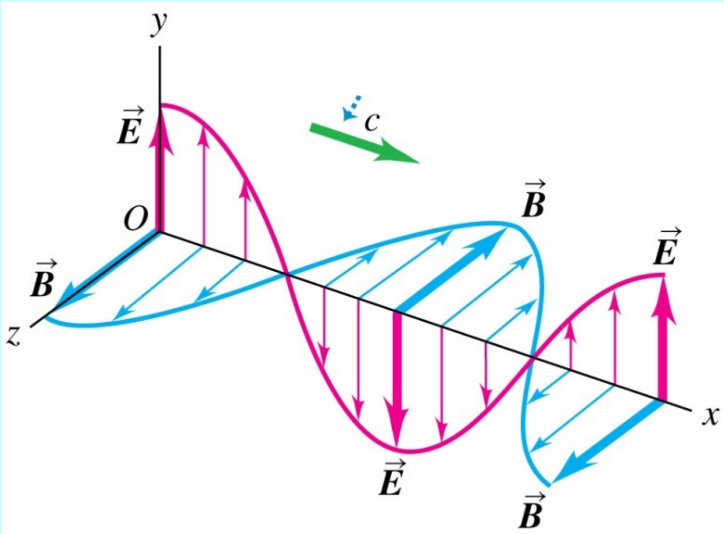
光學 Optics

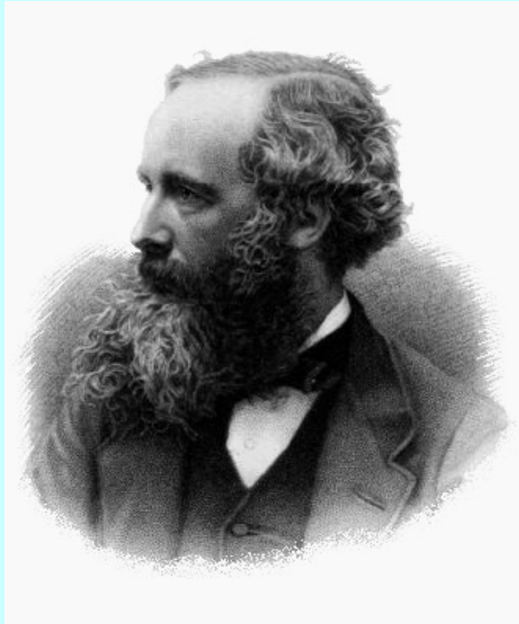



A
θ_1
θ_1'
Air
v_1
Glass
v_2
θ_2


White
40°
42°
White
40°
42°


(a)
Atmosphere
(not to scale)
Light ray
from the sun
Earth
(b)

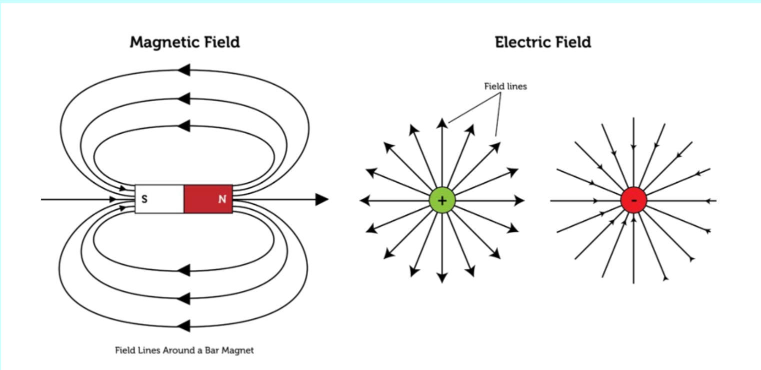


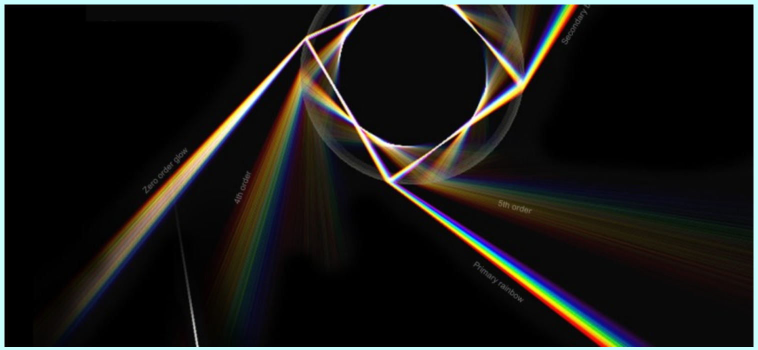


電磁波　Electromagnetic Wave

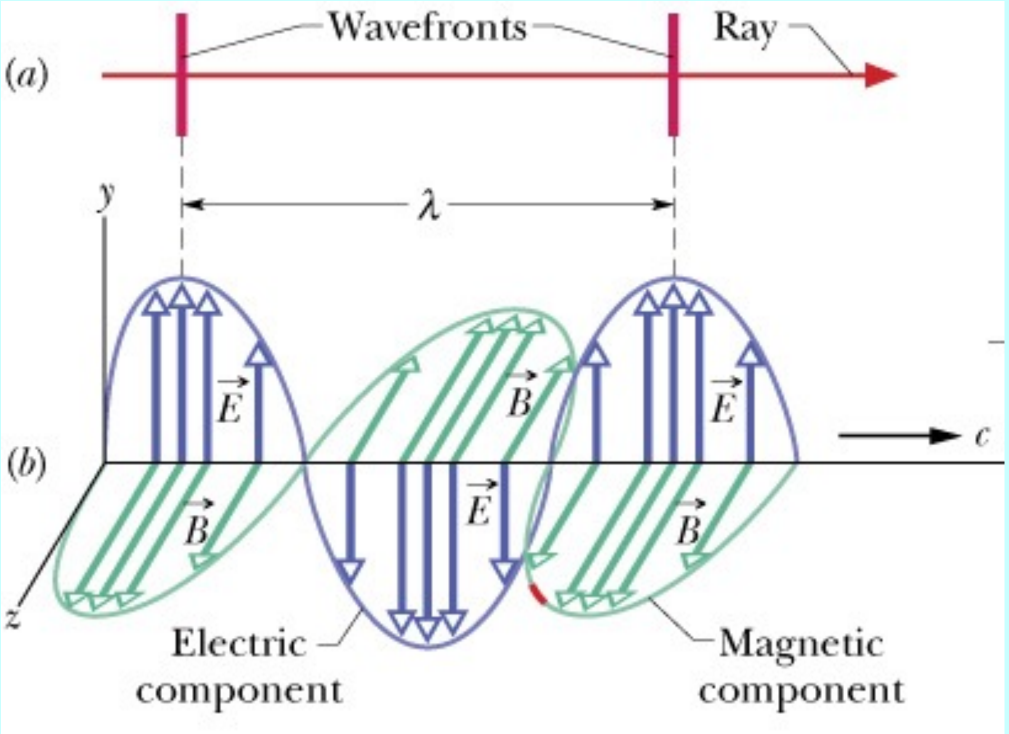
光原來是一種電磁波！

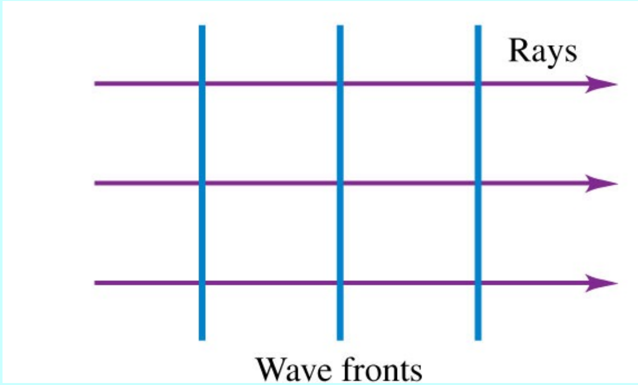
馬克斯威爾統一了電磁學與光學！





平面波

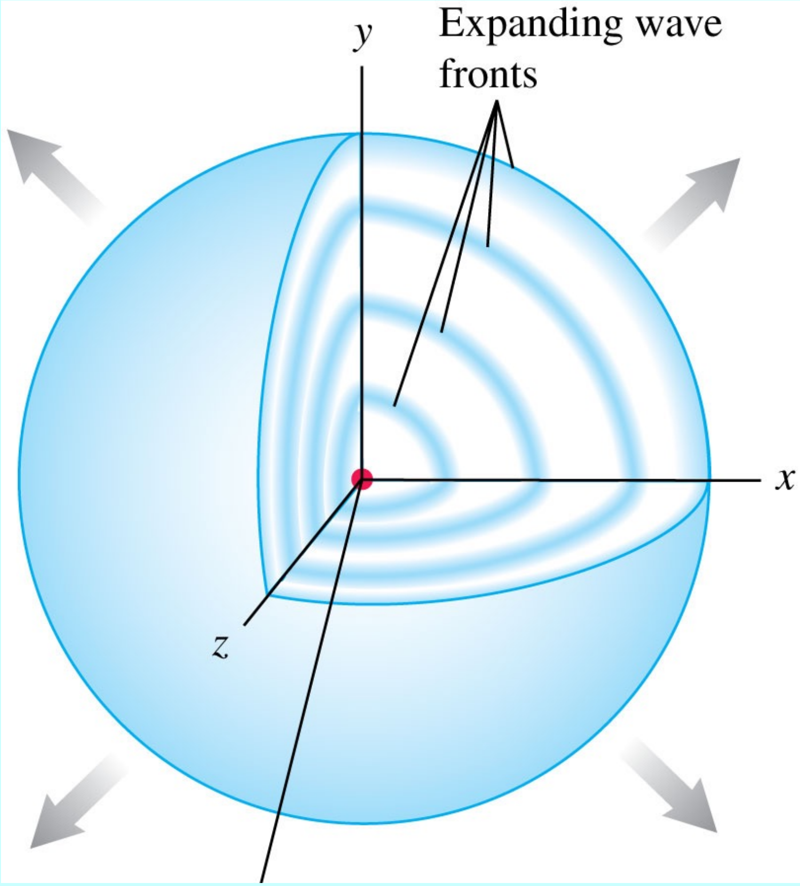


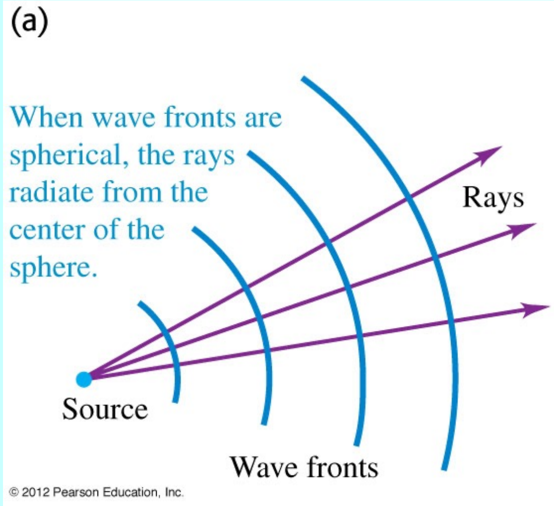


平面波有波峰與波谷，可以連接相鄰的波峰來定義一系列的波前平面（Wavefront）

波前平面會沿與波前垂直的傳播線（Ray）方向以光速傳播！

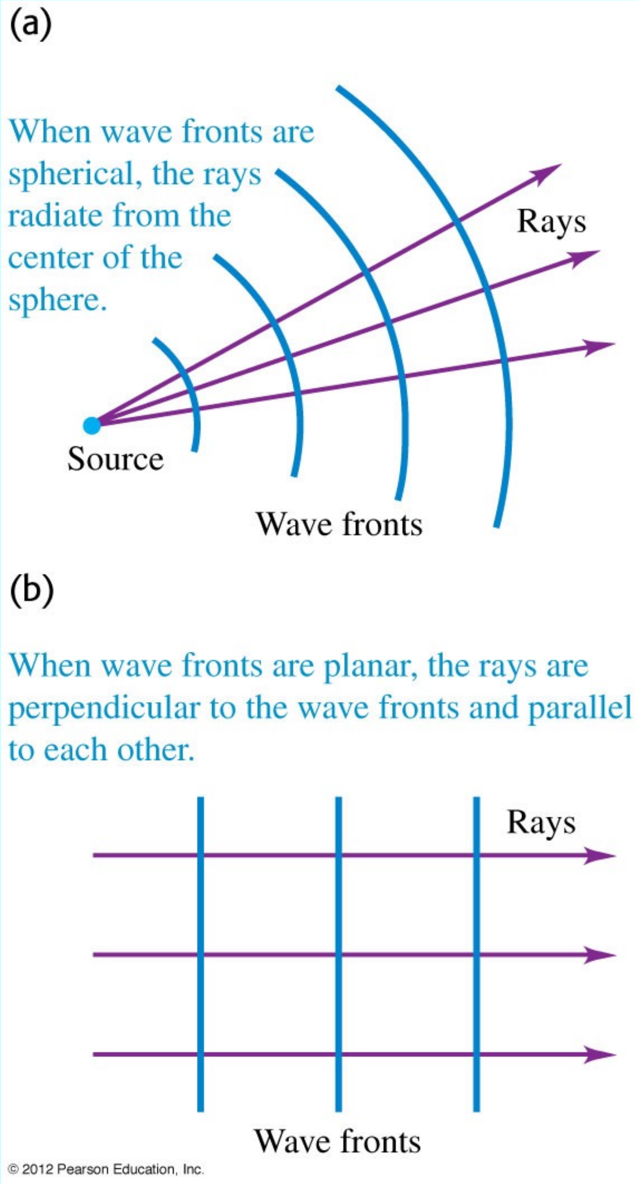
可以近似以波前平面及傳播線（Ray）來描述平面波的傳播





球面波如平面波一樣有波峰與波谷，可以定義球面波前

球面波前平面也會沿與波前垂直的傳播線（Ray）方向以光速傳播！

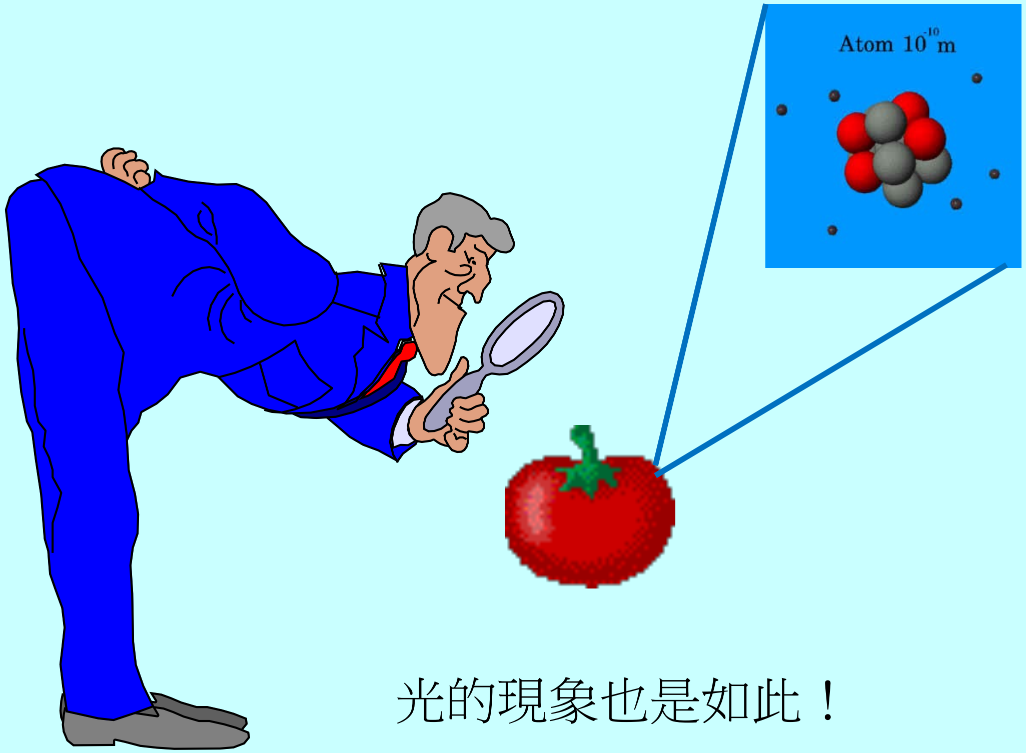


離開光源極遠處，光波可以以平面波近似！

光波可以以直線前進的Ray光線來描述

那我們還可以講光線嗎?

不同精細度的觀察，會看到非常不一樣的圖像

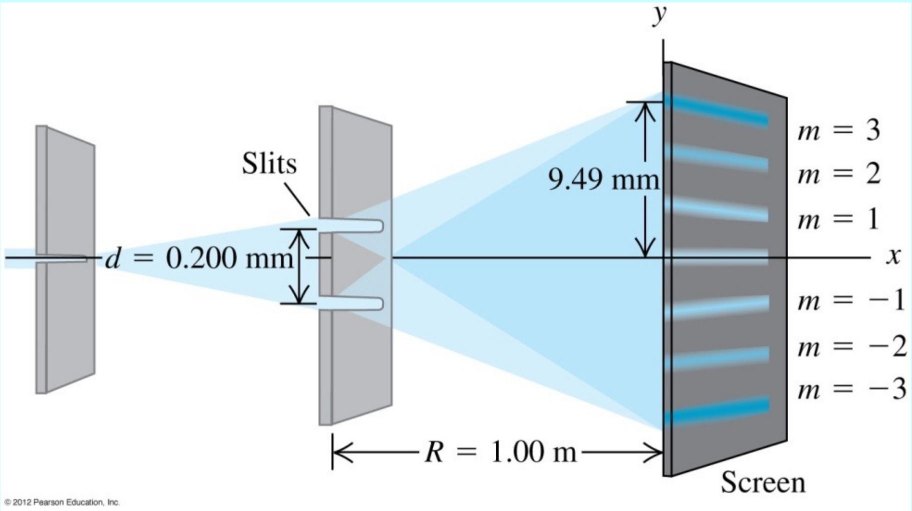


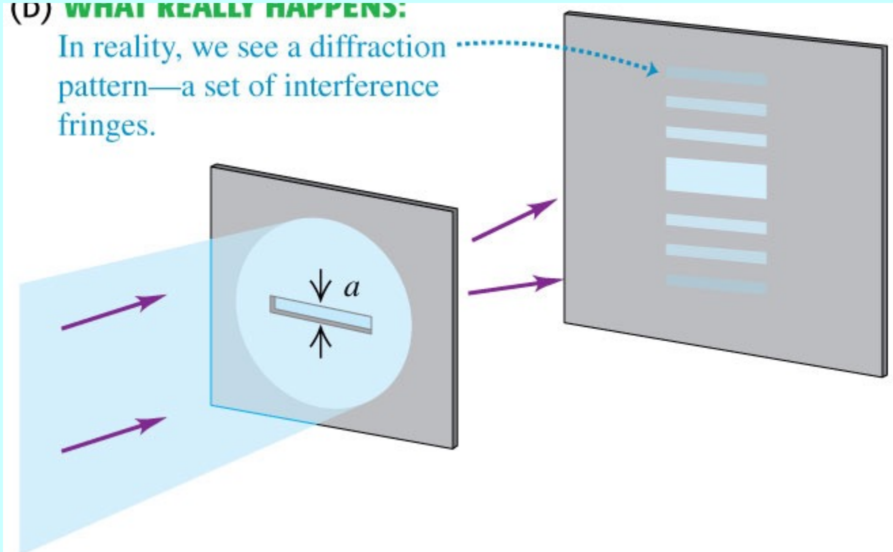
光的現象也是如此！

當觀察的儀器及尺度大約是光波波長

波動的現象就非常重要

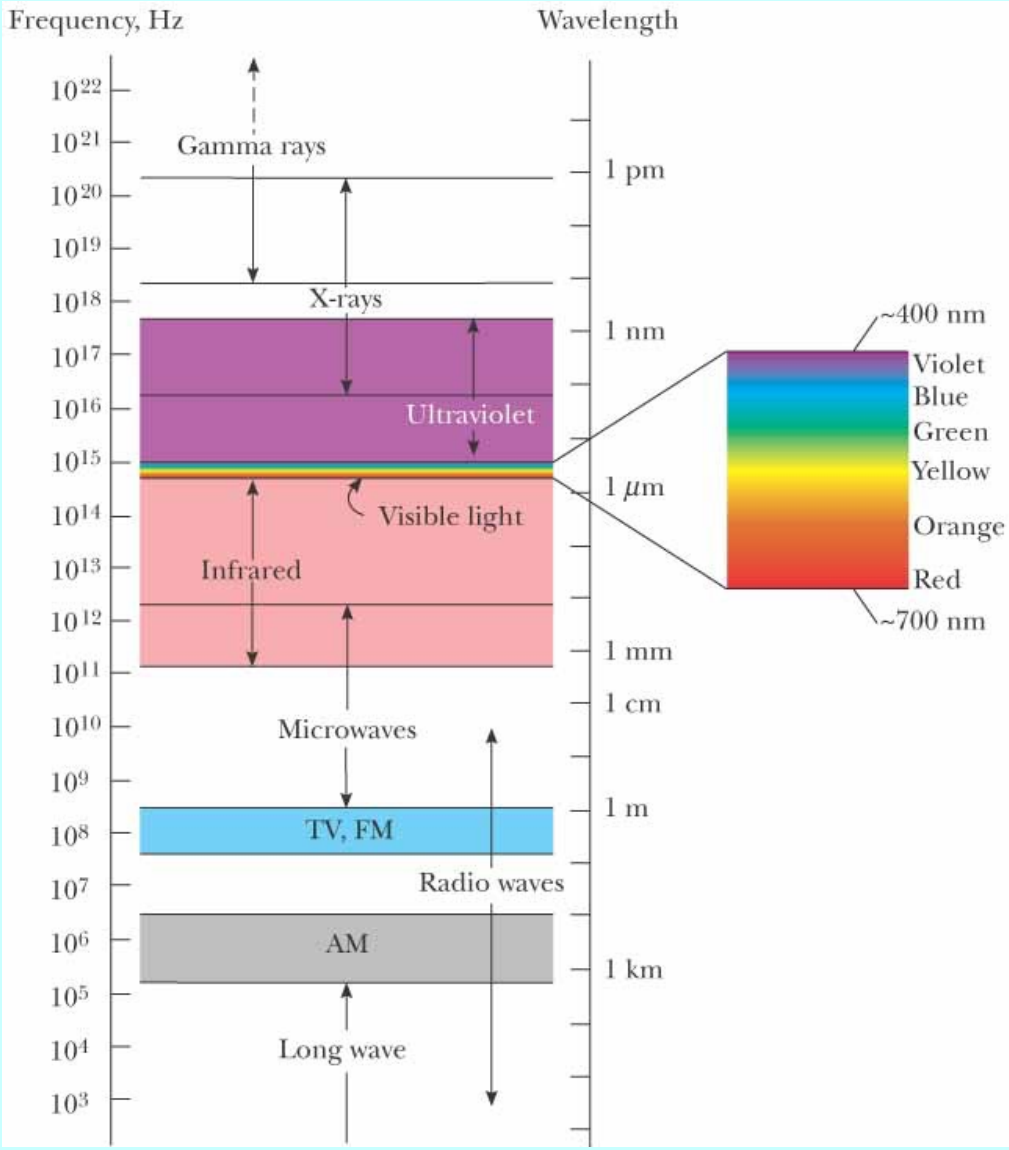
光波必須以波的傳播來討論！





干涉　　　　　　　　　　繞射

物理光學



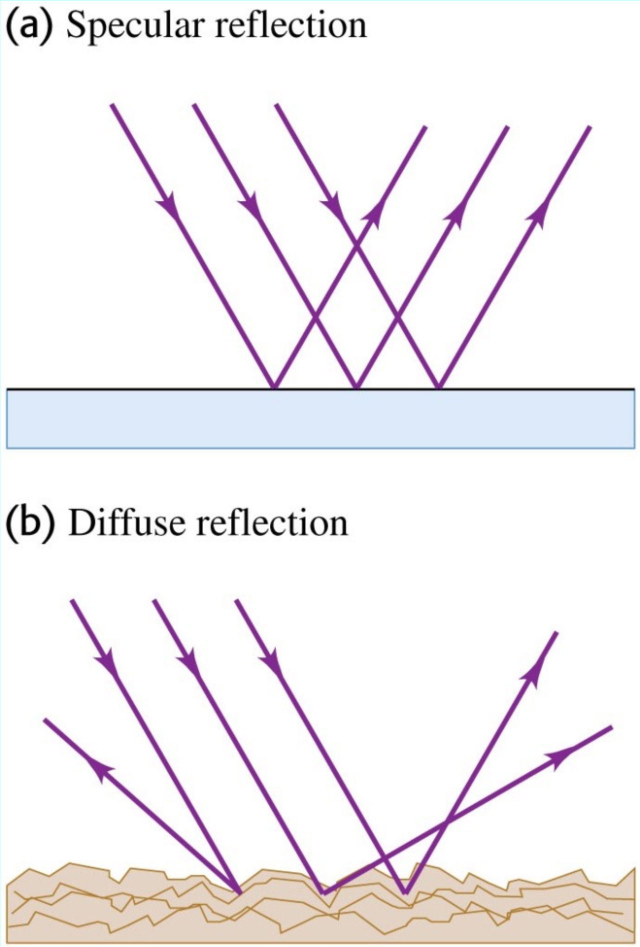
可見光的波長只有 400nm~700nm。

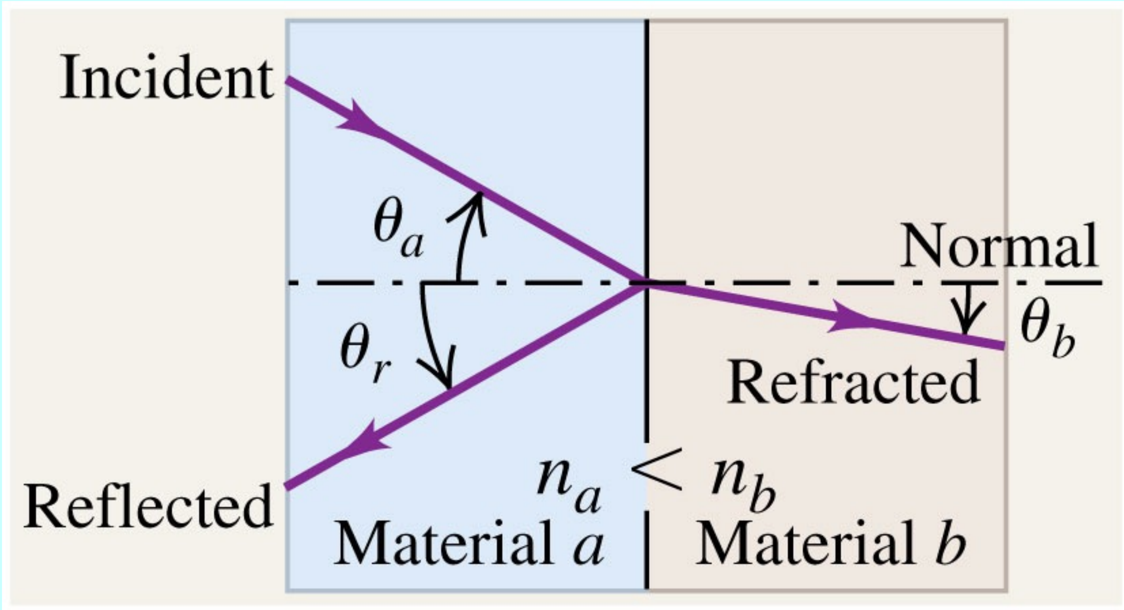
一般是很難看到它的波動性。

當觀察的儀器及尺度遠大於光波波長

波動的現象就不太重要

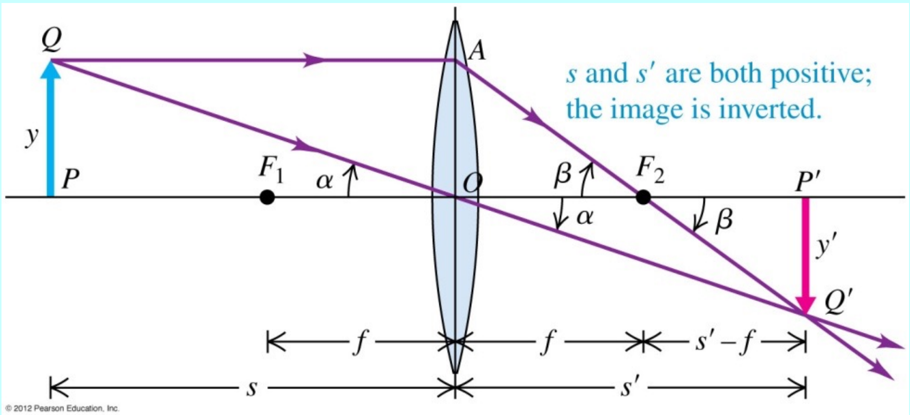
光波可以以直線前進的光線 Ray來代表！





反射與折射

幾何光學


Q
A
s and s′ are both positive;
the image is inverted.
y
P
F1
α
O
β
F2
P′
α
β
y′
Q′
f
f
s′ − f
s
s′
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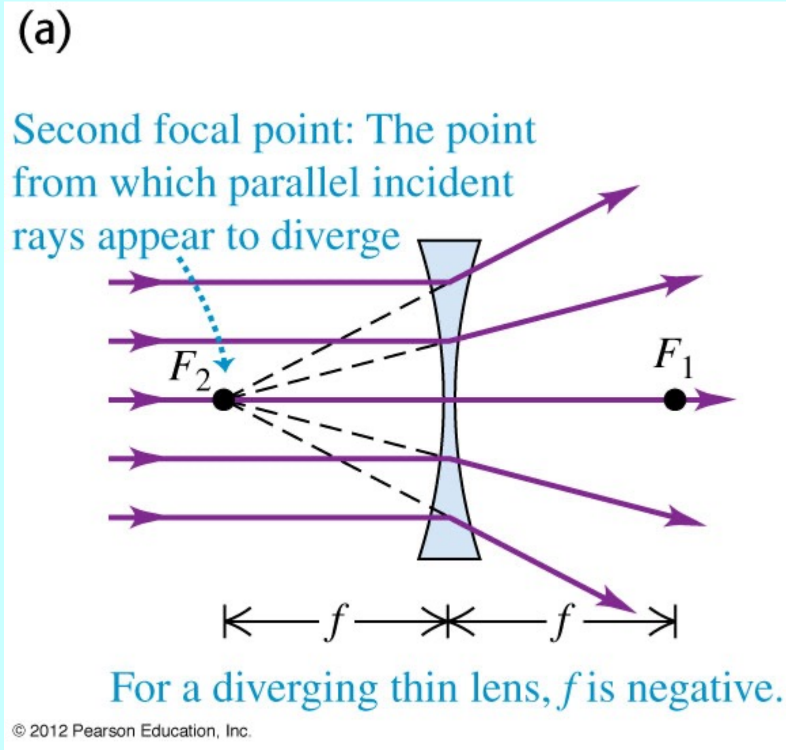
(a)
Second focal point: The point
from which parallel incident
rays appear to diverge
F2
F1
f
f
For a diverging thin lens, f is negative.
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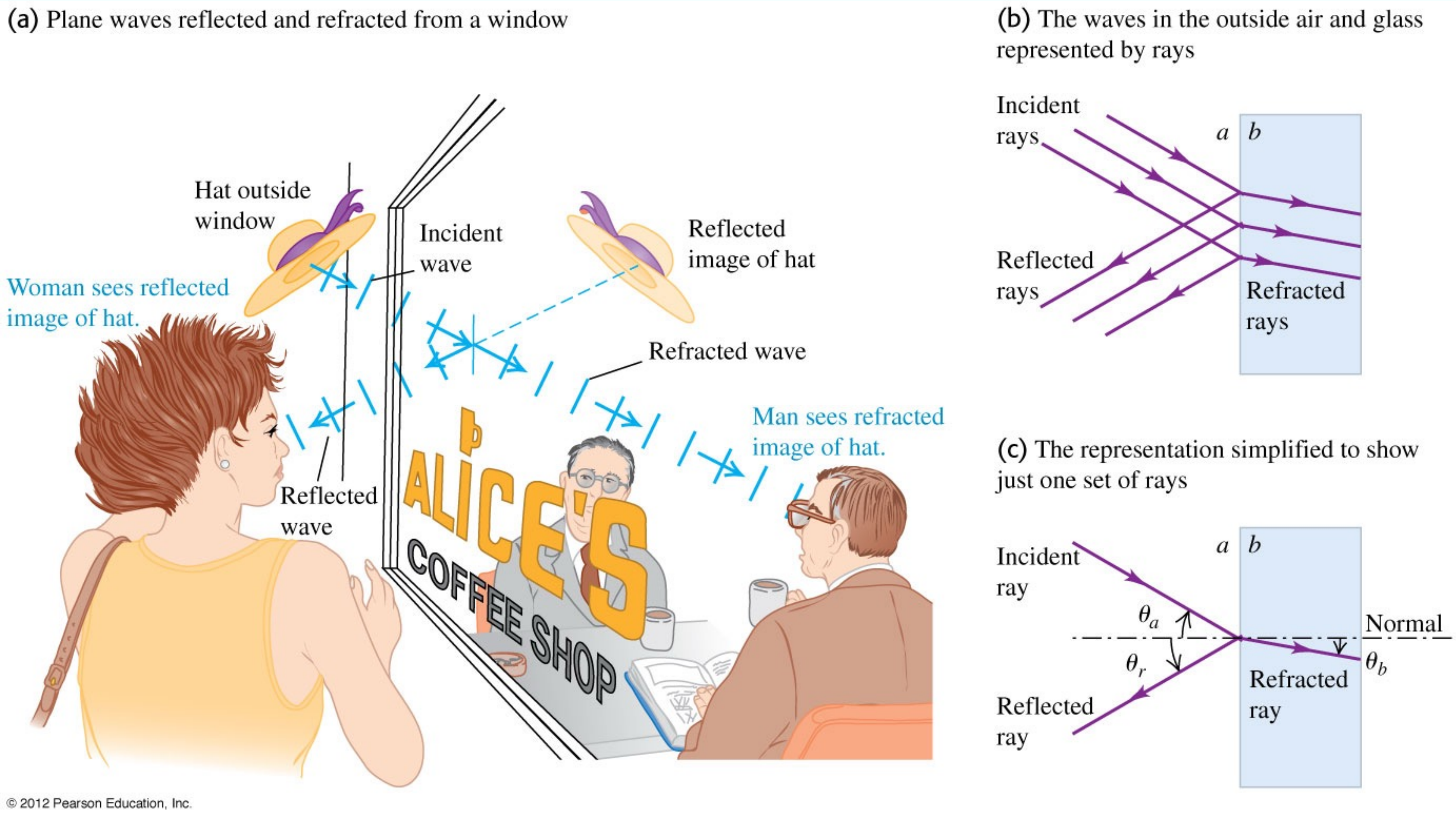
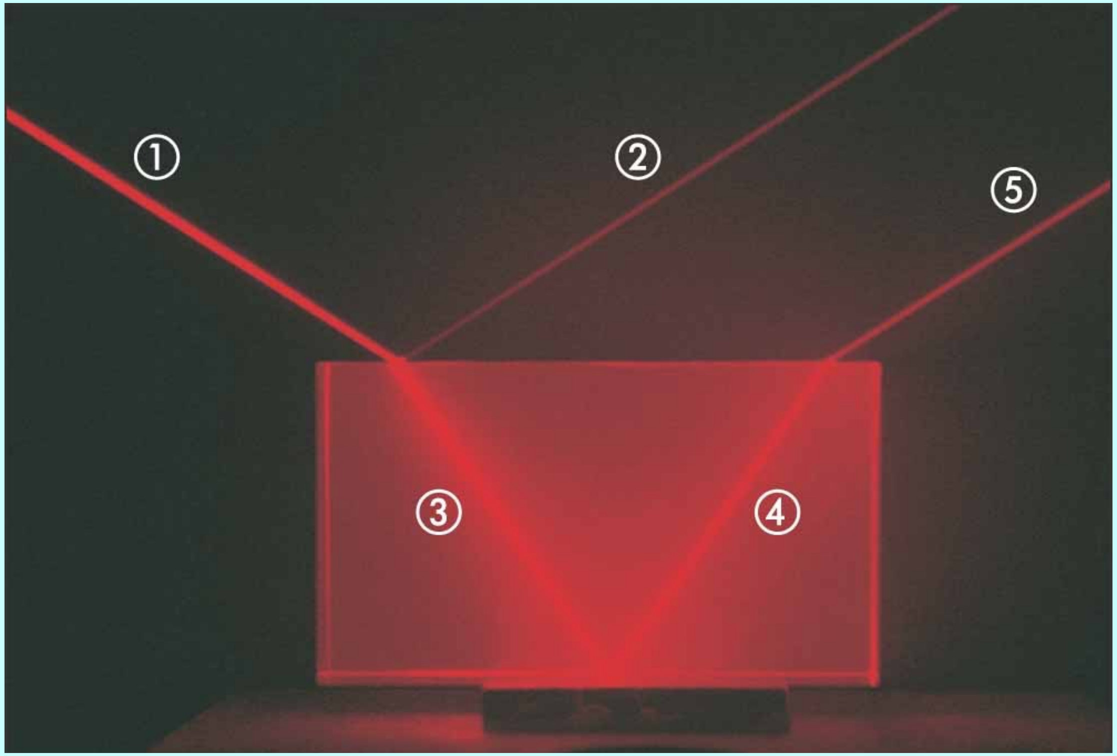
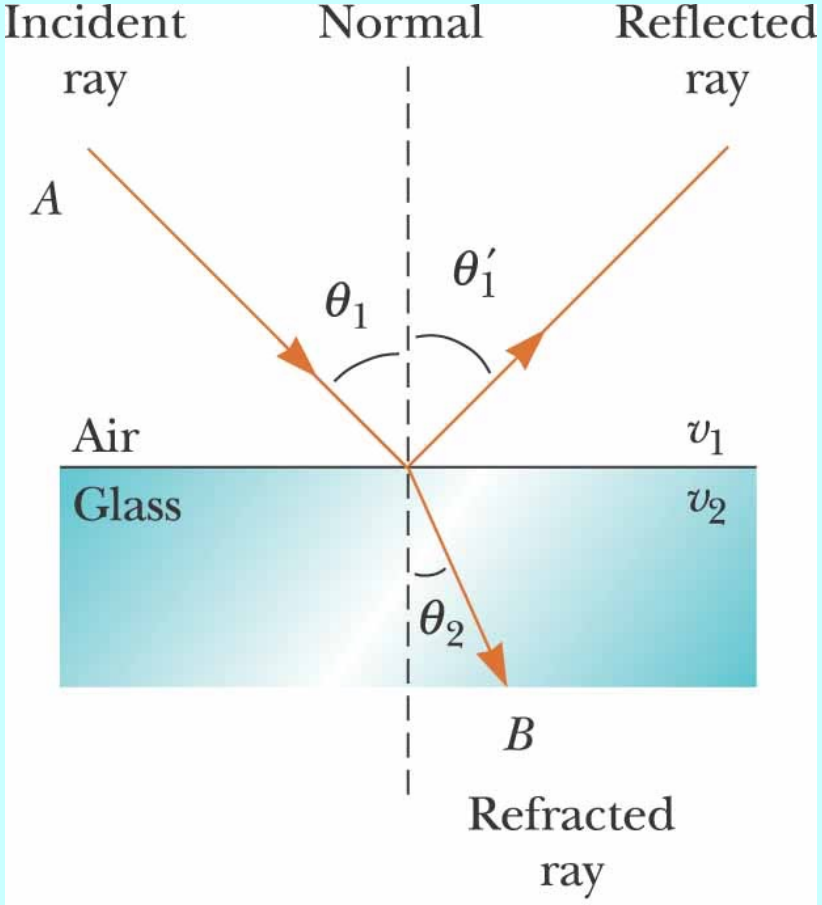
幾何光學最重要的就是反射與折射現象。



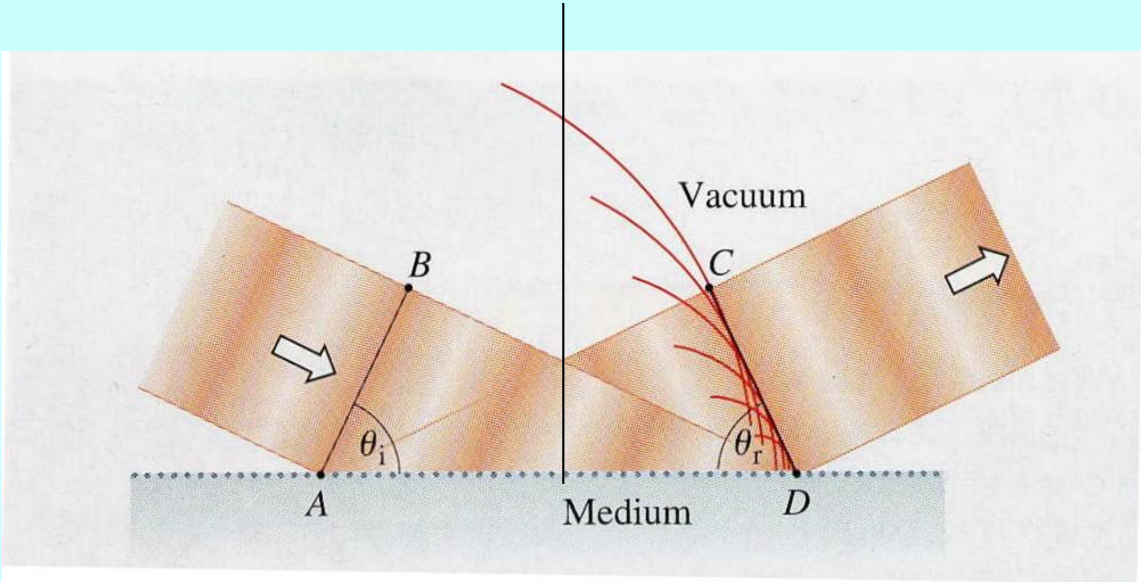
光直行遇到邊界時會發生反射與折射現象

Reflection and Refraction



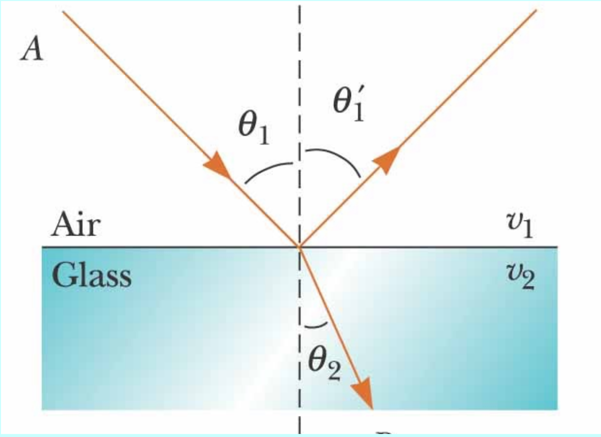


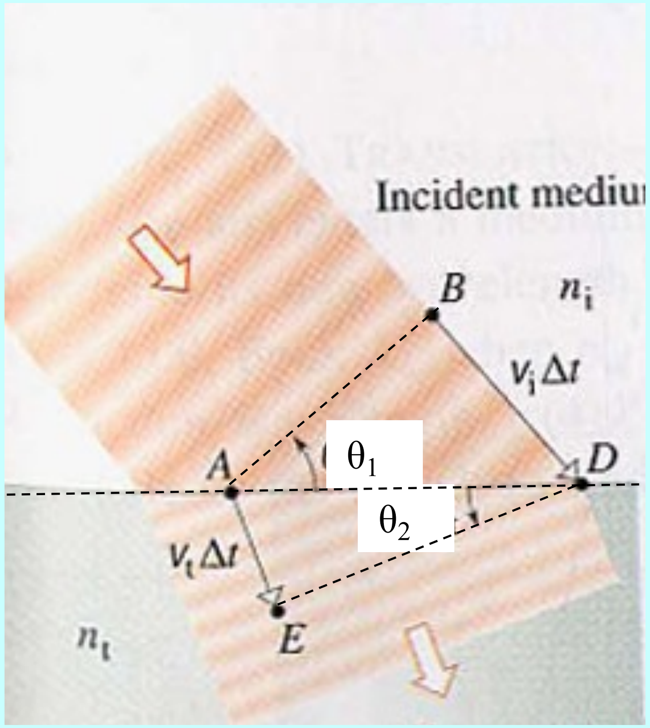
光行進遇到邊界
反射現象



$$\overline{AD}\times\sin\theta_i=\overline{AD}\times\sin\theta_r$$

$$\theta_i=\theta_r$$





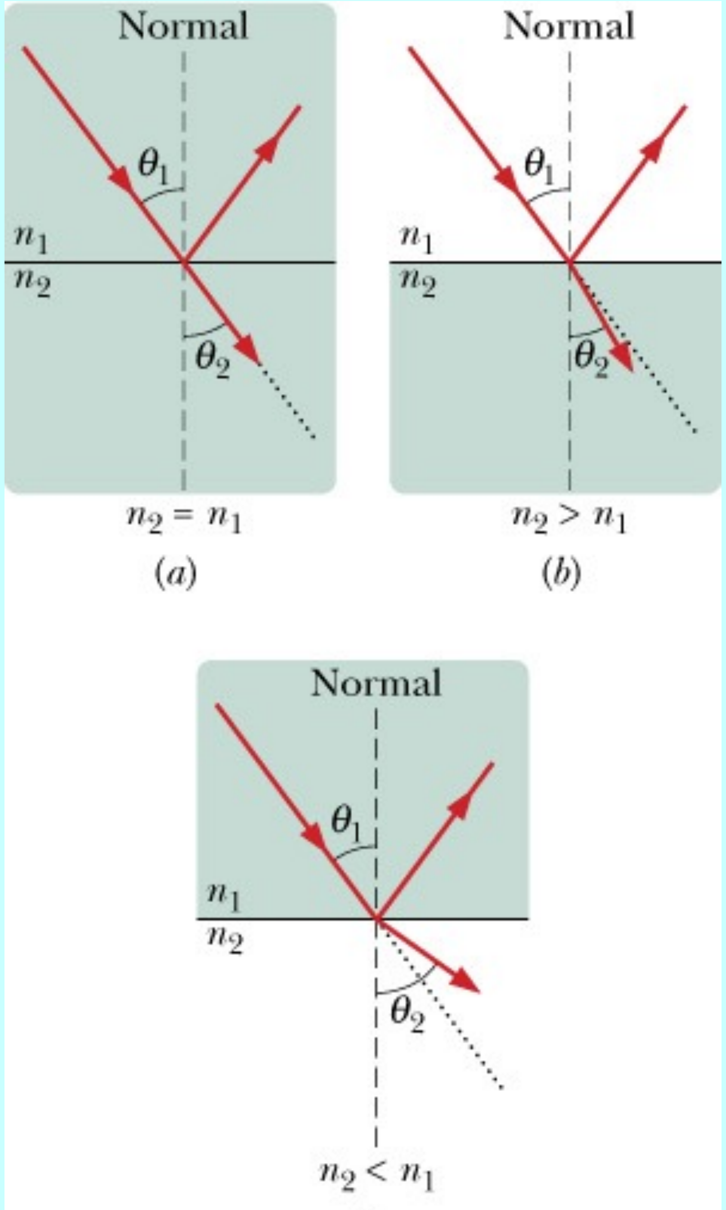
折射現象

$$\overline{\mathrm{BD}} : \overline{\mathrm{AE}} = \lambda_1 : \lambda_2 = v_1 : v_2$$

$$\frac{\overline{\mathrm{BD}}}{\overline{\mathrm{AE}}} = \frac{\overline{\mathrm{AD}} \sin\theta_1}{\overline{\mathrm{AD}} \sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Snell's Law

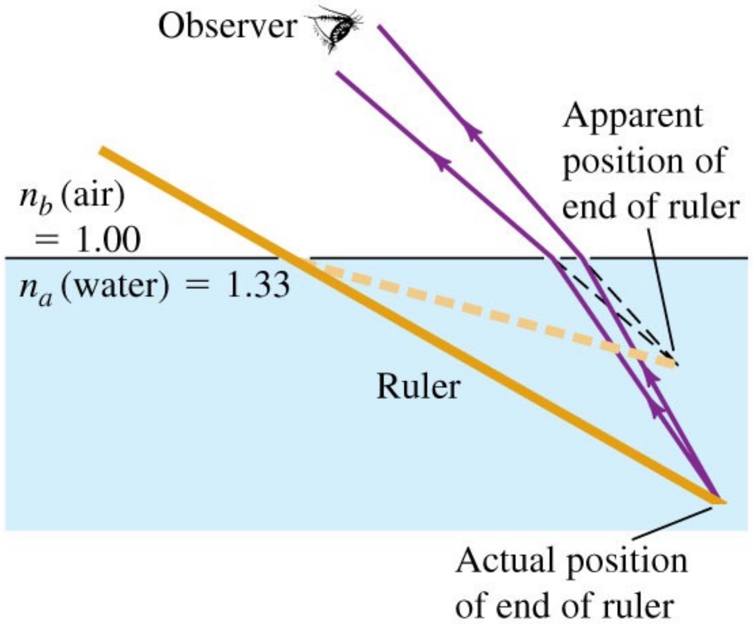


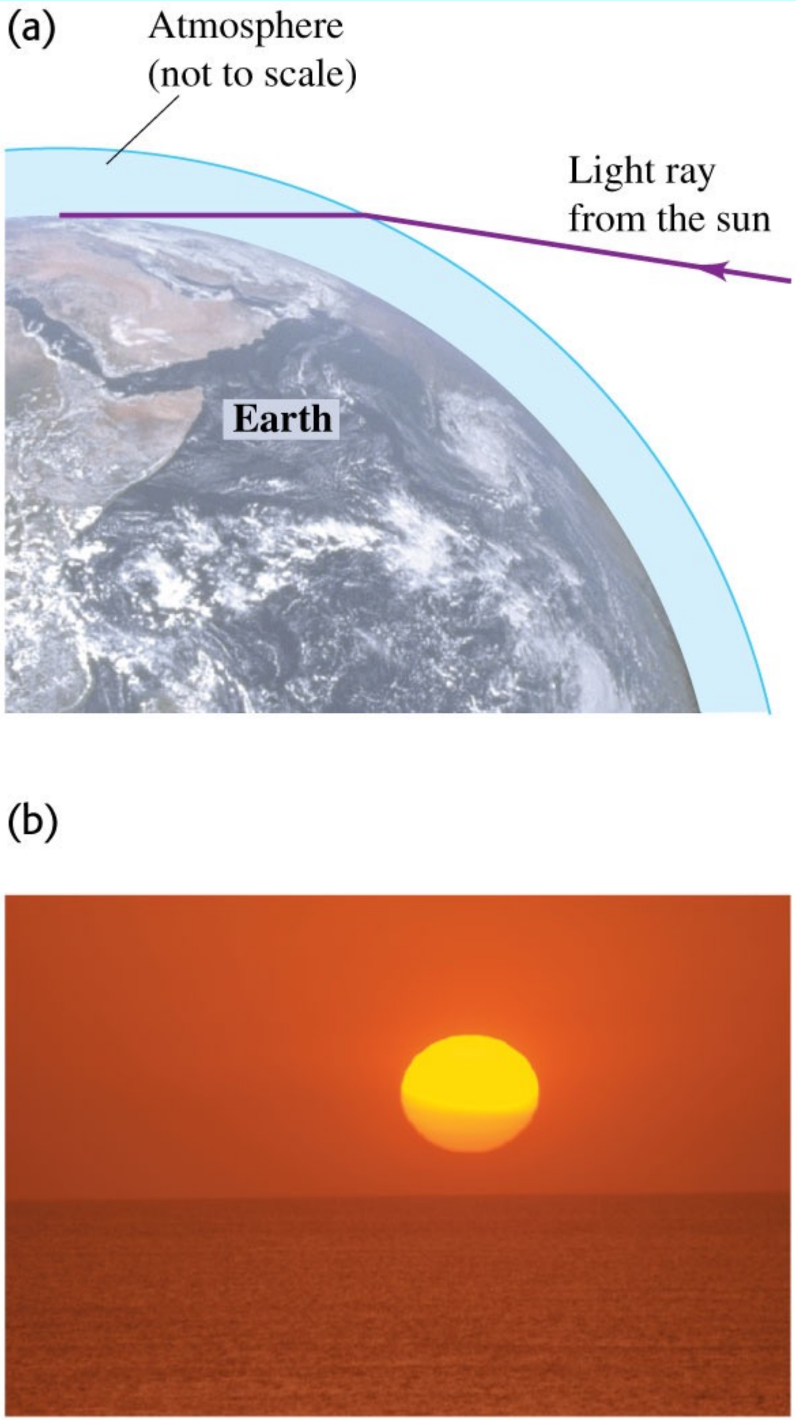
n 越大，角度越小

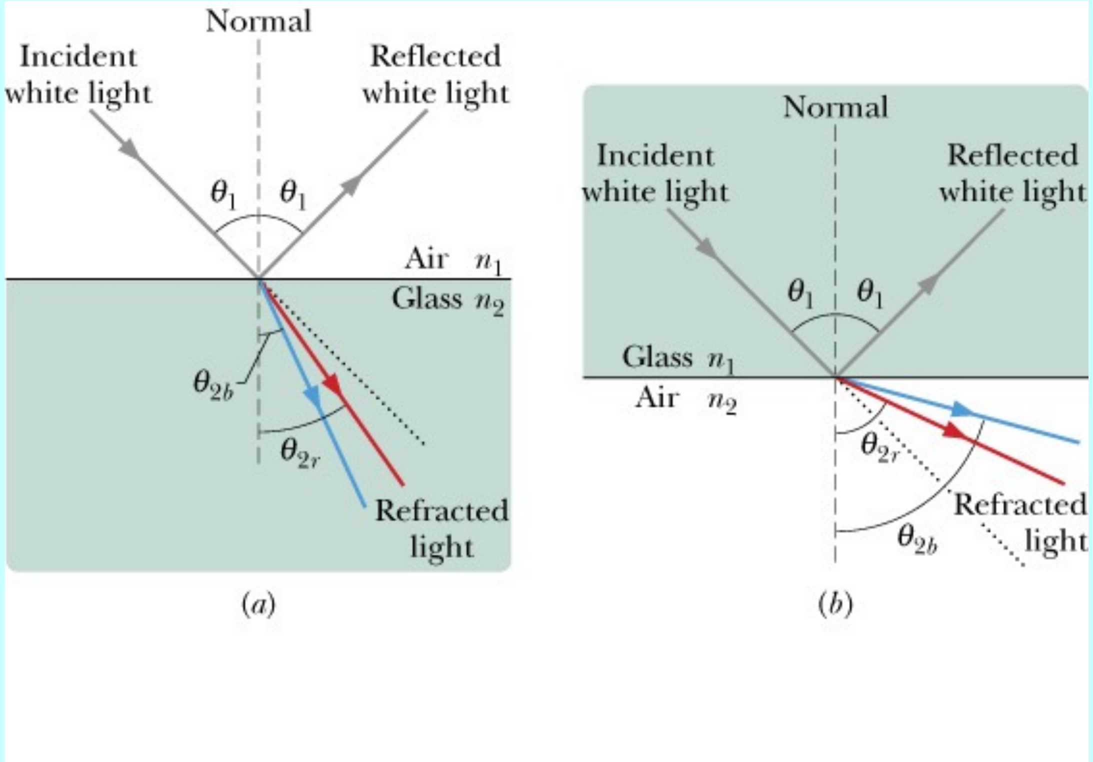
n 越小，角度越大

(a) A straight ruler half-immersed in water

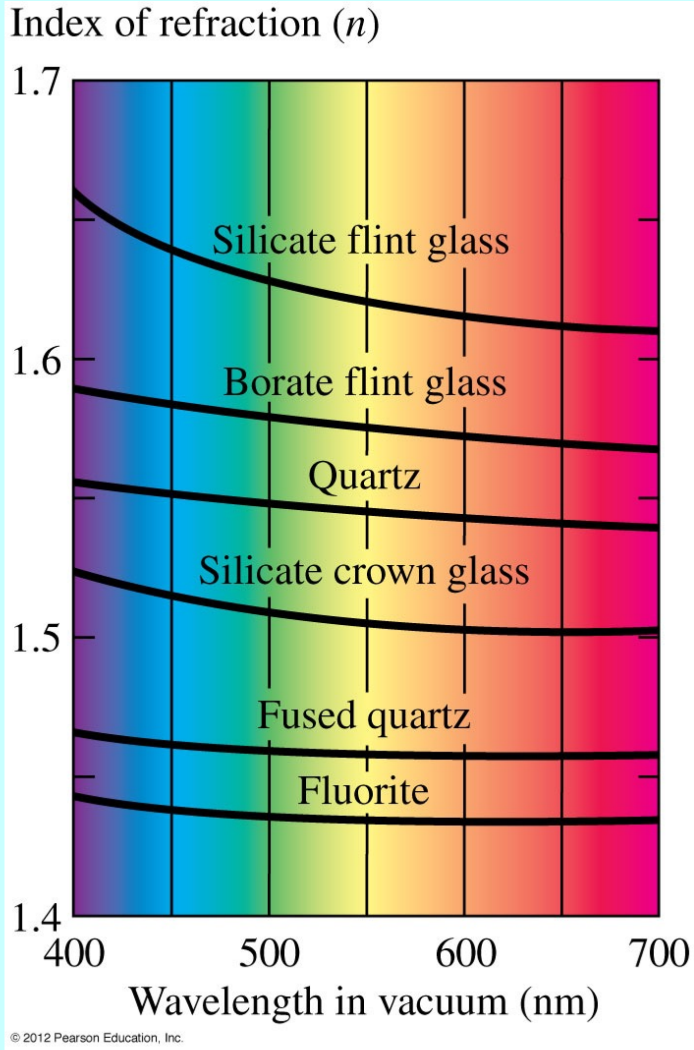
(b) Why the ruler appears bent



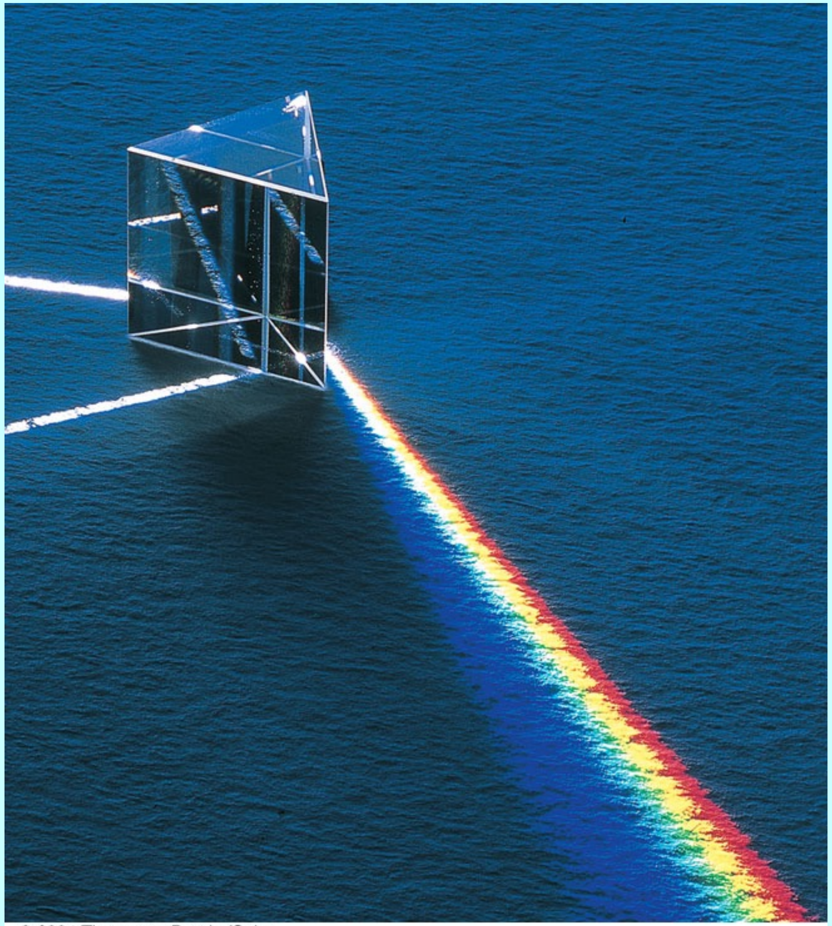

(a)
Atmosphere
(not to scale)
Light ray
from the sun
Earth
(b)

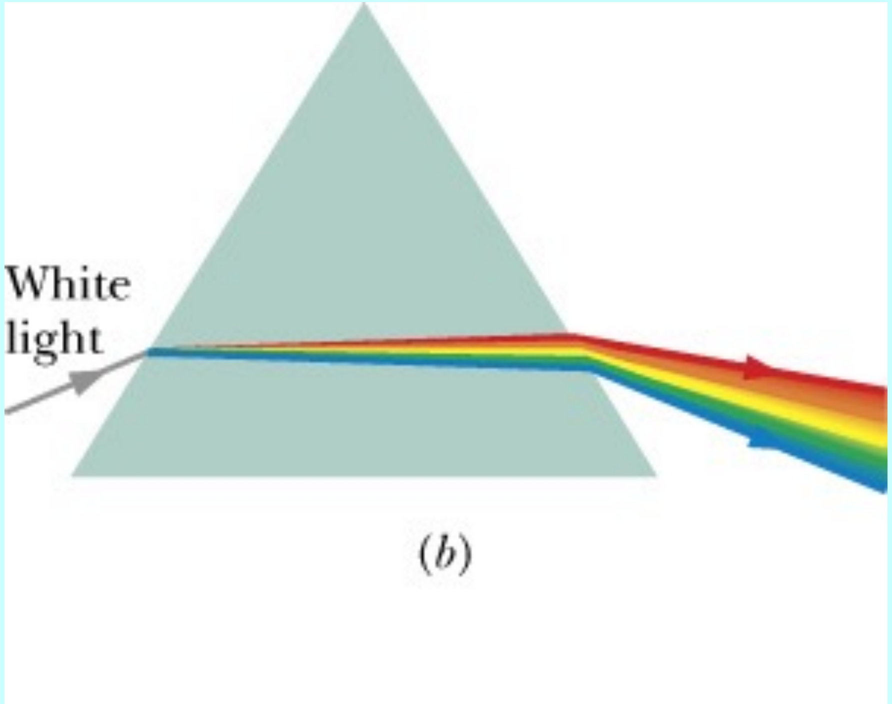

Normal
Incident white light
Reflected white light
θ_1
θ_1
Air n_1
Glass n_2
θ_{2b}
θ_{2r}
Refracted light
(a)
Normal
Incident white light
Reflected white light
θ_1
θ_1
Glass n_1
Air n_2
θ_{2r}
θ_{2b}
Refracted light
(b)

藍光偏折較大

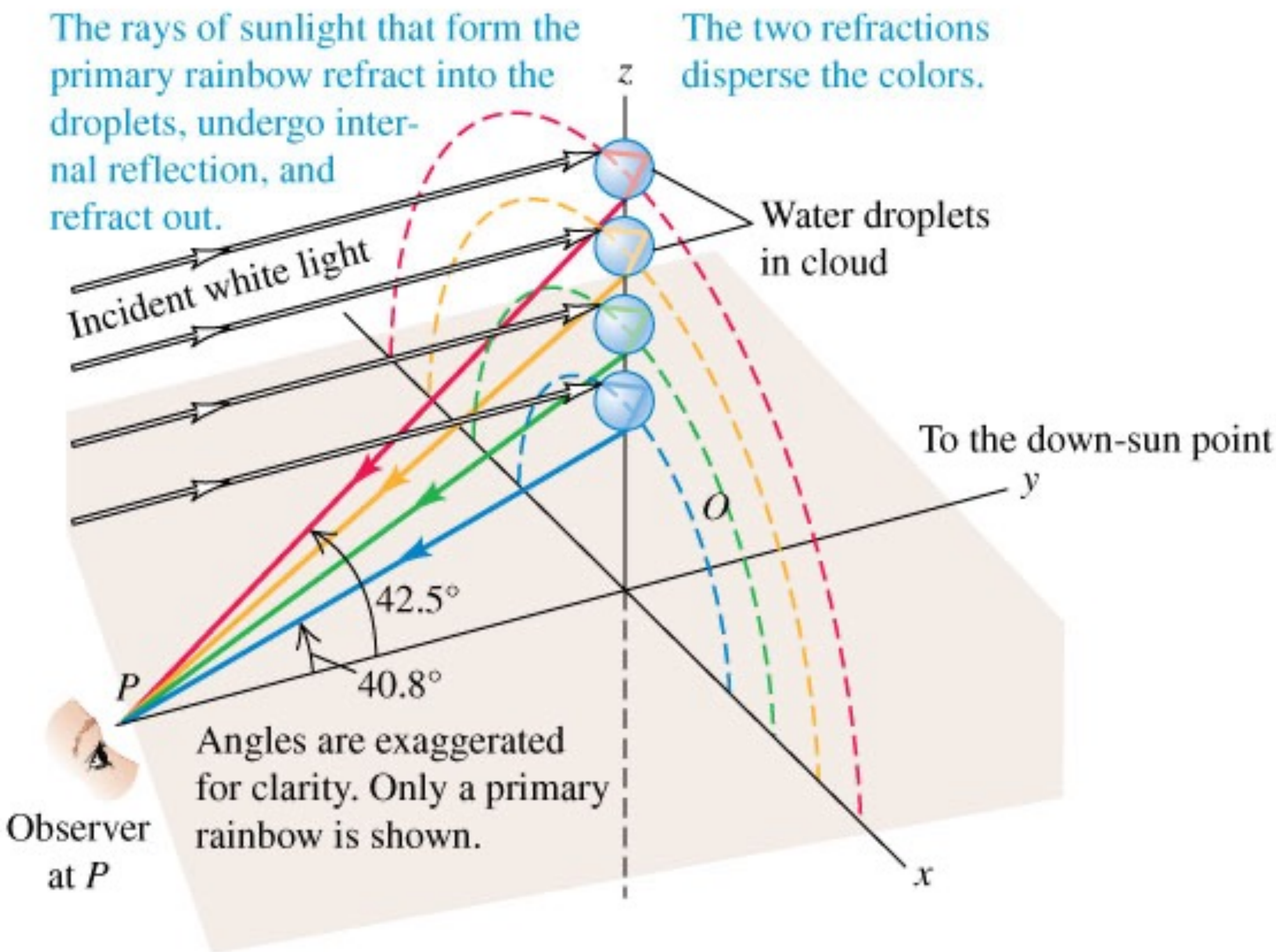

Index of refraction (n)
1.7
1.6
1.5
1.4
Silicate flint glass
Borate flint glass
Quartz
Silicate crown glass
Fused quartz
Fluorite
400
500
600
700
Wavelength in vacuum (nm)
© 2012 Pearson Education, Inc.

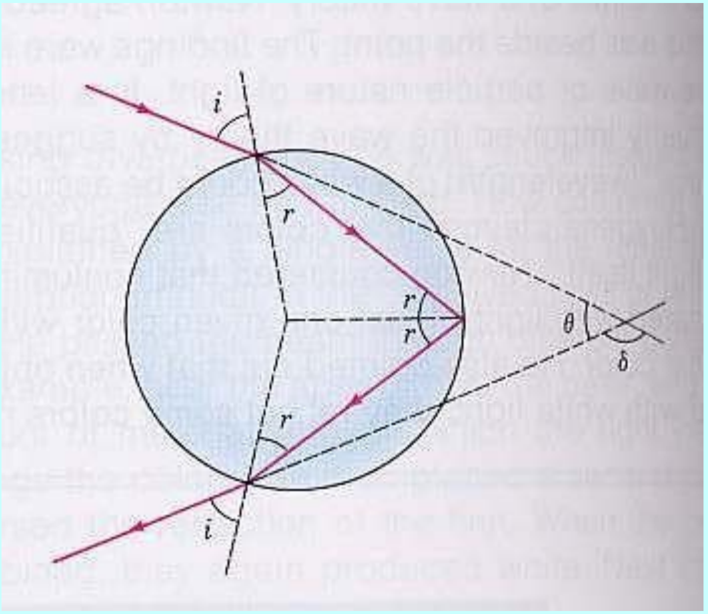
藍光較慢



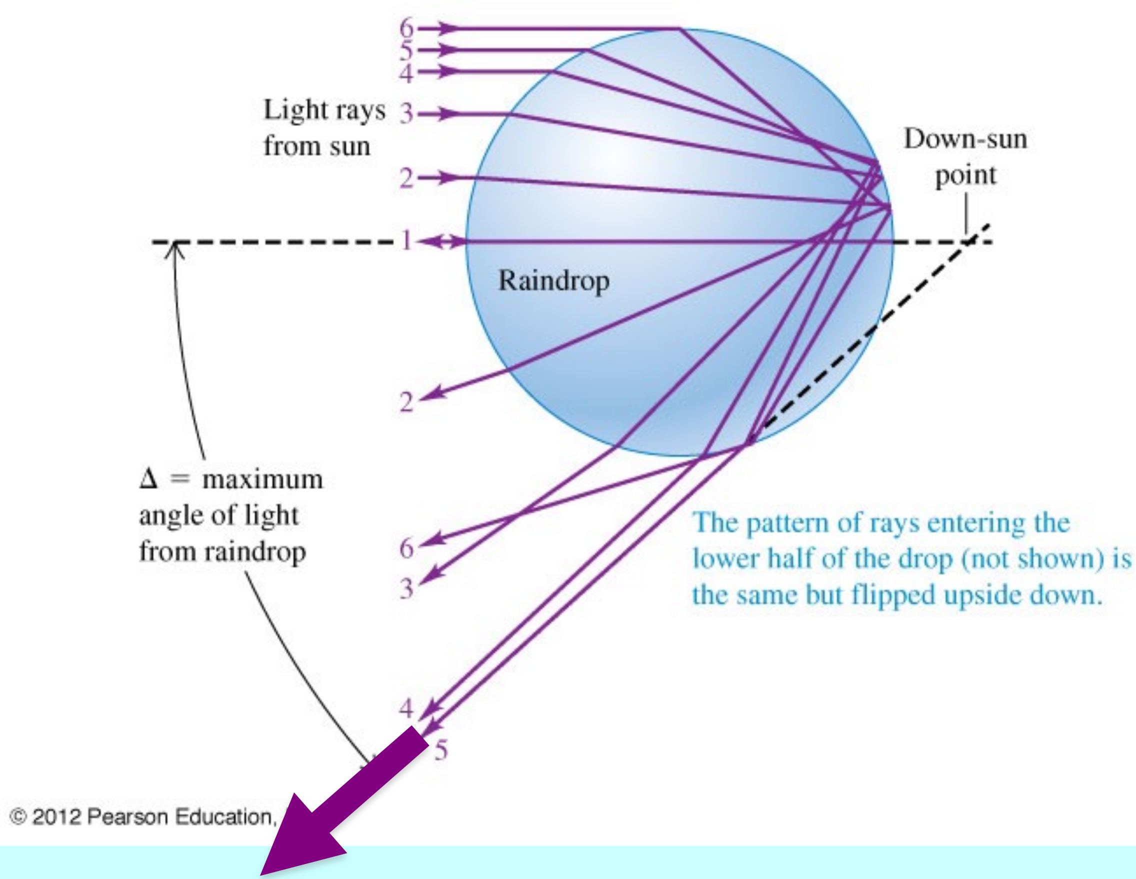

White
light
(b)

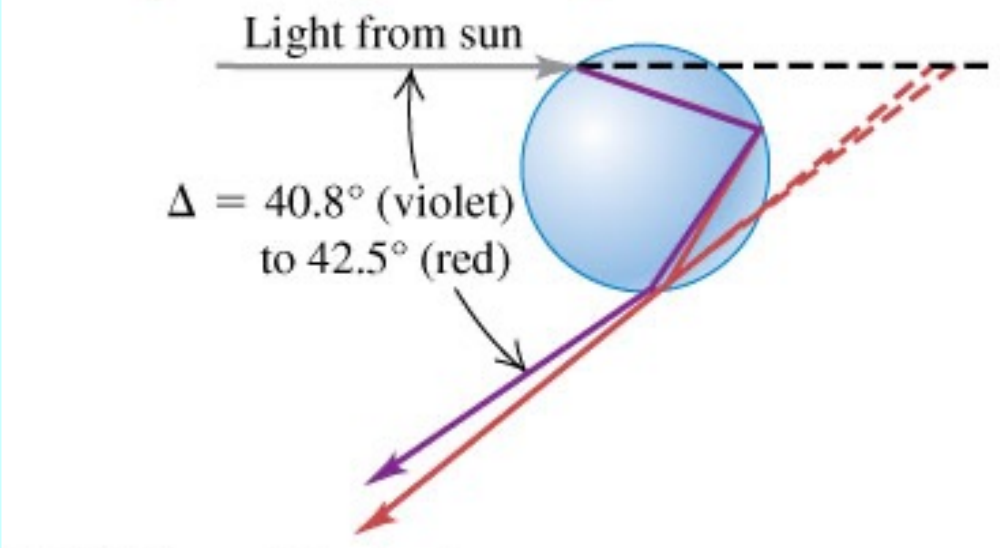
(c) Forming a rainbow. The sun in this illustration is directly behind the observer at P.



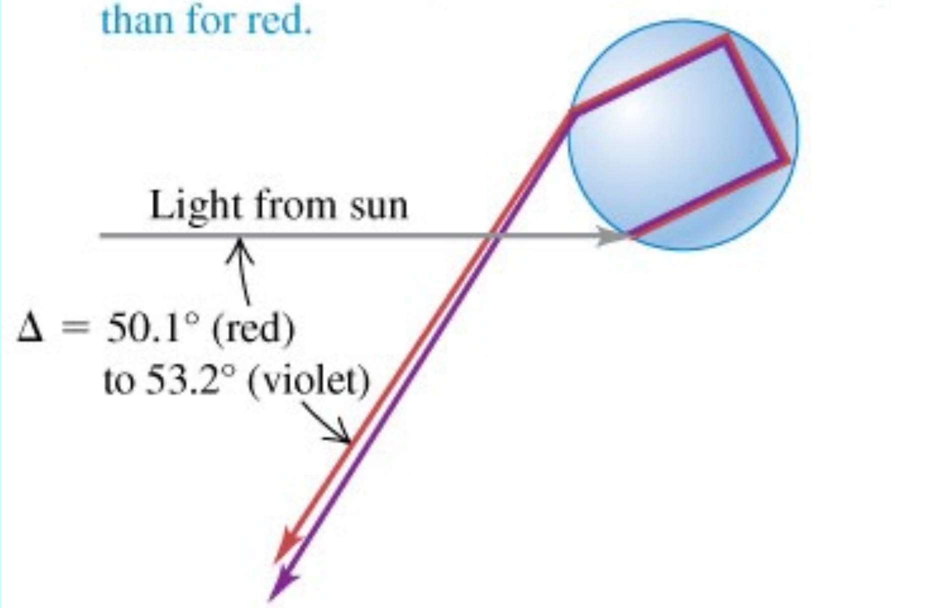


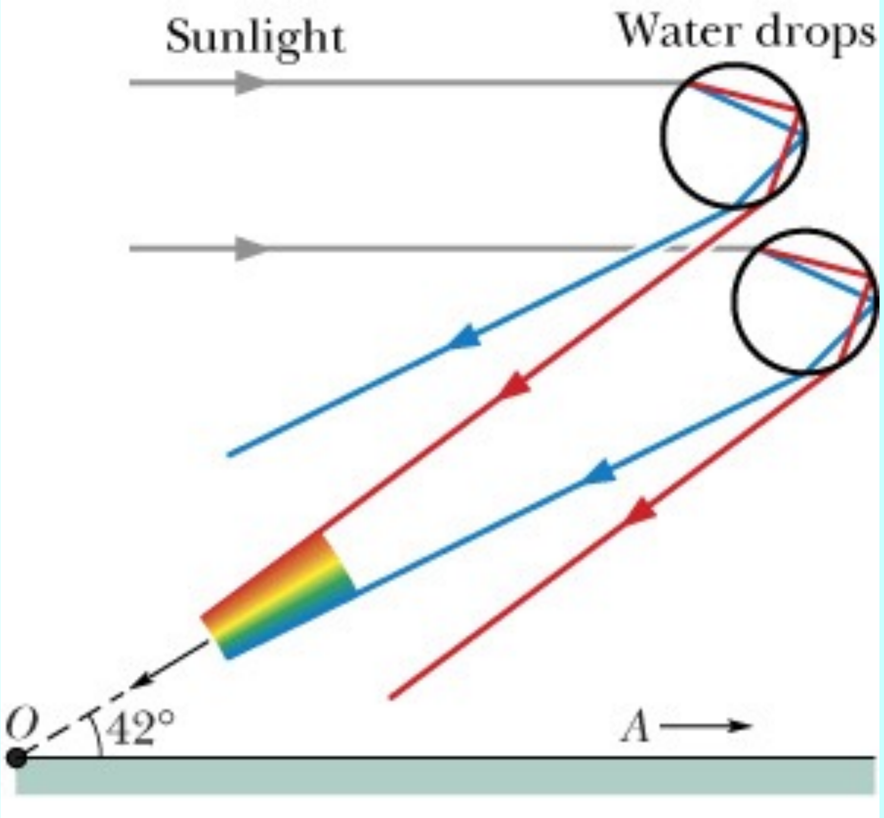
(b) The paths of light rays entering the upper half of a raindrop



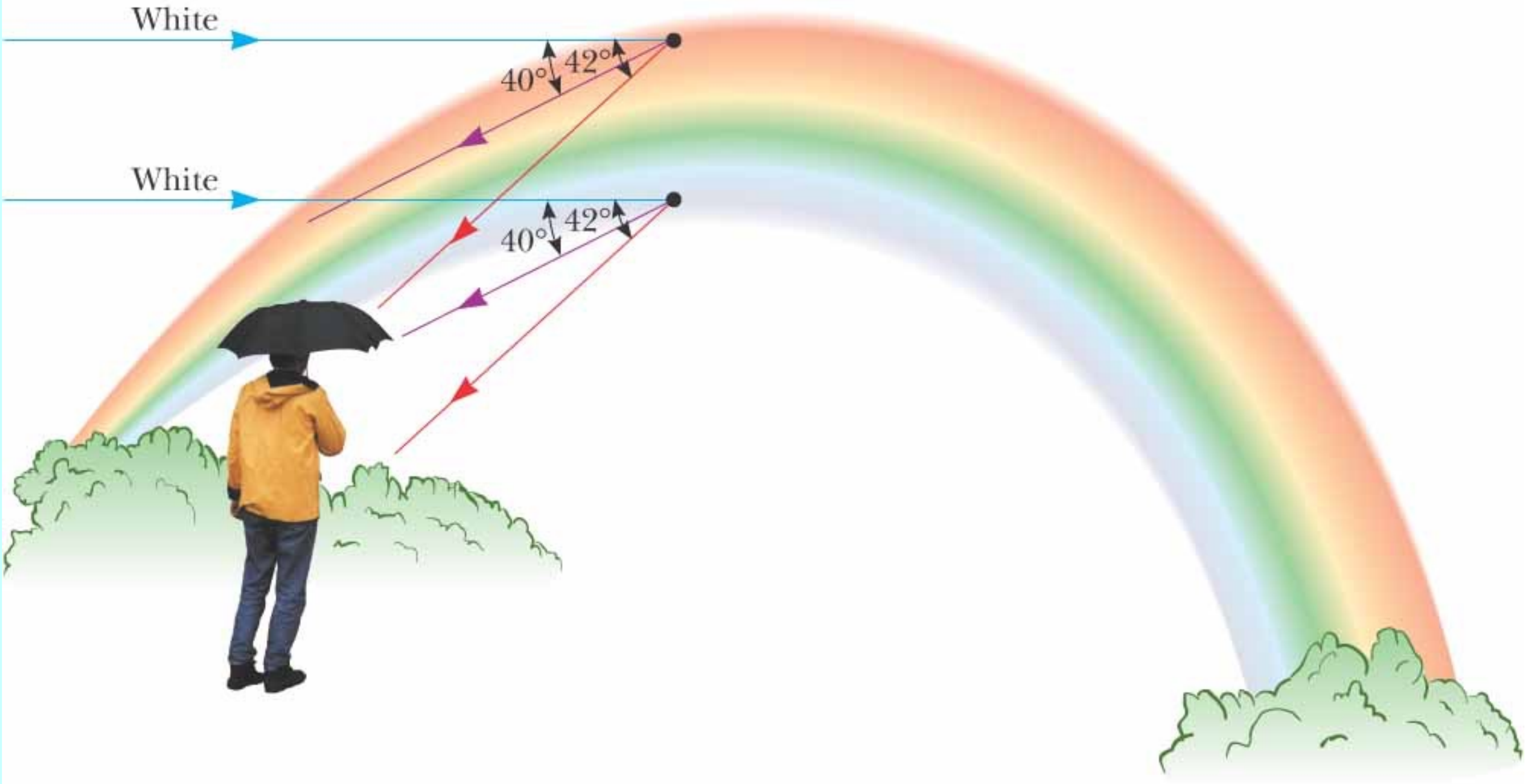


(e) A secondary rainbow is formed by rays that undergo two refractions and *two* internal reflections. The angle Δ is larger for violet light than for red.

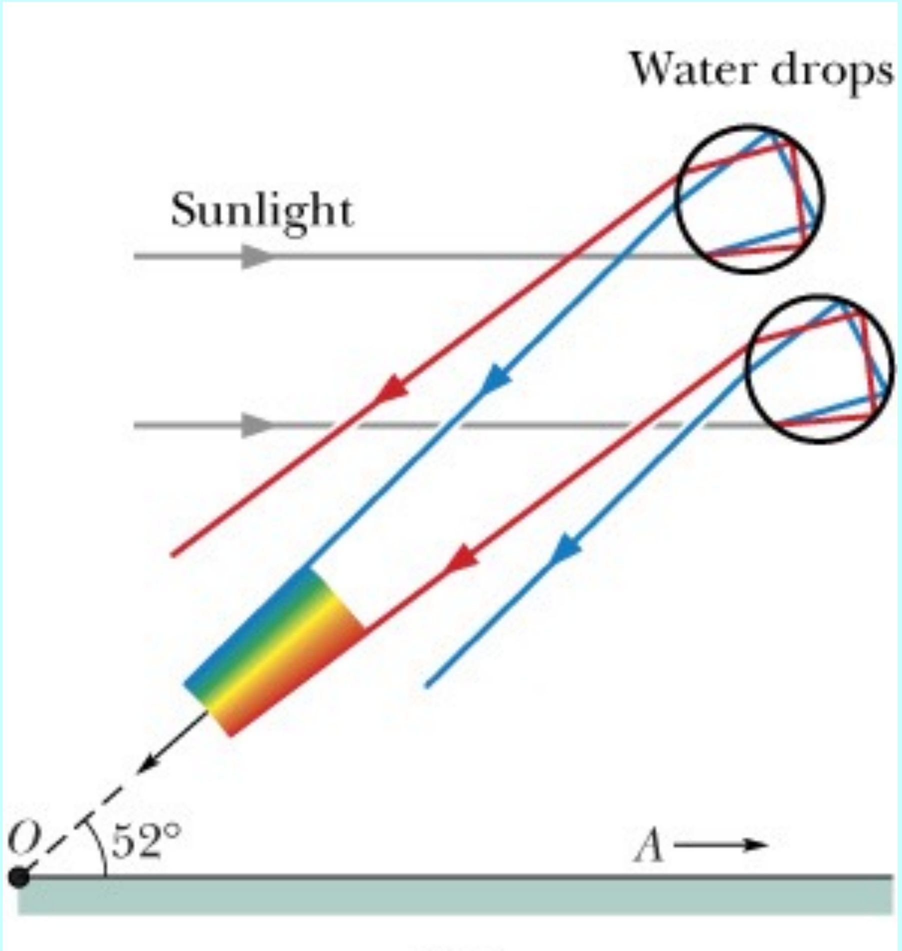




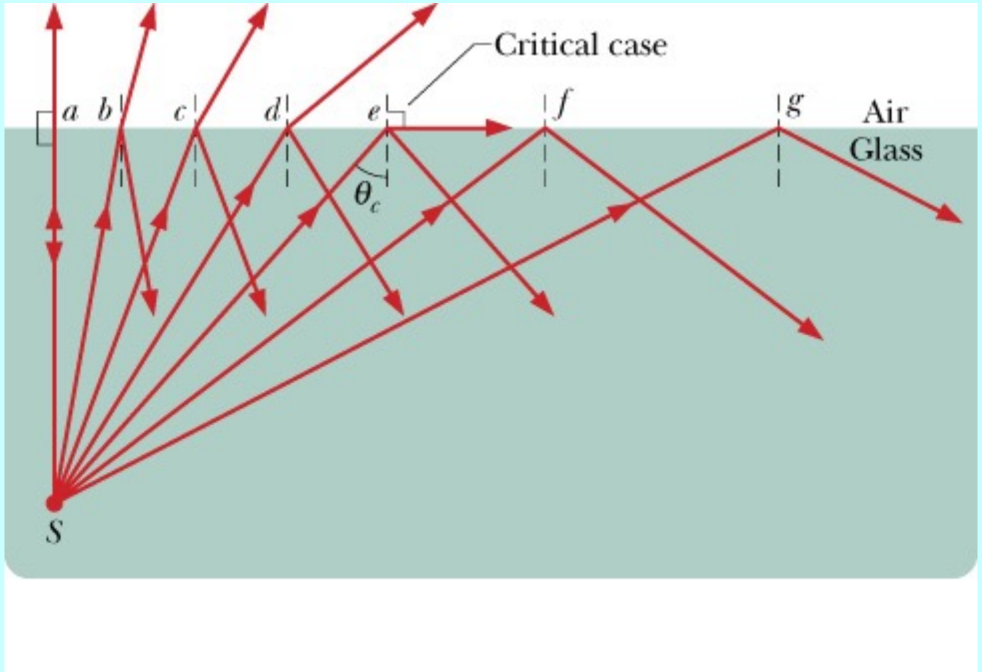
(a)


White
40°
42°
White
40°
42°

Secondary Rainbow

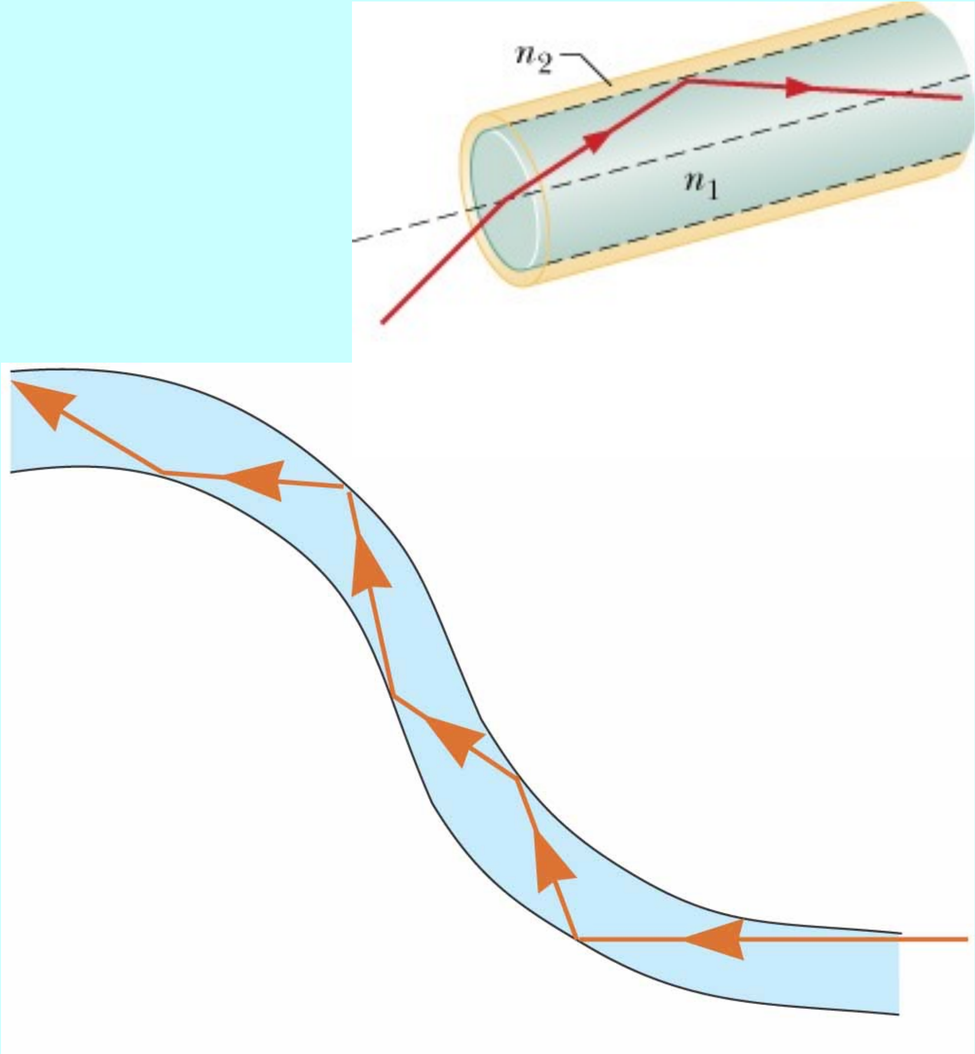


Total Internal Reflection 全反射



$$n_1 \sin\theta_c = n_2 \sin 90^\circ$$

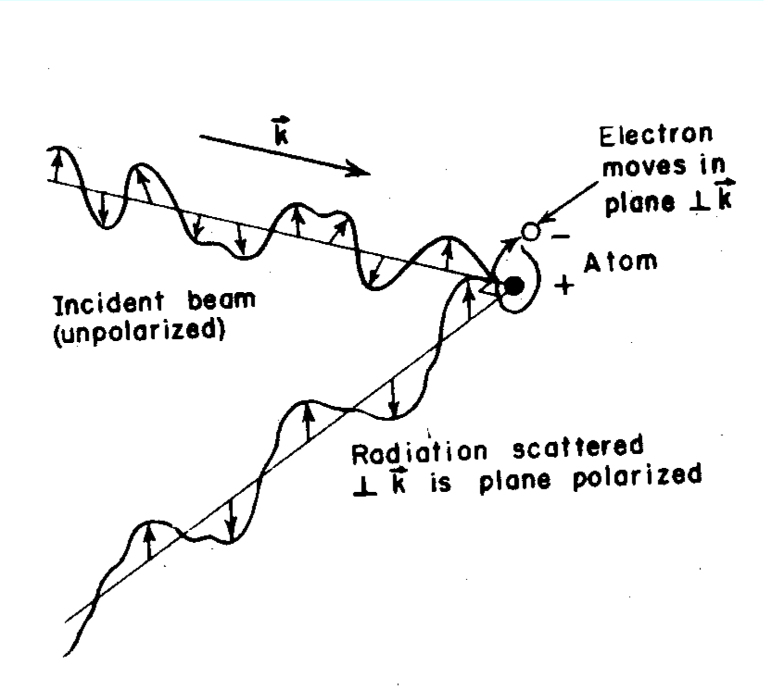
$$\theta_c = \sin^{-1}\frac{n_2}{n_1}$$

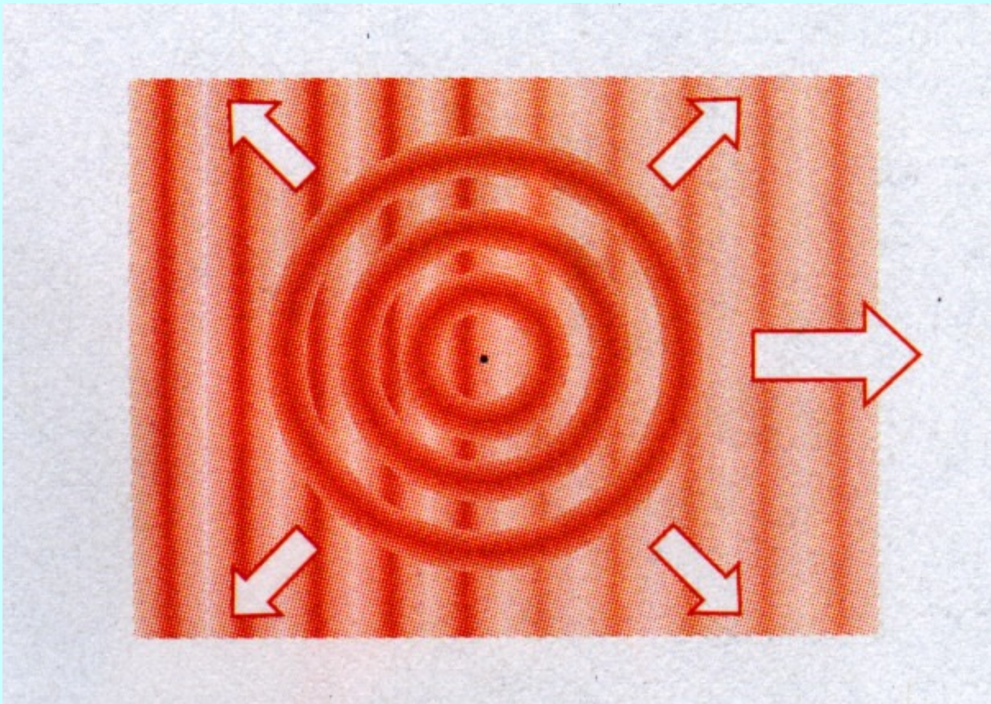

n_2
n_1

物理光學

當觀察的儀器及尺度大約是光波波長

Scattering 散射





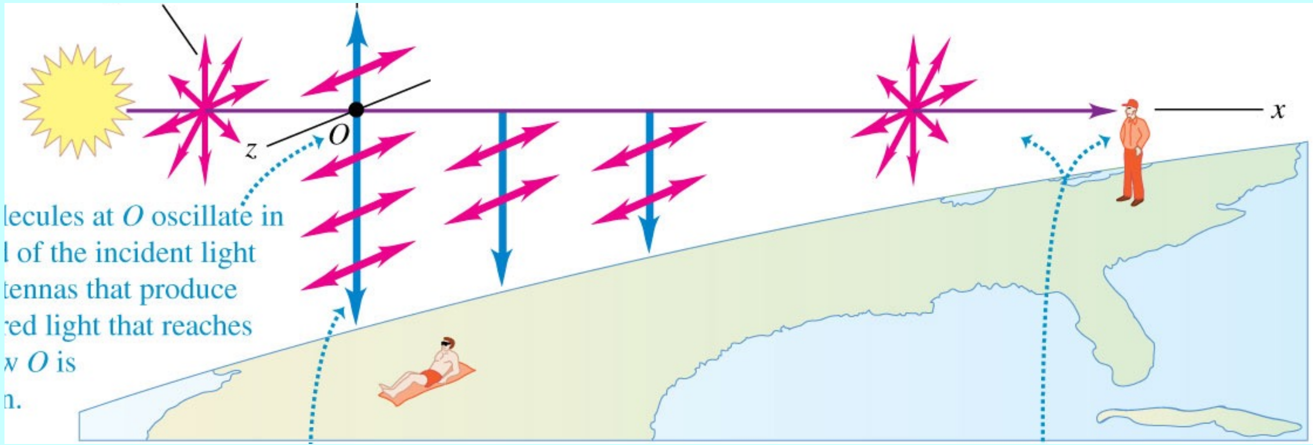
入射的電磁波，帶動雜質分子振盪，震盪的分子發出球狀電磁波。

入射的有定向的平面電磁波，被散射為球狀波。

雜質會使透明介質變模糊

Rayleigh Scattering

因為陽光被大氣層中的粒子散射，天空才有顏色！

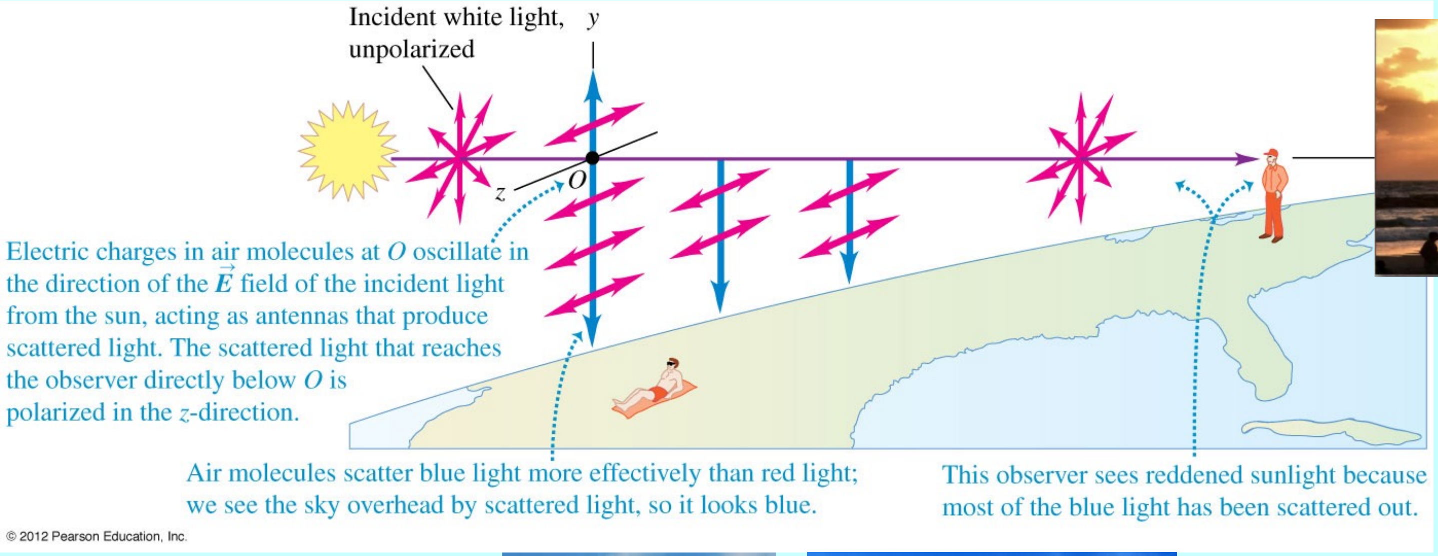


天空的顏色是來自太陽光被大氣層分子散射的結果

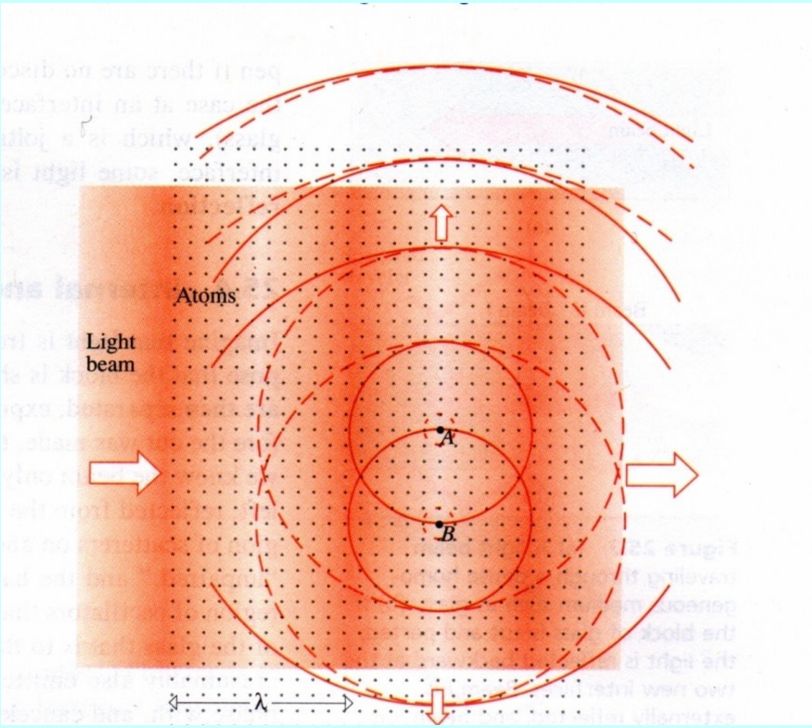
因此不是正對太陽也有陽光散射進入觀察者的眼睛。

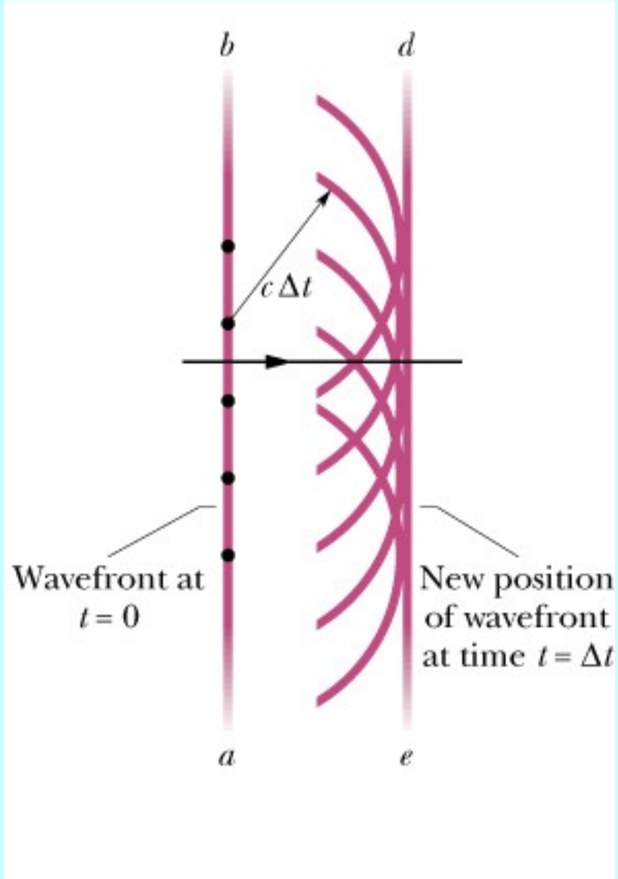
$$I_{\text{scatter}} \propto f^4$$ Rayleigh Scattering

藍光頻率高，散射較多。

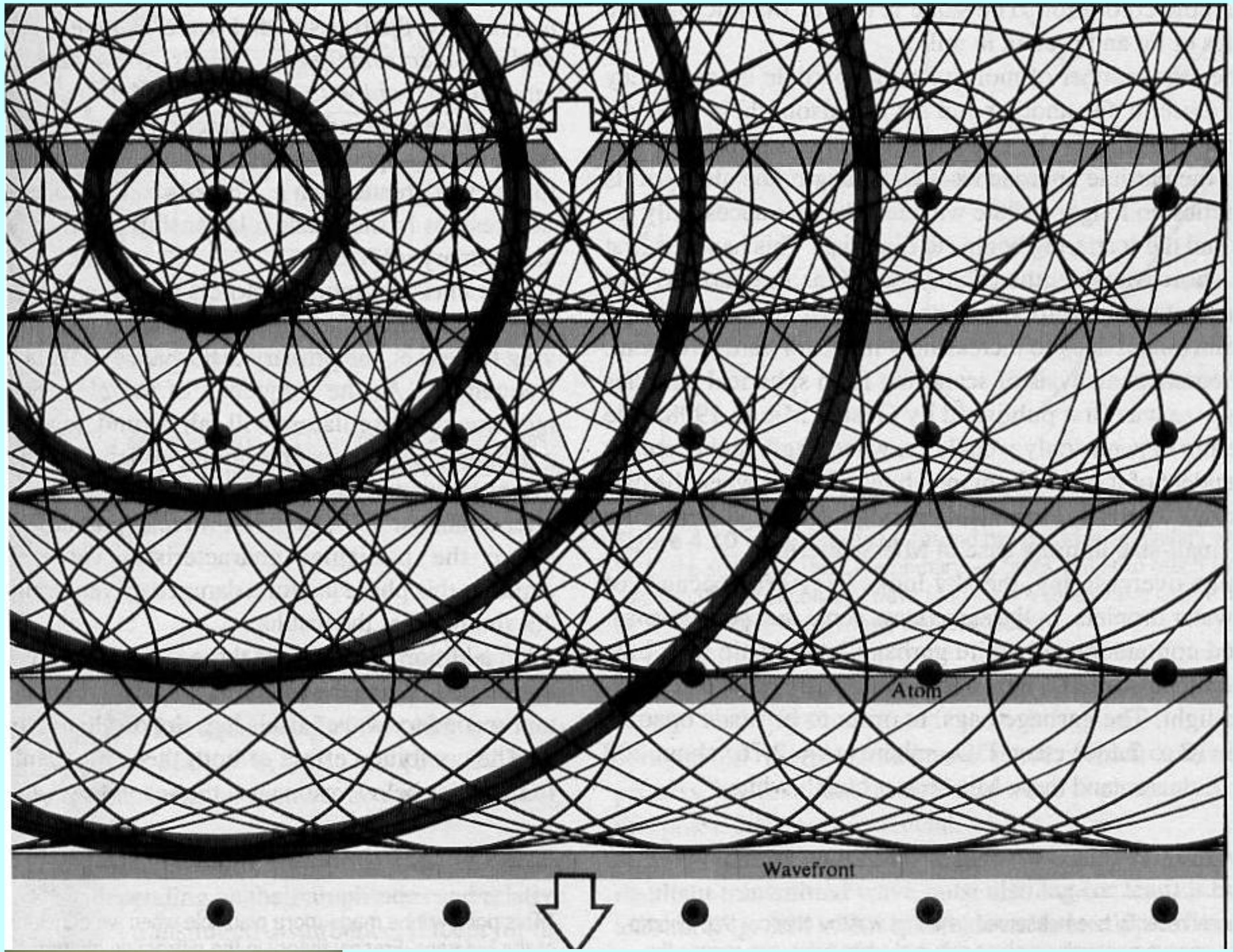


散射粒子極稠密時，側方散射會抵消





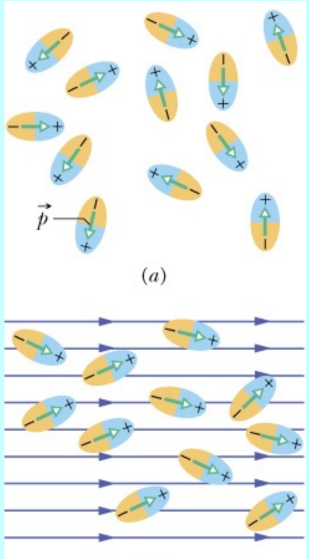
均勻的球面波疊加後形成平面波


Atom
Wavefront

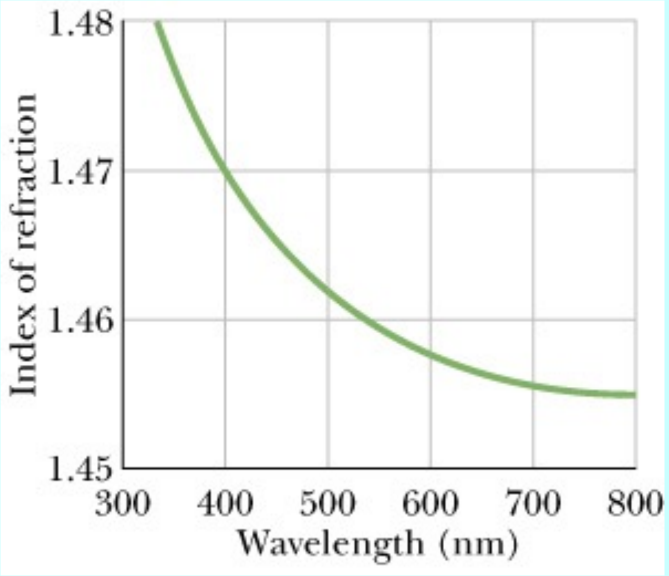
對均勻的介質

$$\varepsilon_0 \rightarrow \varepsilon(f) \qquad \mu_0 \rightarrow \mu(f)$$

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \rightarrow \frac{1}{\sqrt{\varepsilon\mu}} = v(f) = \frac{c}{n(f)}$$



除了光速的變化，光在介質中的性質與在真空中大致一樣，以直線行進。

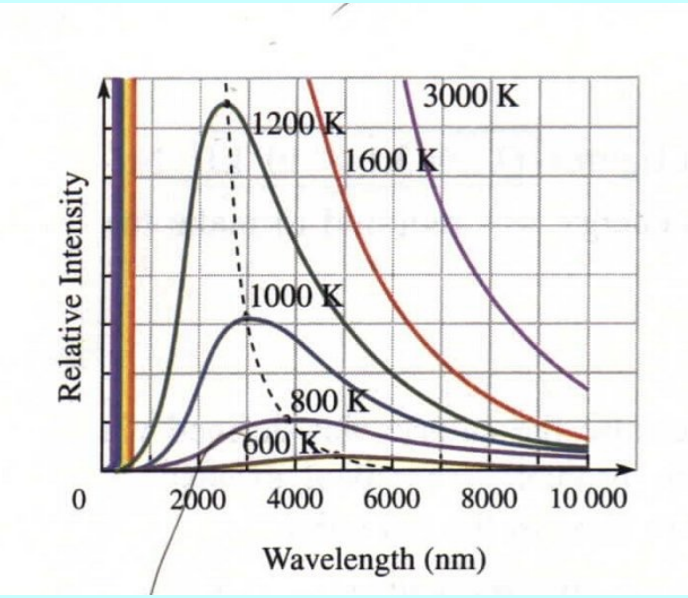


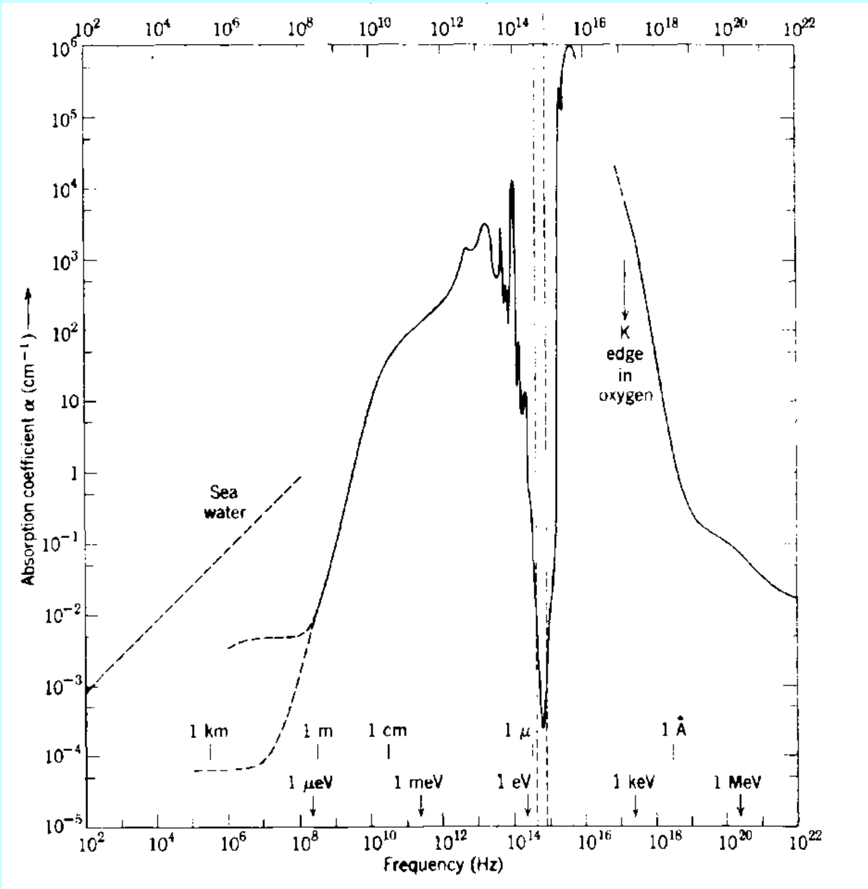
吸收 Absorption

電磁波的場對介質的分子施力，所吸收的能量，除了散射外，亦可轉化為熱。

如此電磁波的能量就被物質所吸收。

吸收率與頻率的關係大致與黑體輻射相近

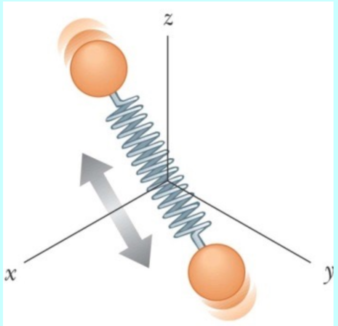


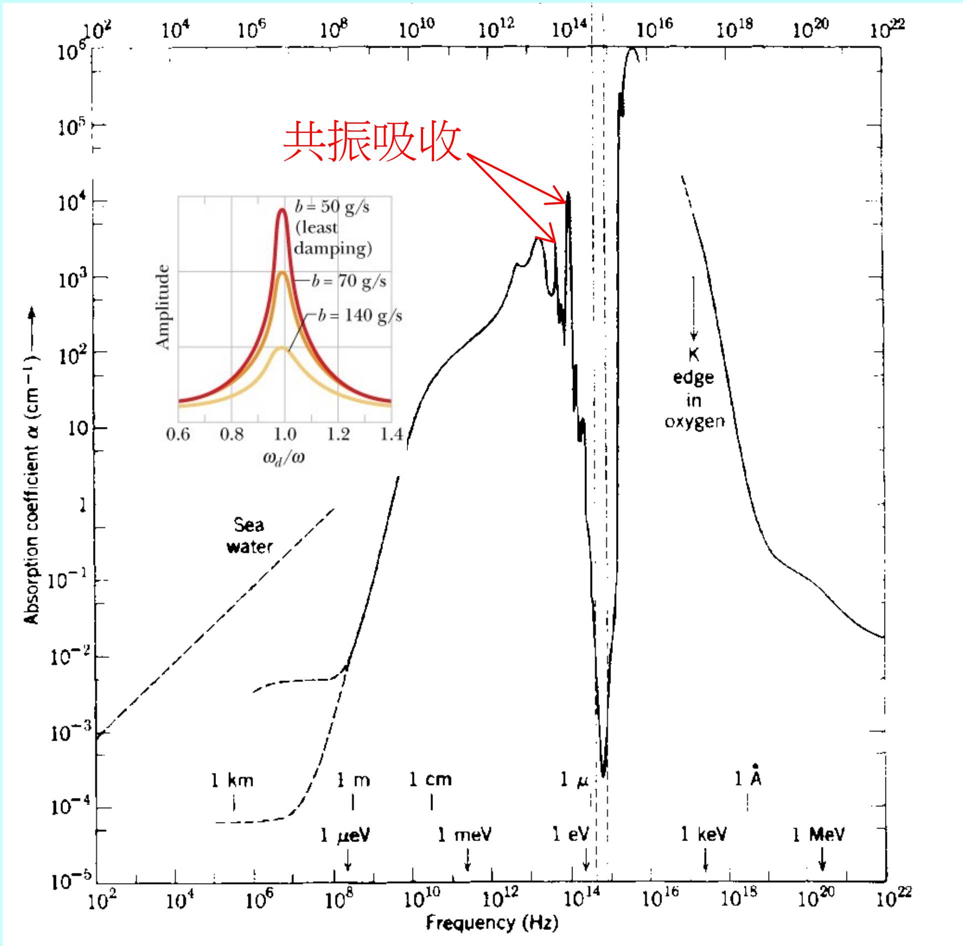


共振吸收：如果波的頻率與內部震盪體的自然頻率接近，

就會形成共振，而大量吸收波的能量，轉化為熱。

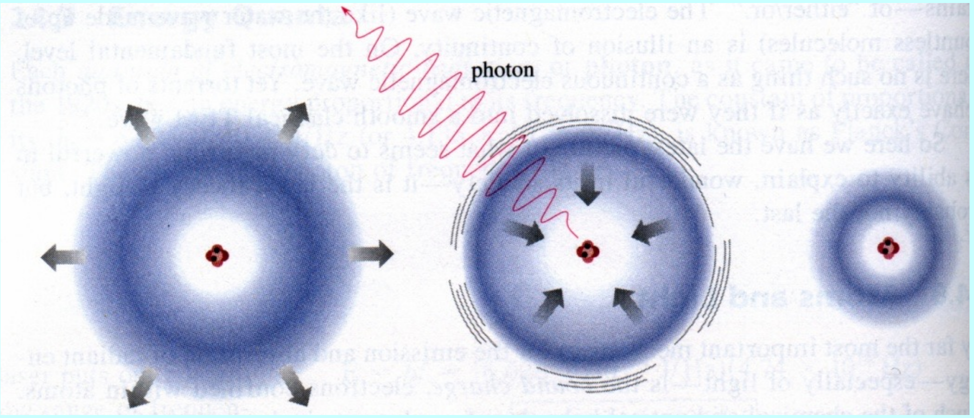
例如紅外線可以被分子內原子的震盪吸收。





可見光的共振吸收就決定了介質的顏色

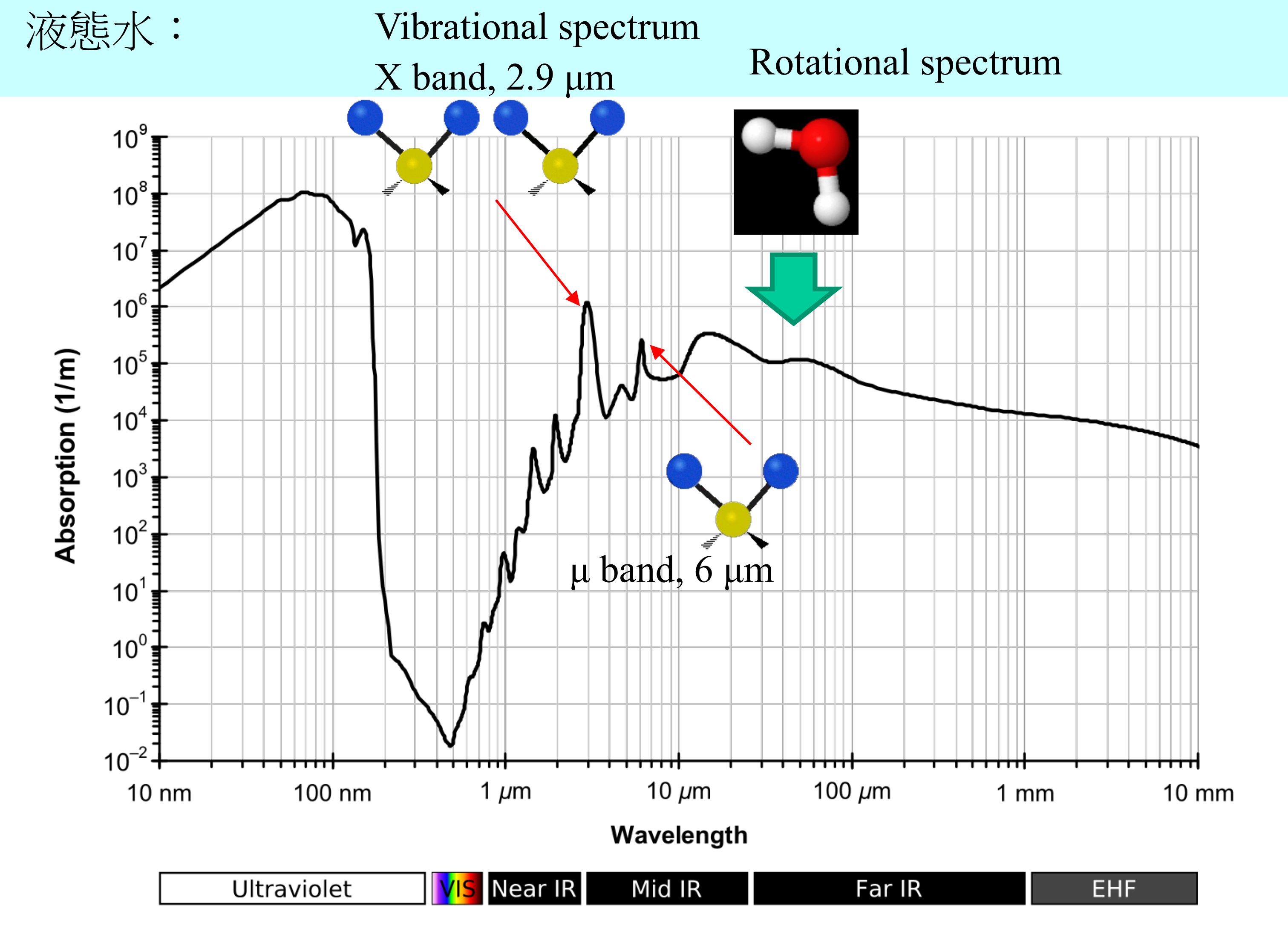
可見光頻率一般對應的是原子內電子的能階。



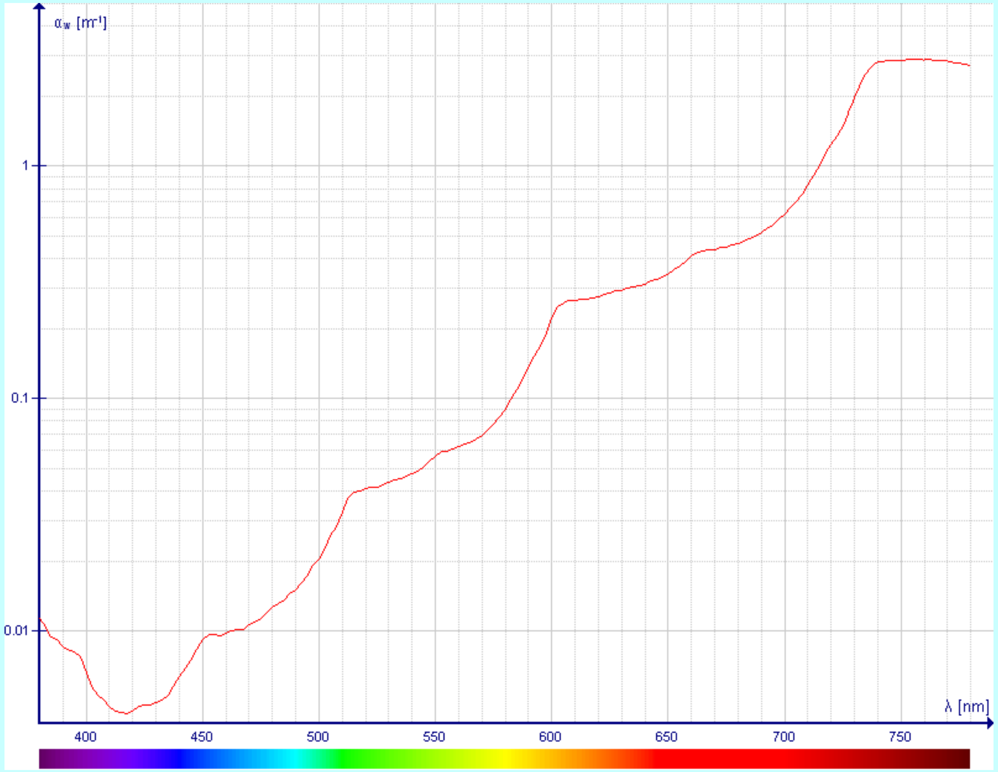
例如紅色的蘋果即因果皮中的色素吸收了藍綠色光

Electromagnetic absorption by water

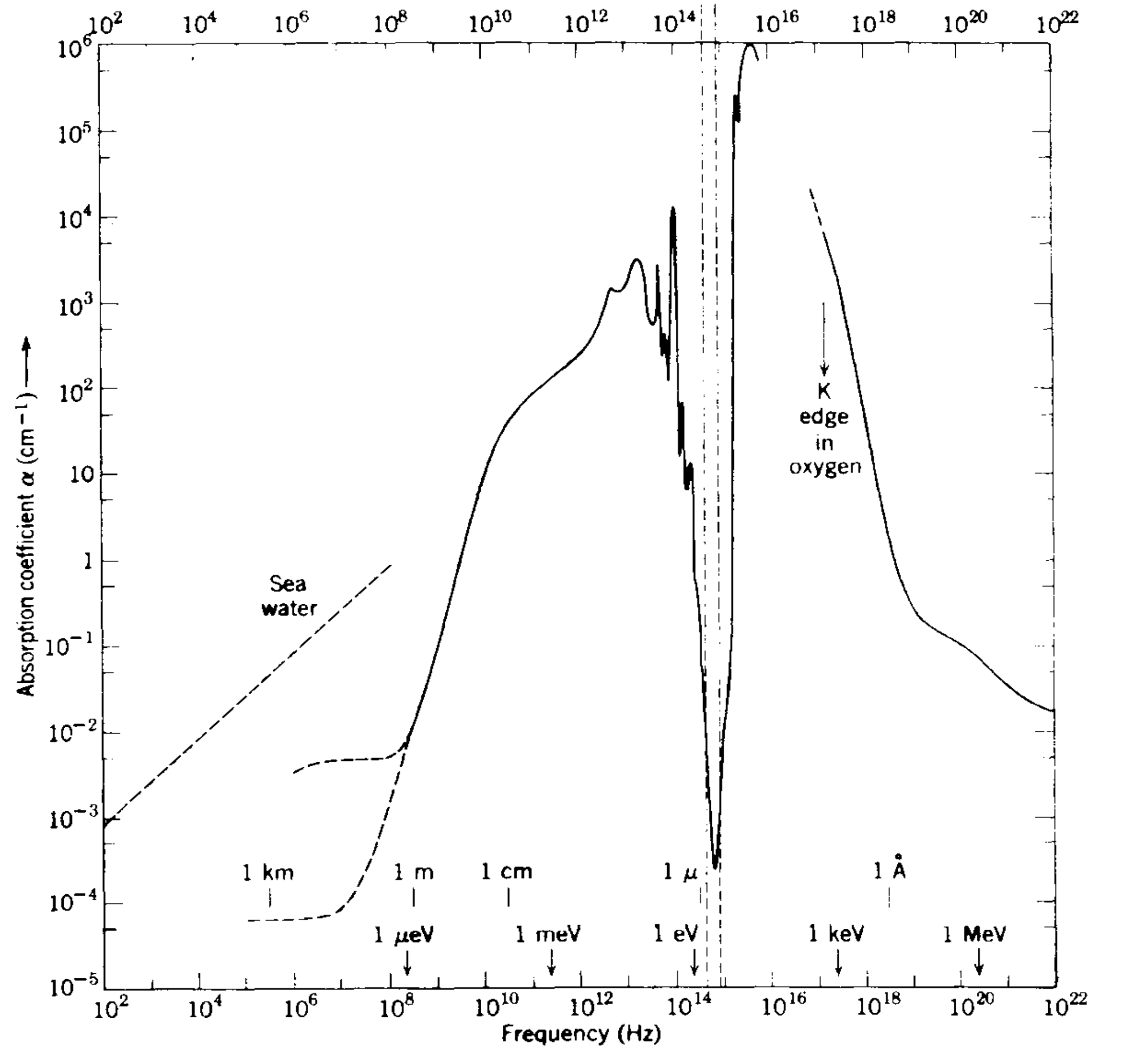
液態水：



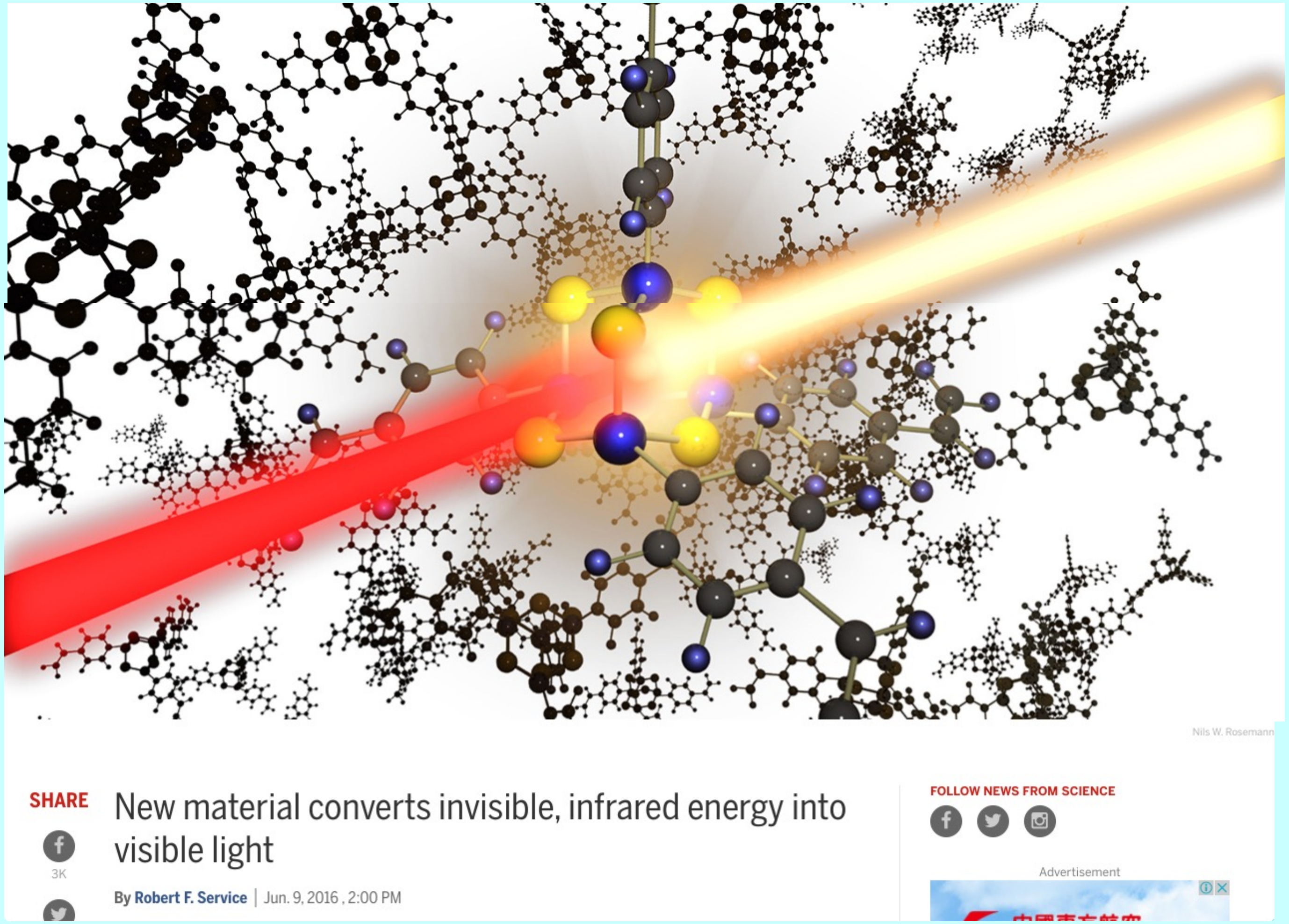
Liquid water absorption spectrum



水吸收較多紅色光，因此顯得藍綠色。



Absorption coefficient α (cm⁻¹)
Frequency (Hz)
Sea water
K edge in oxygen
1 km
1 m
1 cm
1 μ
1 Å
1 μeV
1 meV
1 eV
1 keV
1 MeV



有些介質可以改變光的頻率！

OPTICAL MATERIALS

A highly efficient directional molecular white-light emitter driven by a continuous-wave laser diode

Nils W. Rosemann,[1,2] Jens P. Eußner,[2,3] Andreas Beyer,[1,2] Stephan W. Koch,[1,2] Kerstin Volz,[1,2] Stefanie Dehnen,[2,3]* Sangam Chatterjee[1,2,4]*

Tailored light sources have greatly advanced technological and scientific progress by optimizing the emission spectrum or color and the emission characteristics. We demonstrate an efficient spectrally broadband and highly directional warm-white-light emitter based on a nonlinear process driven by a cheap, low-power continuous-wave infrared laser diode. The nonlinear medium is a specially designed amorphous material composed of symmetry-free, diamondoid-like cluster molecules that are readily obtained from ubiquitous resources. The visible part of the spectrum resembles the color of a tungsten-halogen lamp at 2900 kelvin while retaining the superior beam divergence of the driving laser. This approach of functionalizing energy-efficient state-of-the-art semiconductor lasers enables a technology complementary to light-emitting diodes for replacing incandescent white-light emitters in high-brilliance applications.

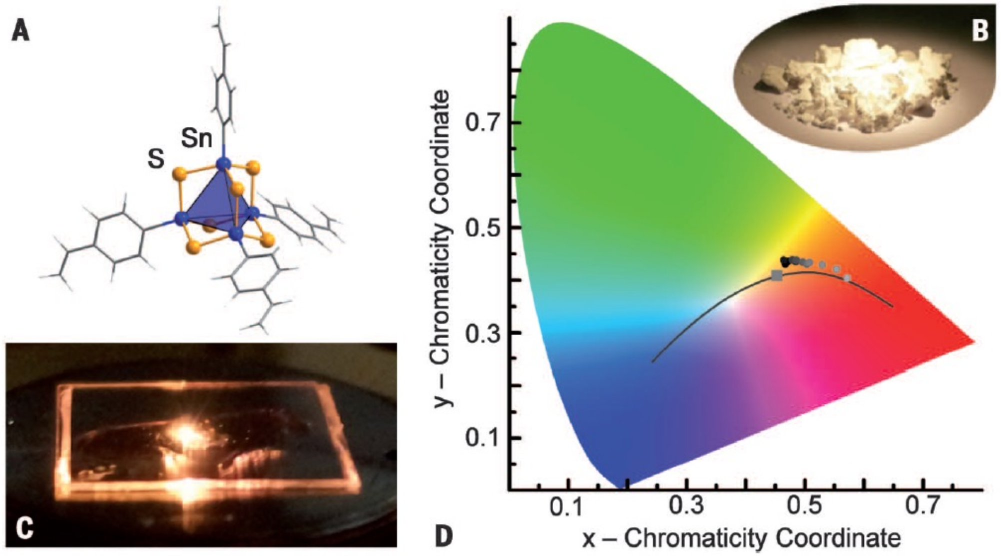


Fig. 1. Molecular structure and appearance as well as color temperatures associated with the emission. (**A**) Adamantane-like cluster $[(R^{deloc}Sn)_4S_6]$ (R^{deloc} = 4–(CH_2=CH)–C_6H_4), with tin and sulfur atoms drawn as blue and yellow spheres, respectively; carbon (gray) and hydrogen (white) atoms are given as wires. (**B**) Photograph of the as-prepared powder. (**C**) Photograph of a polymer film containing the cluster sandwiched between two cover glass slips excited by 800-nm laser light in the bright center spot. (**D**) Color temperatures given for various excitation fluencies, as indicated by individual gray-scale data points. The characteristic ideal black-body emission for various temperatures is indicated by the solid line; the square indicates the color temperature of standard emitter at T = 2856 K.

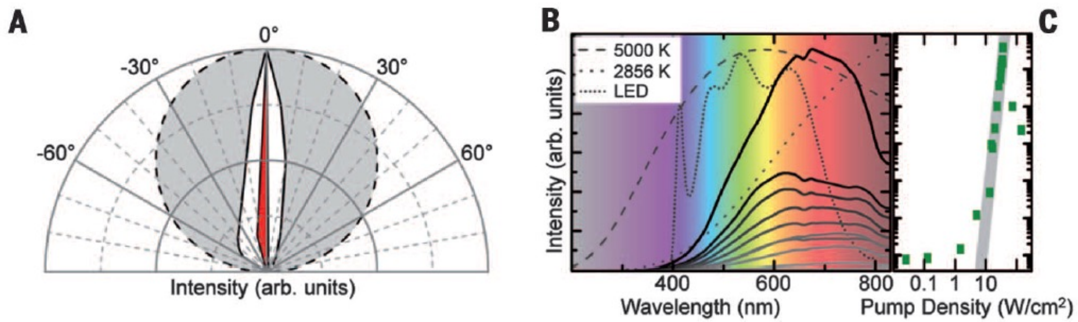
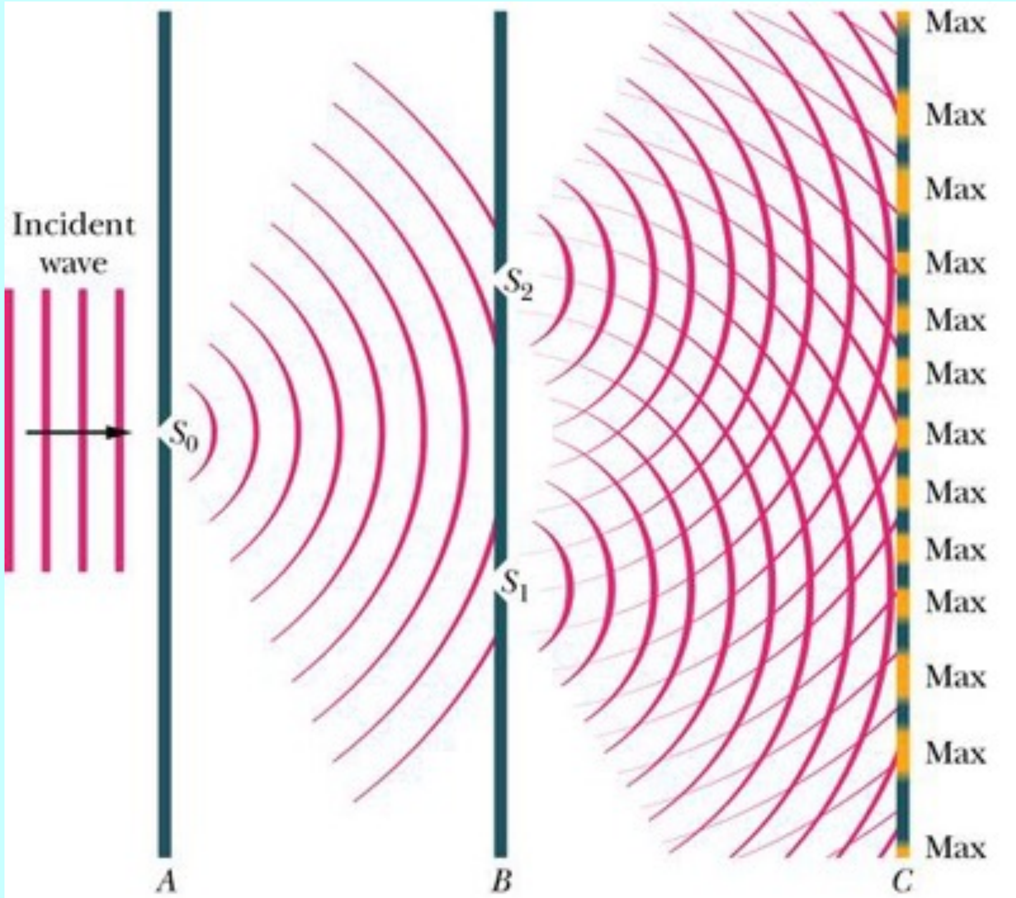
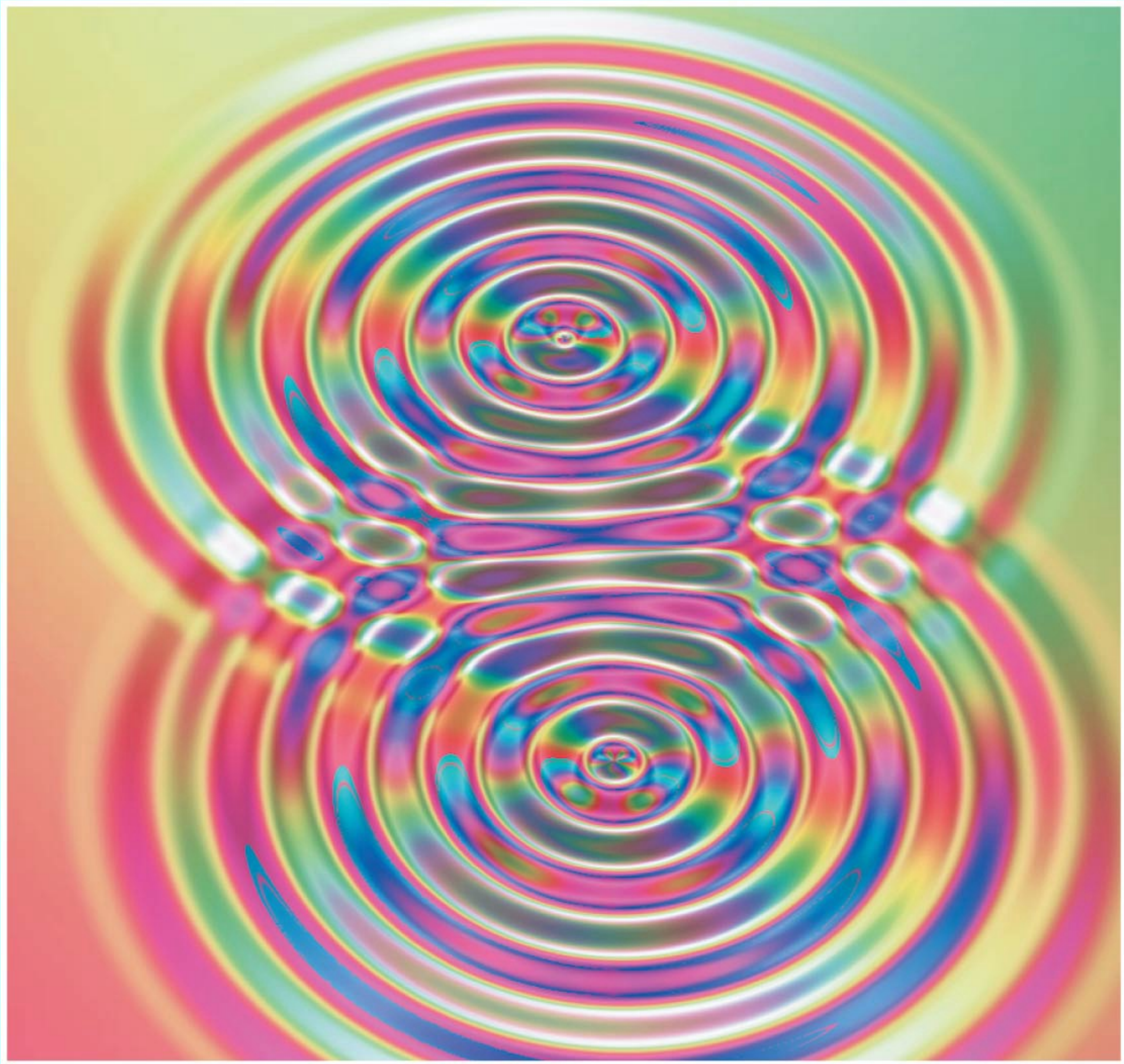
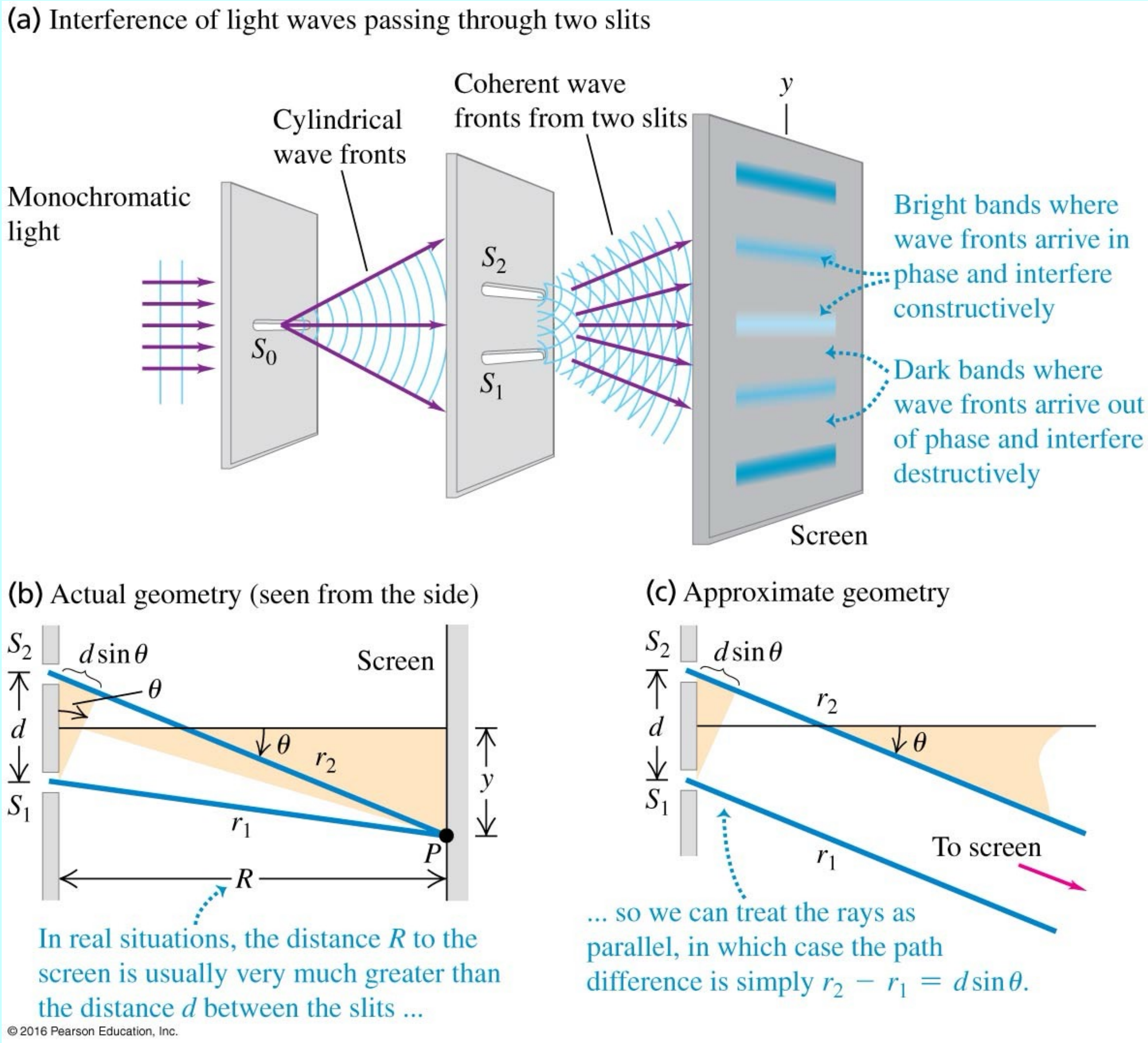


Fig. 2. Emission characteristics. (**A**) Highly directional spatial emission pattern of the white-light spectrum (white) and the CW excitation laser at 980 nm (red). The intensity distribution of a perfect Lambertian emitter (gray) is given for reference. (**B**) White-light spectra for a pump wavelength of 980 nm. The pump power is varied from 6 mW (light gray solid line) to 18 mW (black solid line). The normalized curves for black-body radiation (T = 5000 K, dashed line; T = 2856 K, spaced dots) and a GaN-based white-light LED (narrow dots) are shown for comparison. (**C**) Double-logarithmic plot of the white light input-output characteristics.

Interference 干涉






(a) Interference of light waves passing through two slits
Monochromatic light
Cylindrical wave fronts
Coherent wave fronts from two slits
S_0
S_2
S_1
y
Bright bands where wave fronts arrive in phase and interfere constructively
Dark bands where wave fronts arrive out of phase and interfere destructively
Screen
(b) Actual geometry (seen from the side)
S_2
$d \sin\theta$
θ
d
S_1
Screen
θ
r_2
r_1
y
P
R
In real situations, the distance R to the screen is usually very much greater than the distance d between the slits ...
(c) Approximate geometry
S_2
$d \sin\theta$
r_2
d
θ
S_1
r_1
To screen
... so we can treat the rays as parallel, in which case the path difference is simply $r_2 - r_1 = d \sin\theta$.
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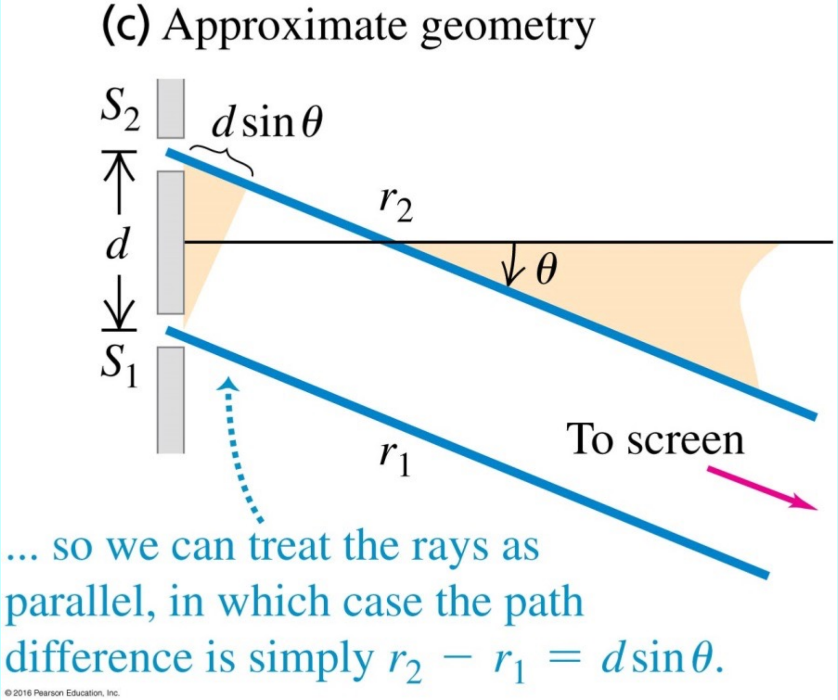
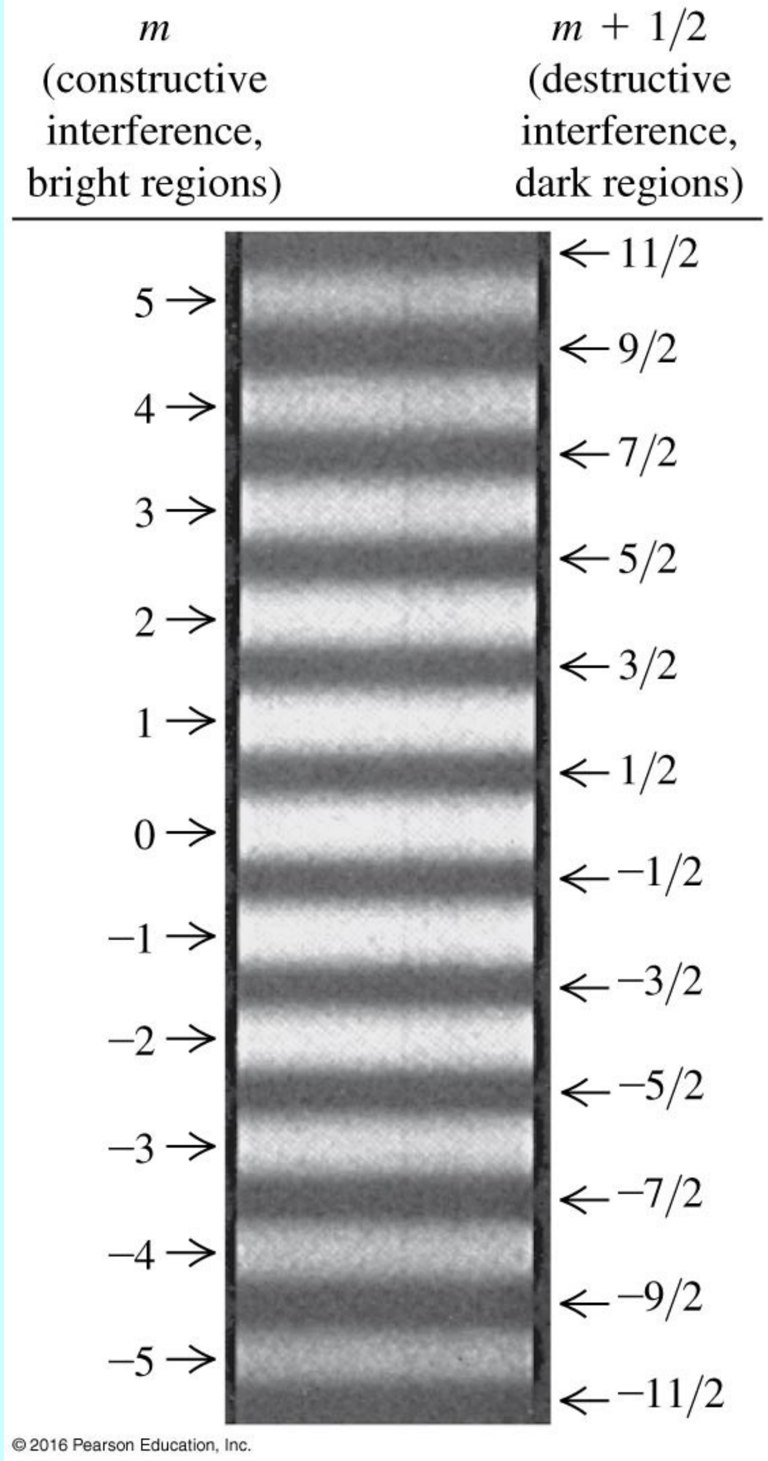


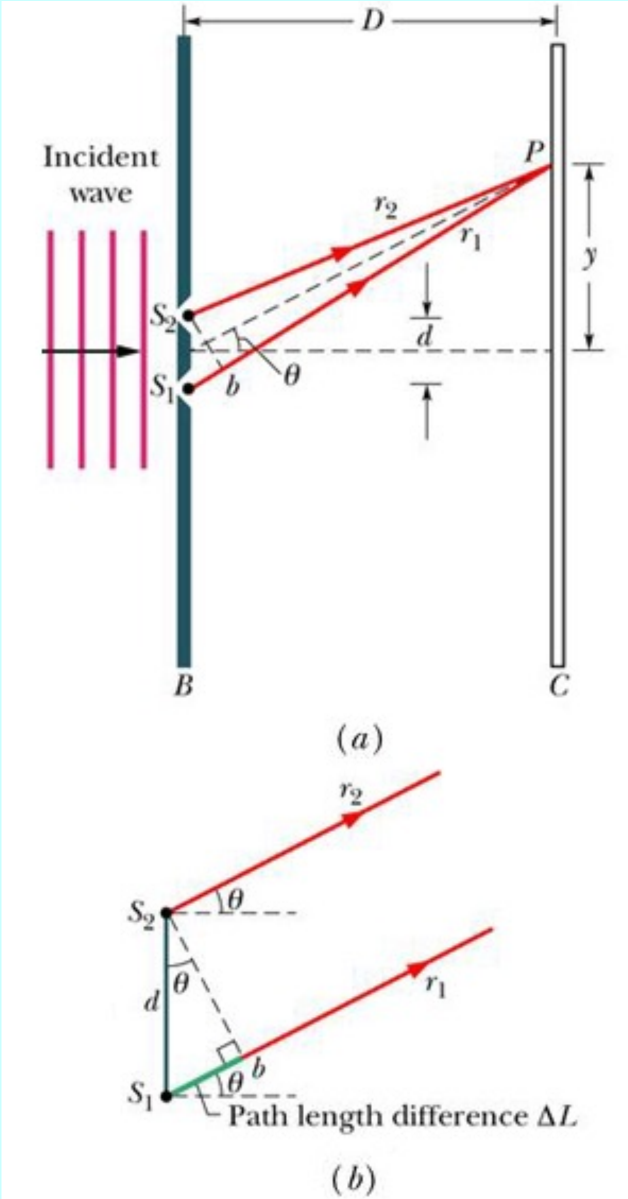
亮紋

$$d \sin\theta = m\lambda$$

暗紋

$$d \sin\theta = \left(m + \frac{1}{2}\right)\lambda$$



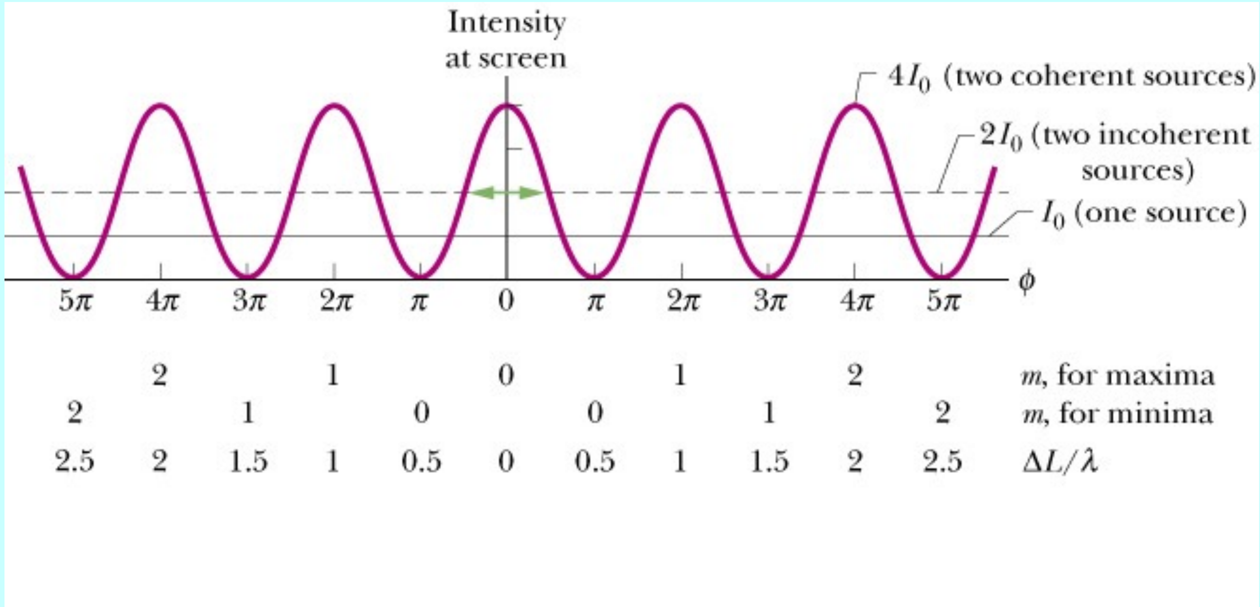


亮紋

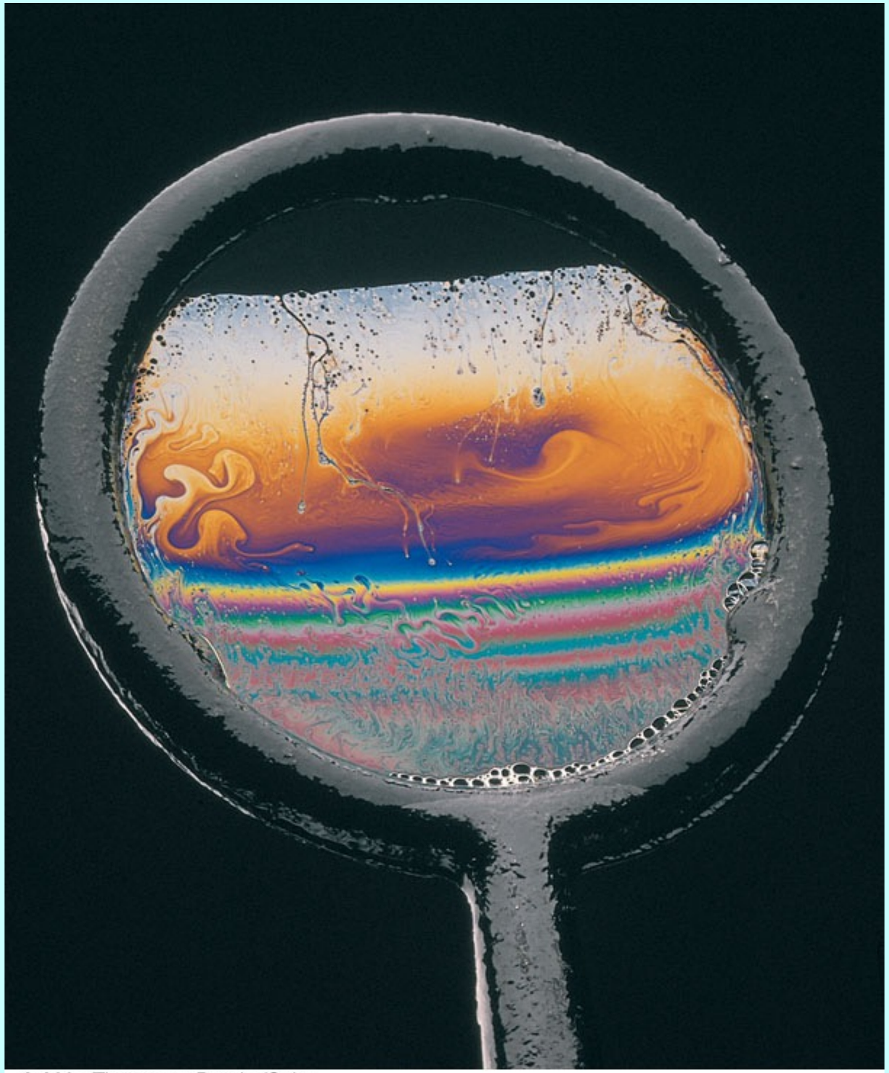
$$d \sin\theta = m\lambda$$

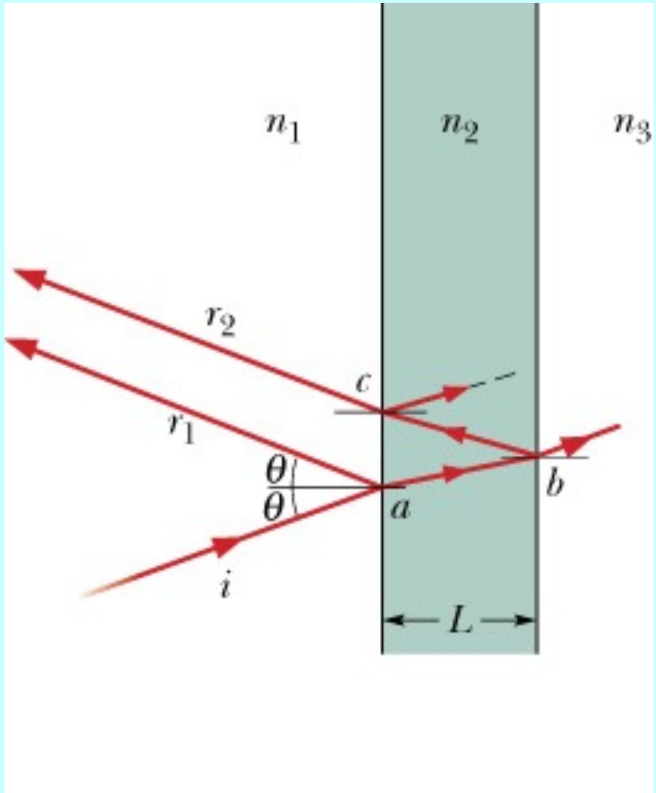
暗紋

$$d \sin\theta = \left(m + \frac{1}{2}\right)\lambda$$

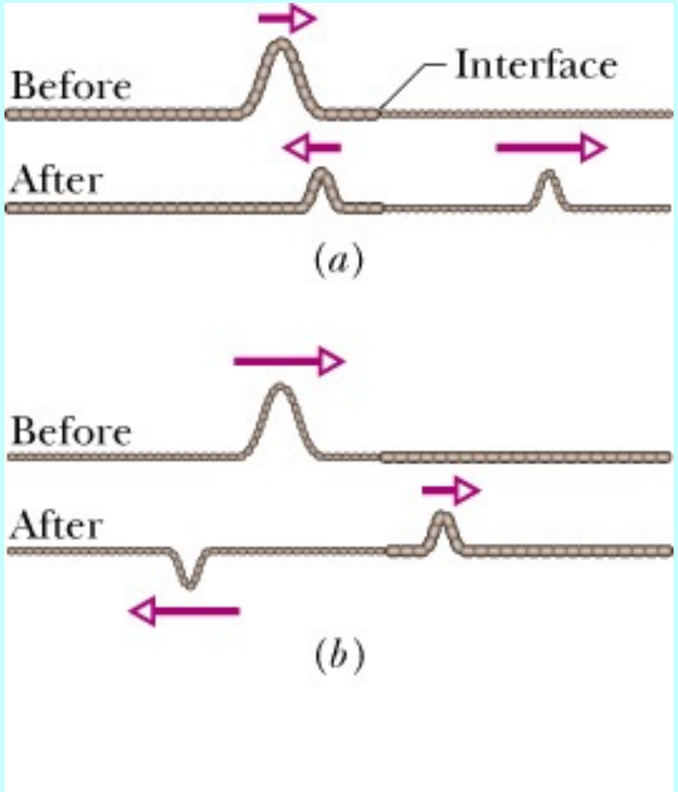

Intensity
at screen
$4I_0$ (two coherent sources)
$2I_0$ (two incoherent sources)
I_0 (one source)
ϕ
5π 4π 3π 2π π 0 π 2π 3π 4π 5π
2 1 0 1 2 m, for maxima
2 1 0 0 1 2 m, for minima
2.5 2 1.5 1 0.5 0 0.5 1 1.5 2 2.5 $\Delta L/\lambda$

薄膜干涉

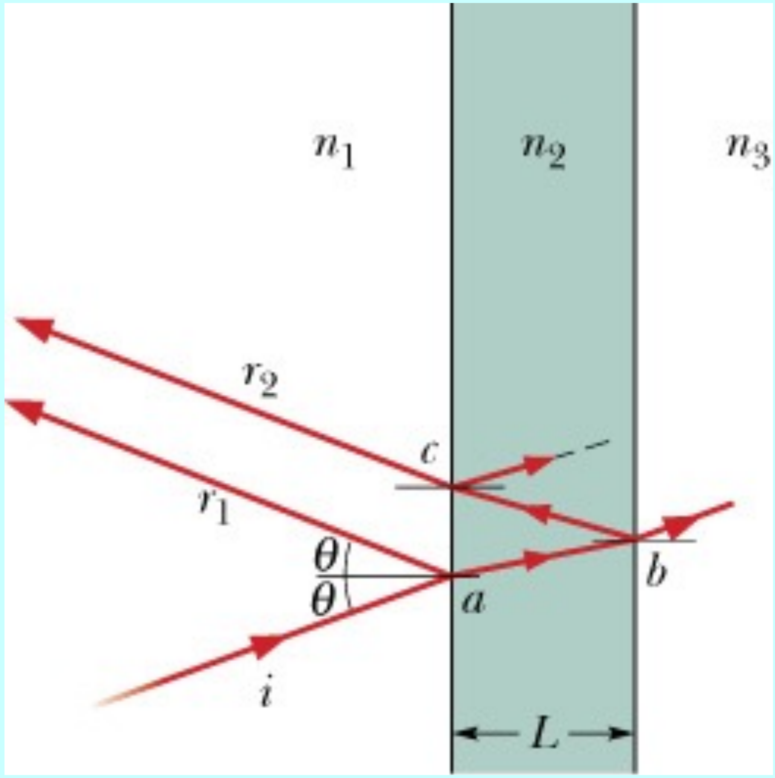




n_1
n_2
n_3
r_2
r_1
c
θ
θ
a
b
i
L



Before
Interface
After
(a)
Before
After
(b)

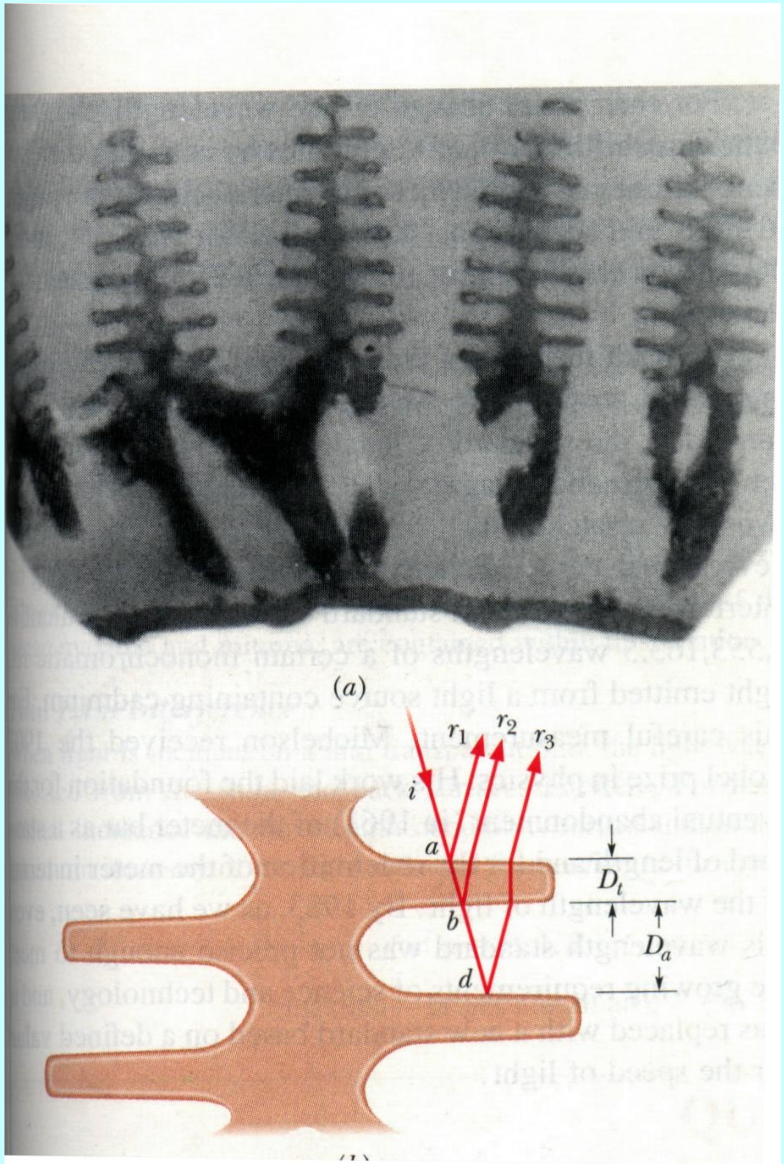


亮紋

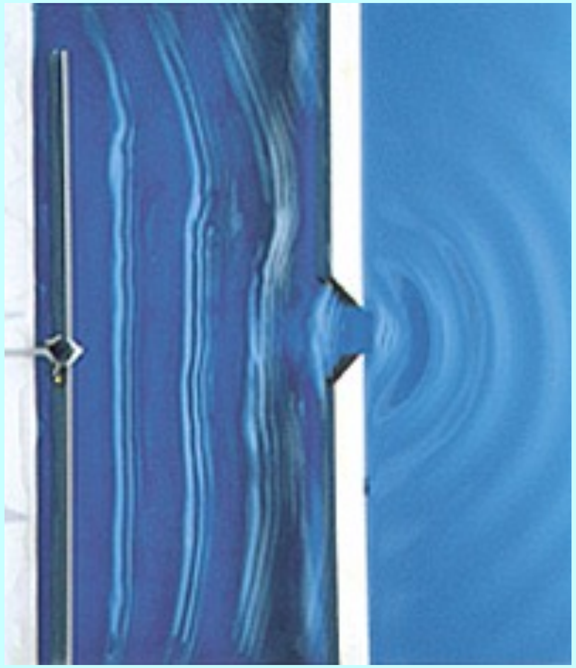
$$2L = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_2}$$

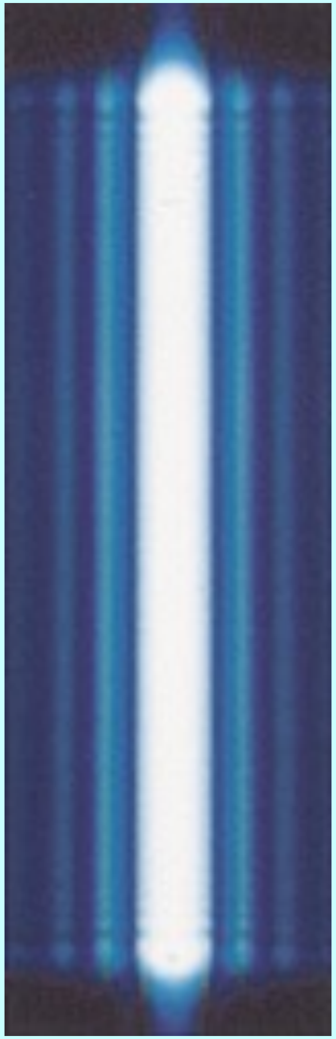
暗紋

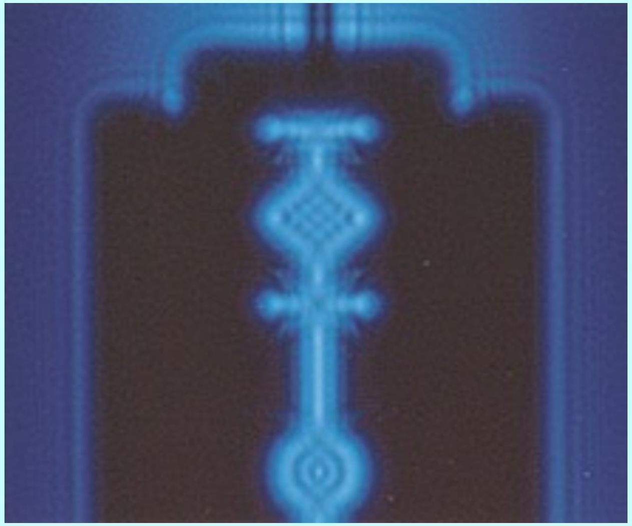
$$2L = (m)\frac{\lambda}{n_2}$$

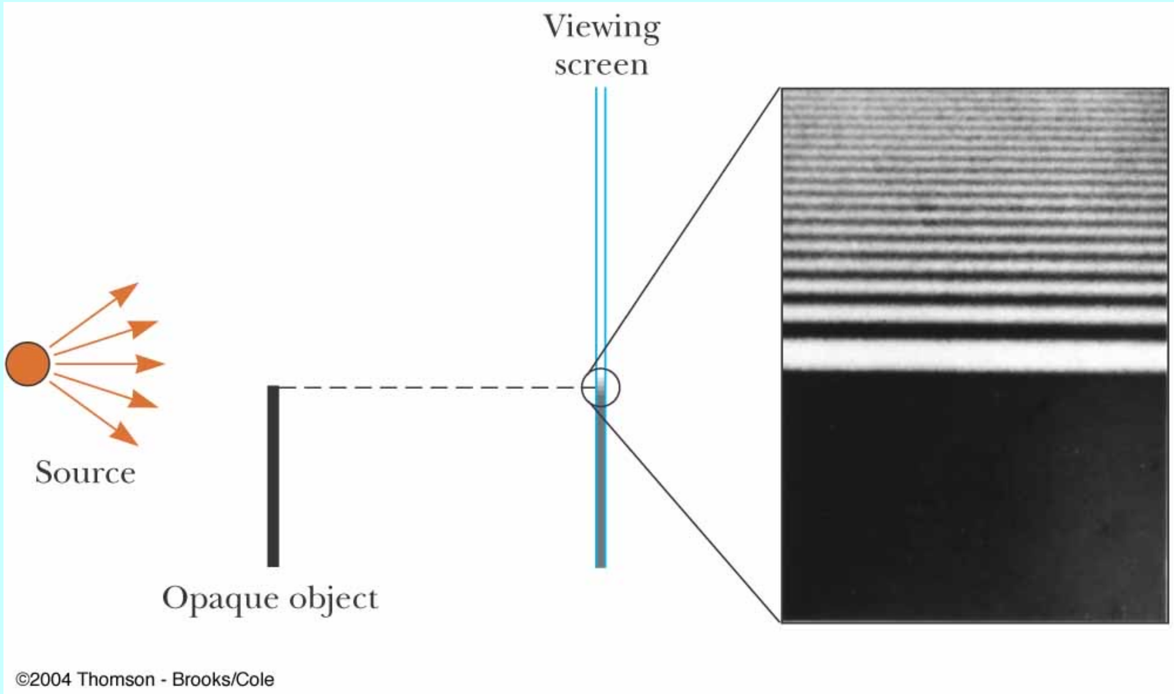

(a)
i
r1
r2
r3
a
b
d
Dt
Da

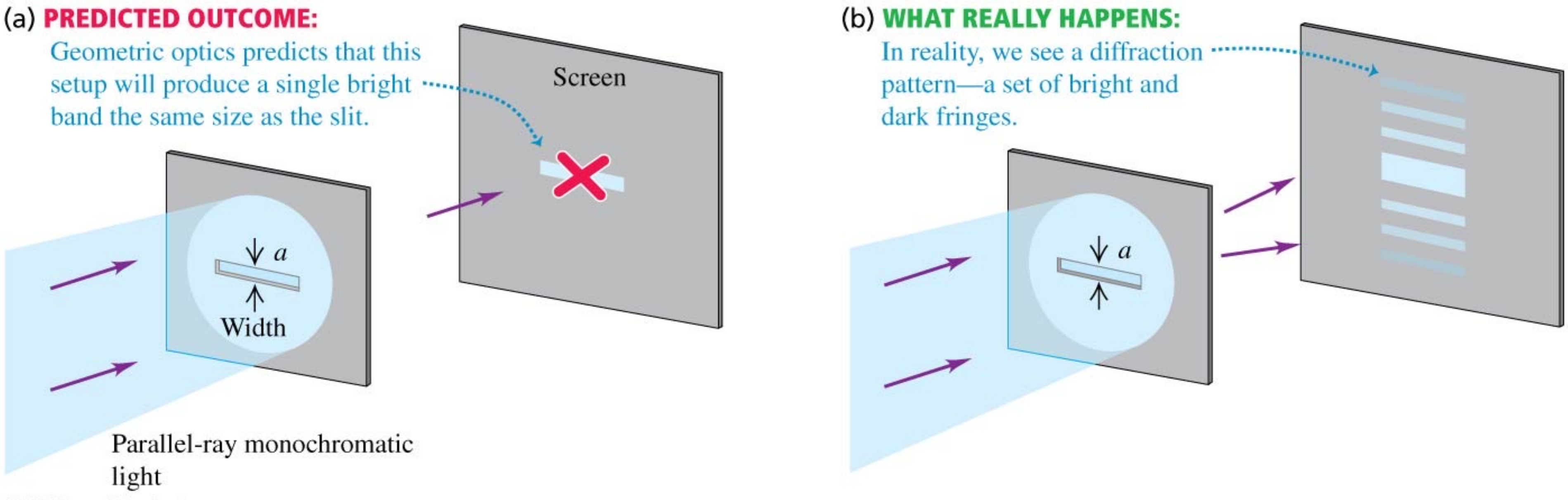
Diffraction 繞射





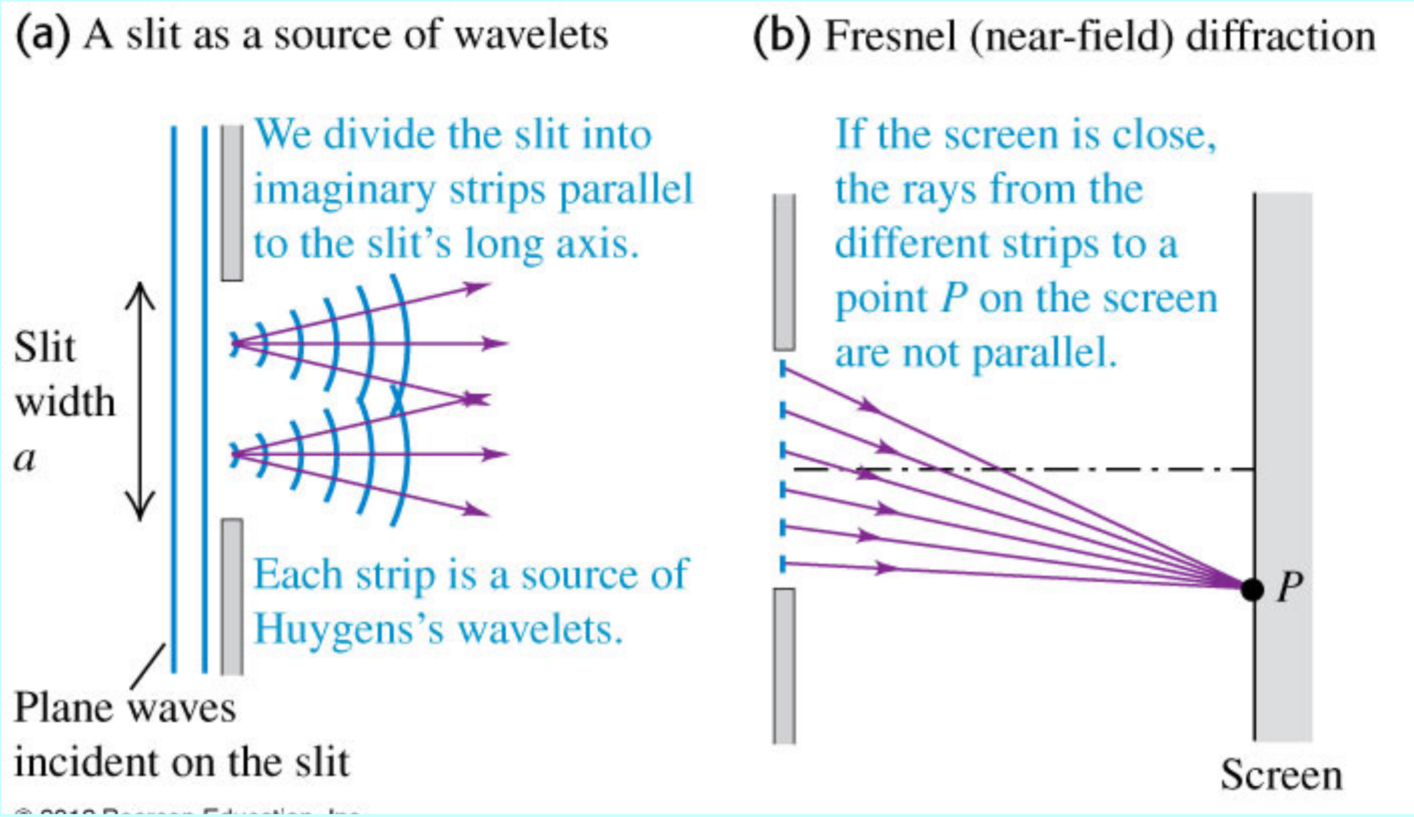


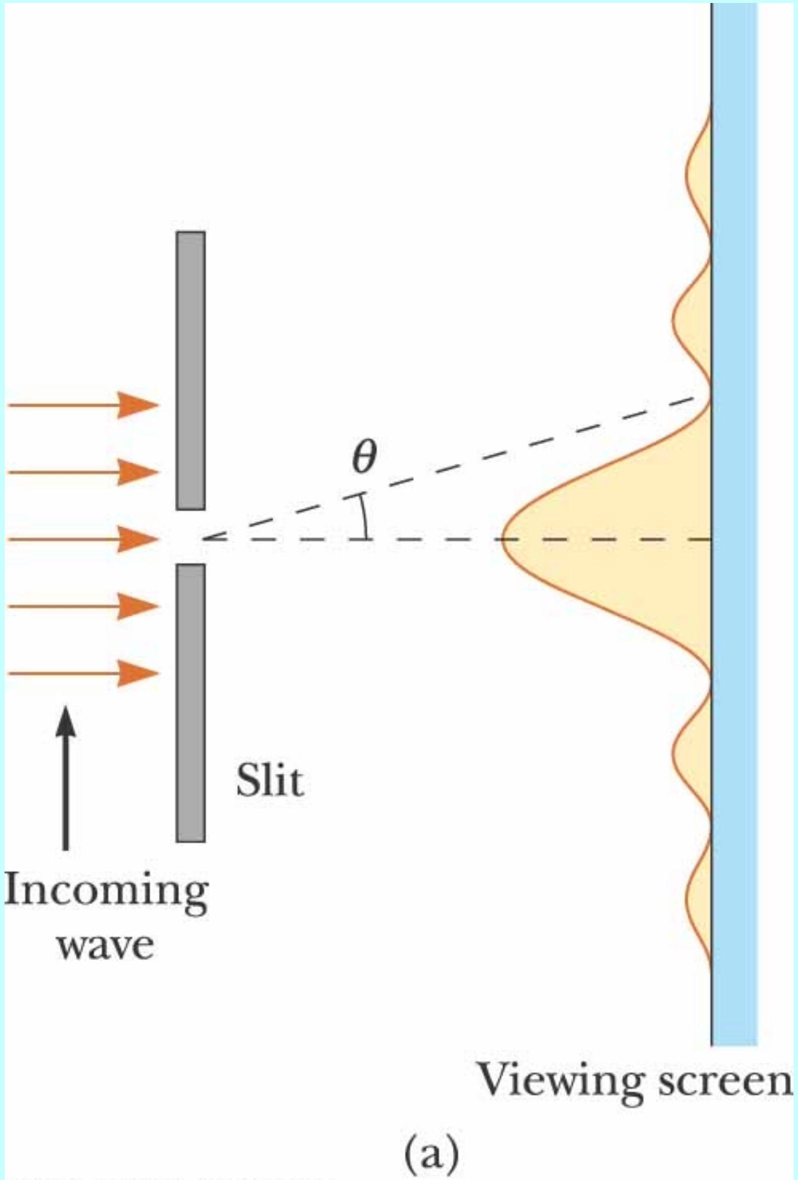

Viewing screen
Source
Opaque object
©2004 Thomson - Brooks/Cole

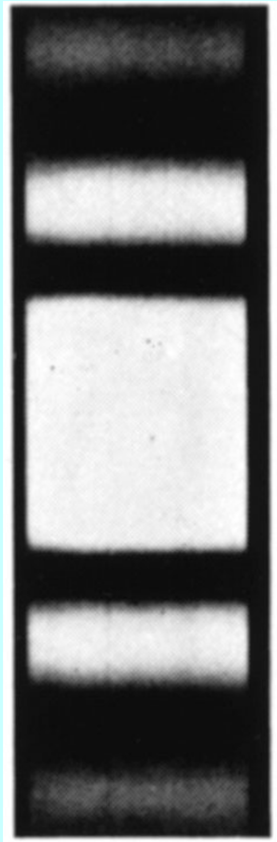

(a) PREDICTED OUTCOME:
Geometric optics predicts that this setup will produce a single bright band the same size as the slit.
Screen
a
Width
Parallel-ray monochromatic light
(b) WHAT REALLY HAPPENS:
In reality, we see a diffraction pattern—a set of bright and dark fringes.
a

狹縫中的波可以看成一個一個點波源

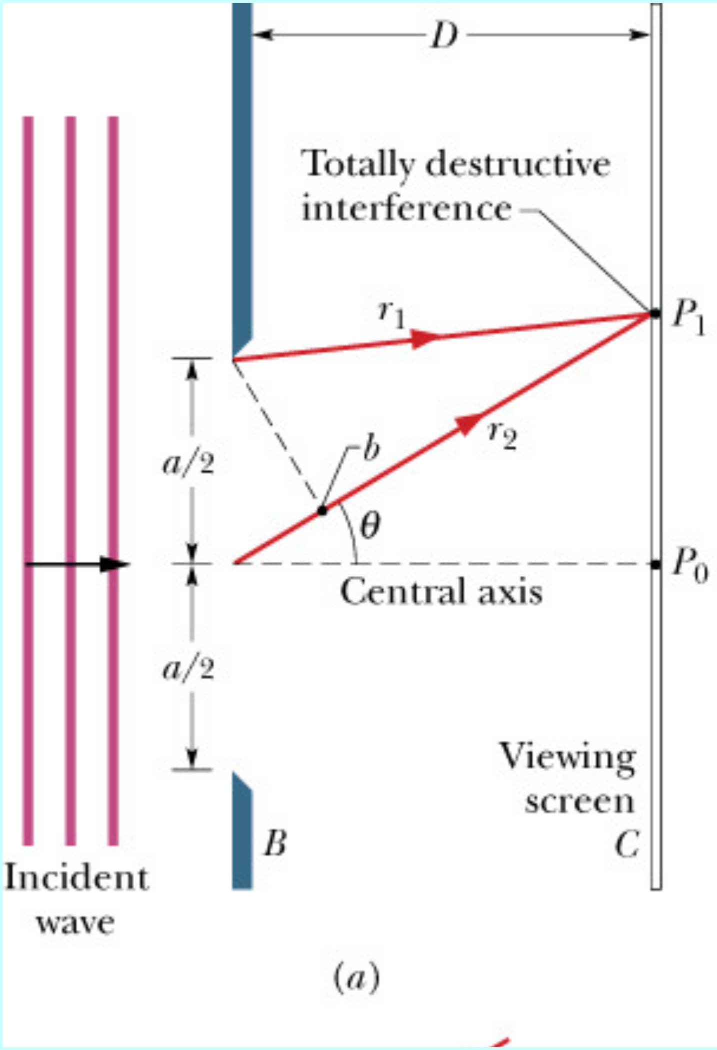
屏幕上的波即是這些波源所發出的球面波的疊加！

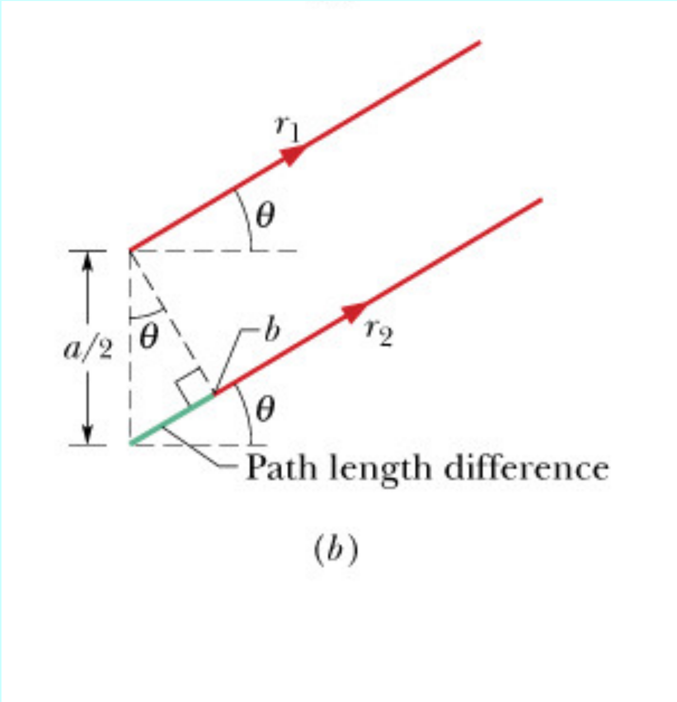



θ
Slit
Incoming
wave
Viewing screen
(a)



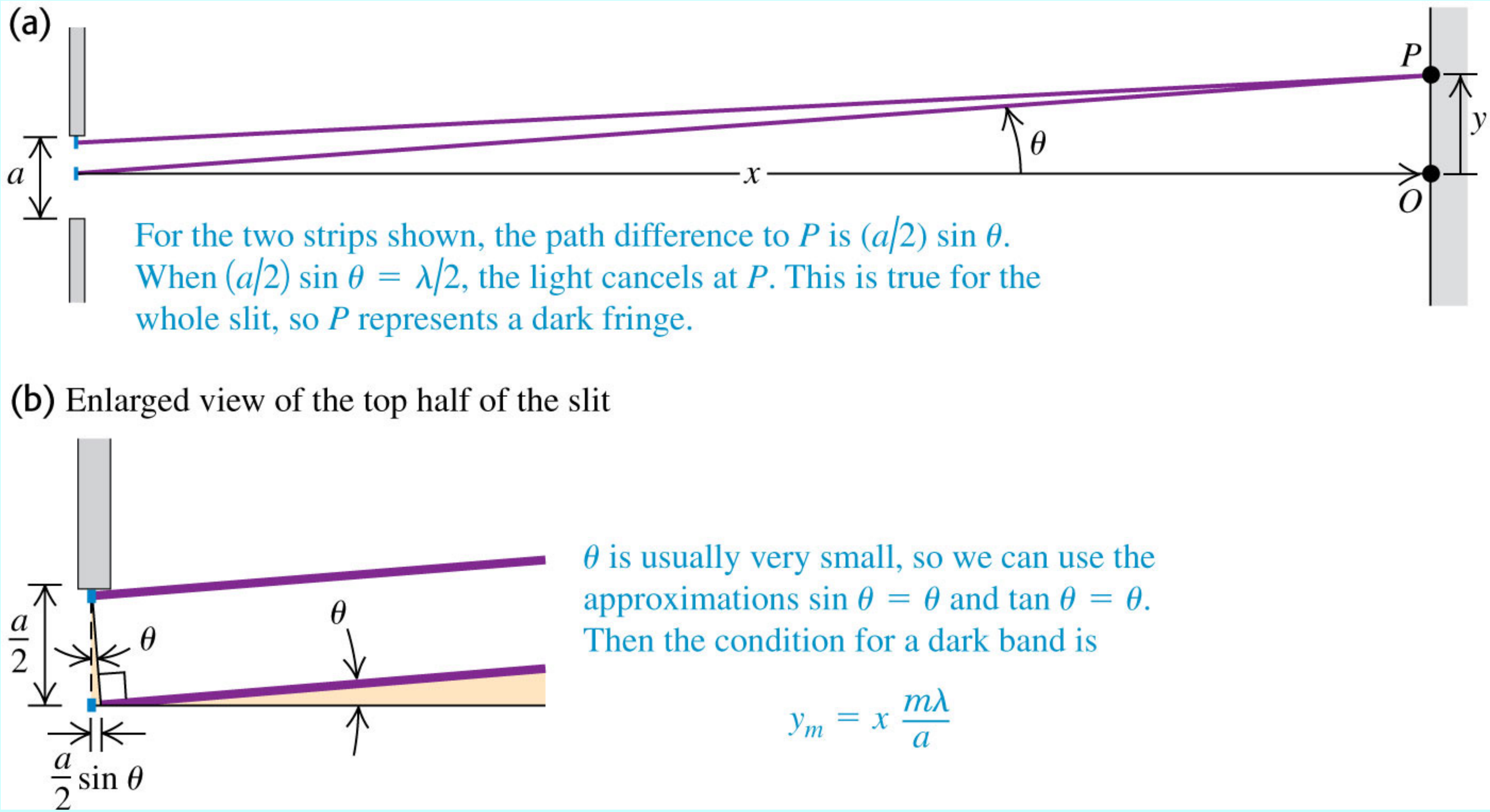
第一暗紋





$$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$$

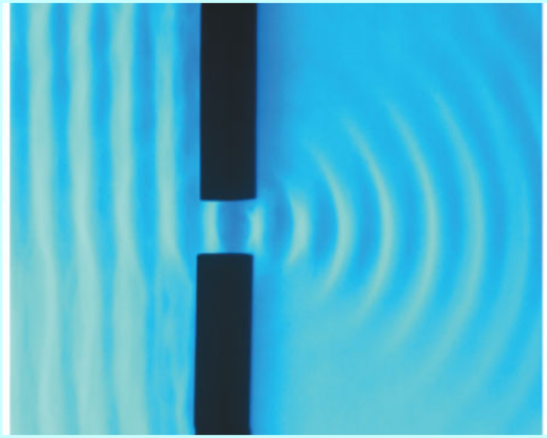
$$a\sin\theta = \lambda$$

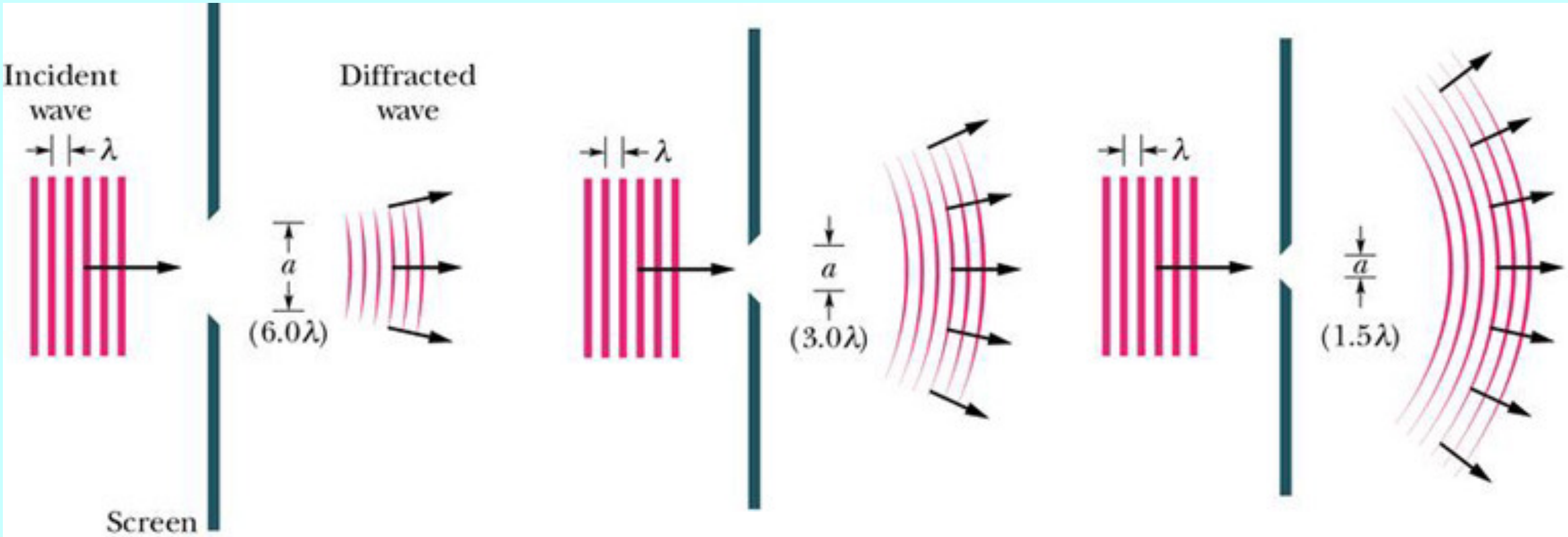


$$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$$

$$a\sin\theta = \lambda$$

$$\frac{y}{x} = \frac{\lambda}{a}$$

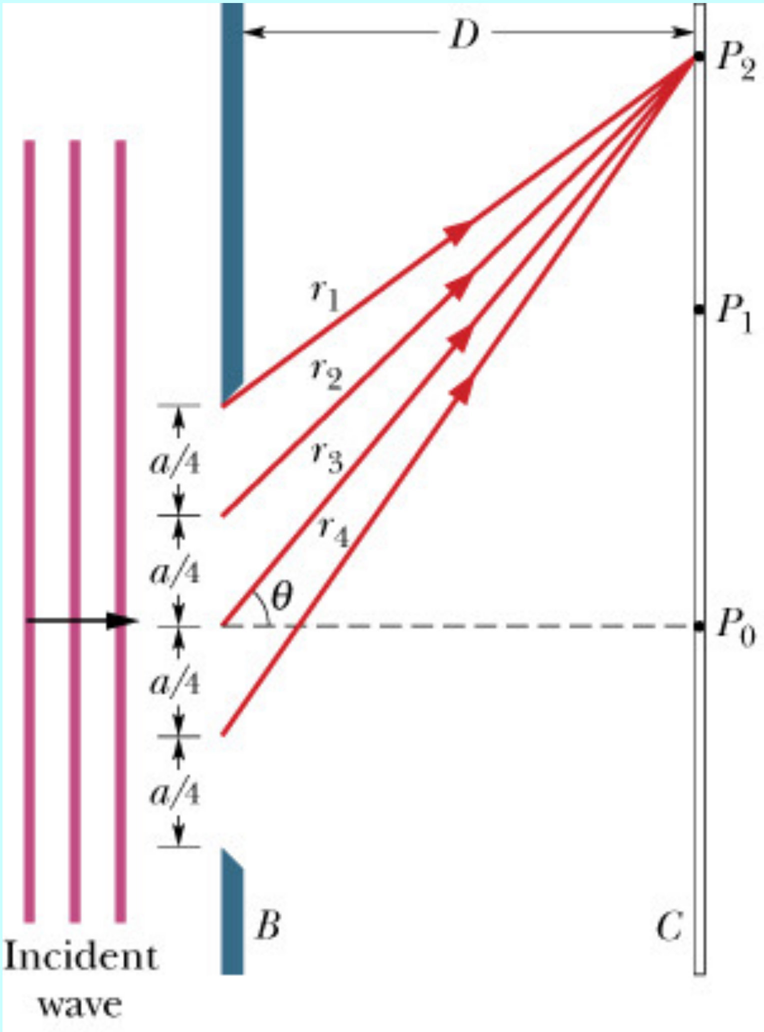


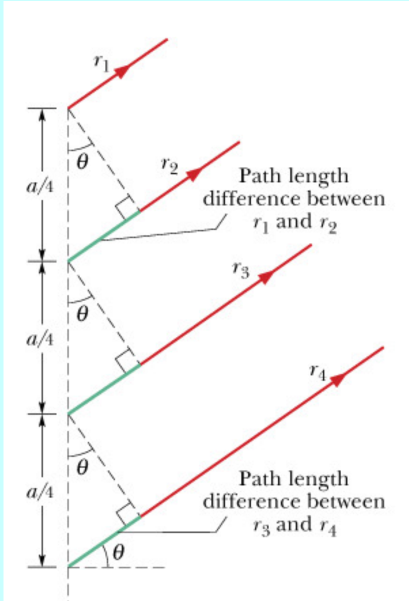


$$a \sin\theta = \lambda$$

$$a \downarrow \Rightarrow \theta \uparrow$$

第二暗紋



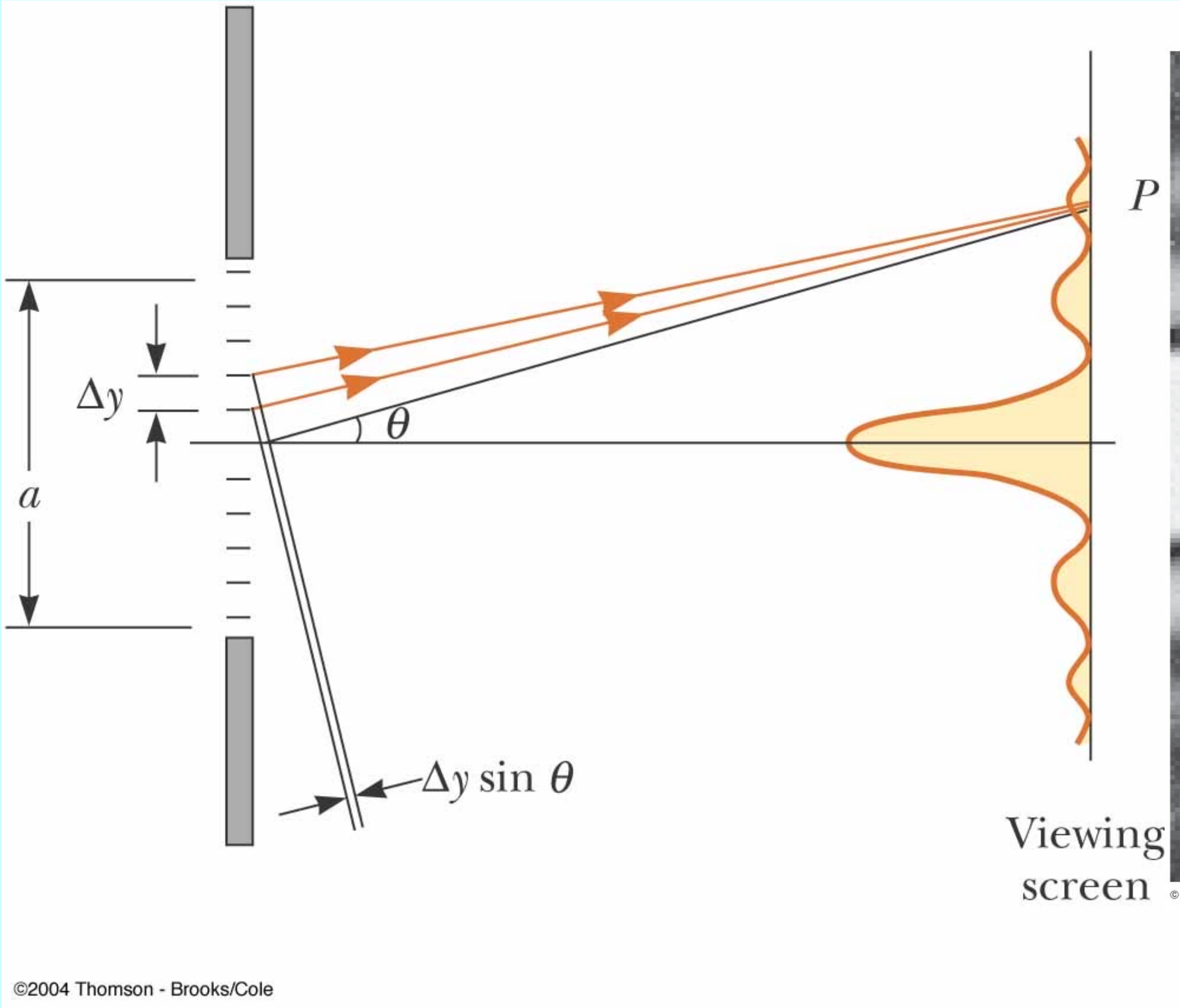


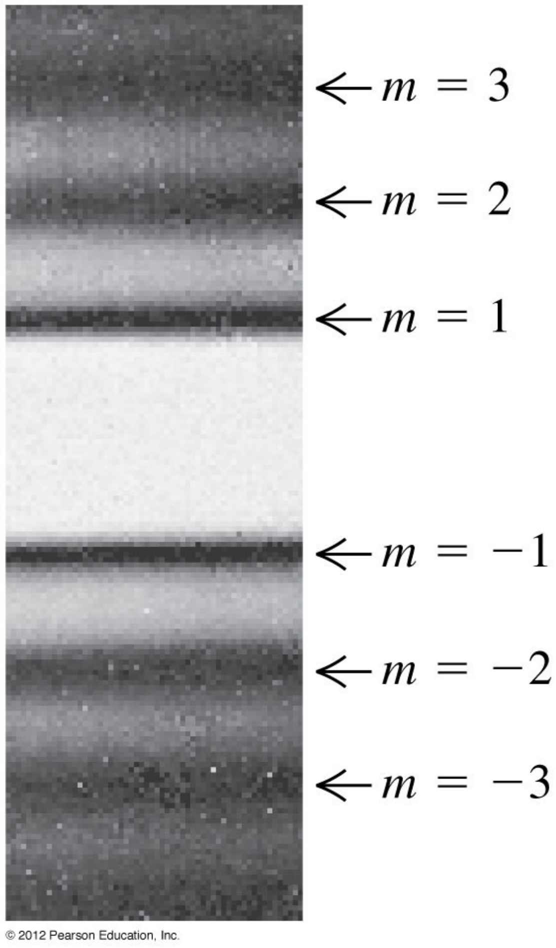
$$\frac{a}{4}\sin\theta = \frac{\lambda}{2}$$

$$a\sin\theta = 2\lambda$$

第 m 暗紋

$$a\sin\theta = m\lambda$$


Δy
a
θ
P
Δy sin θ
Viewing screen
©2004 Thomson - Brooks/Cole


← m = 3
← m = 2
← m = 1
← m = −1
← m = −2
← m = −3
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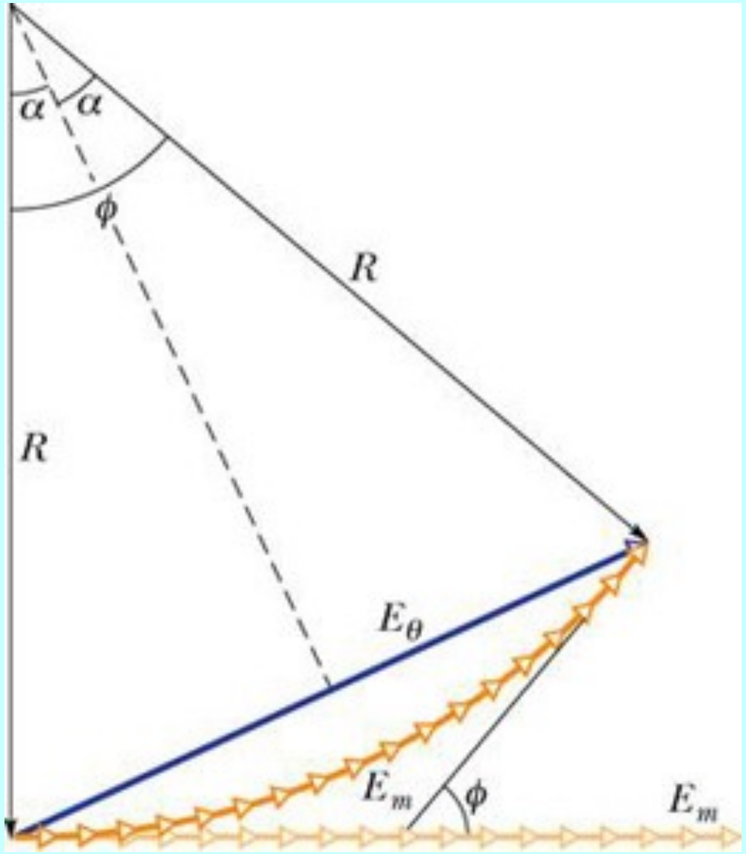
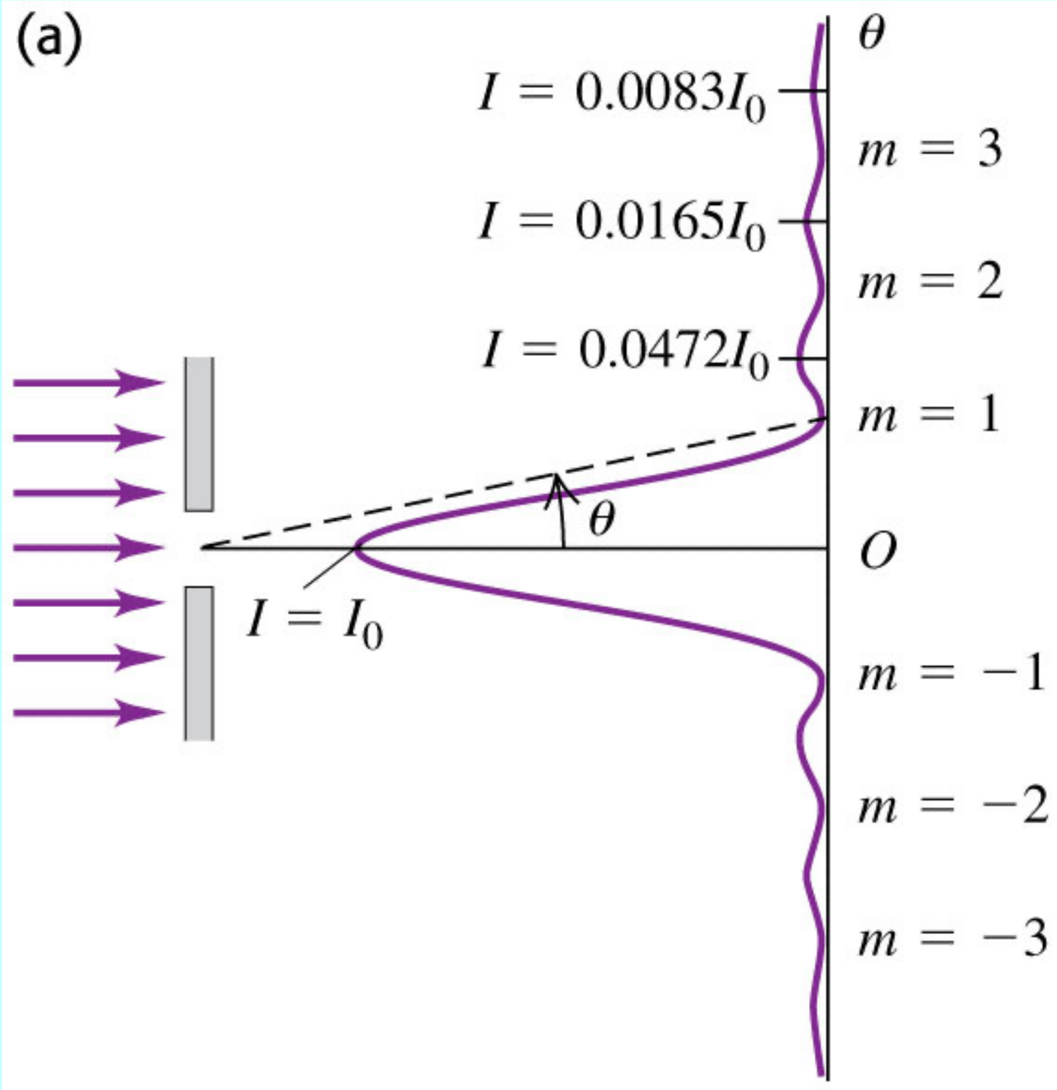
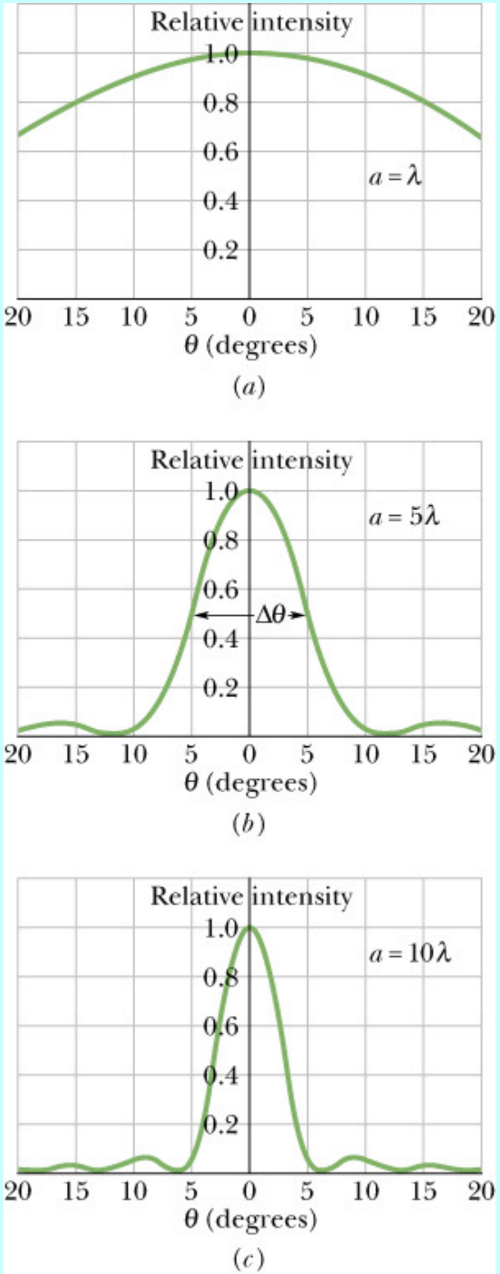
定量結果



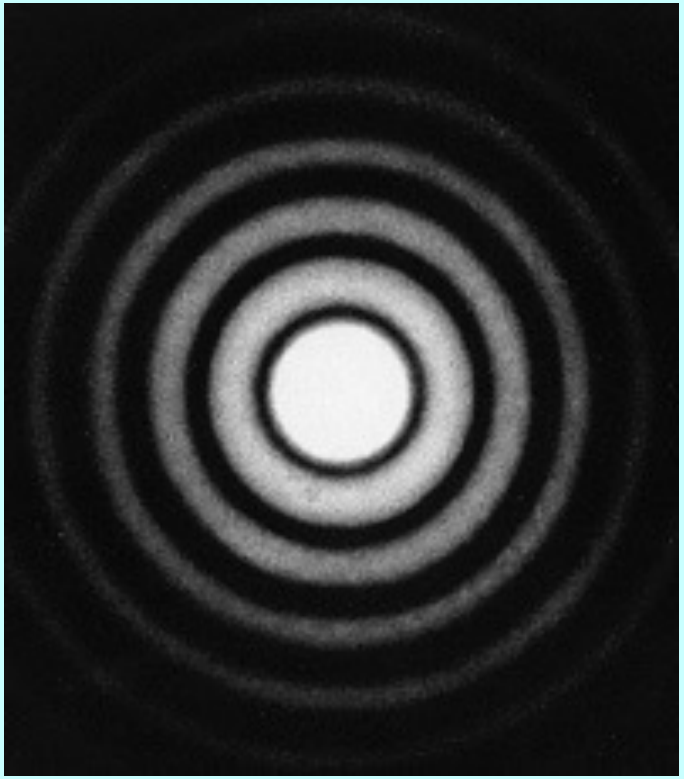
$$I(\theta) = I_m \left(\frac{\sin \alpha}{\alpha} \right)^2$$

$$\alpha = \frac{1}{2}\phi = \frac{\pi a}{\lambda} \sin \theta$$


(a)
θ
I = 0.0083I0
m = 3
I = 0.0165I0
m = 2
I = 0.0472I0
m = 1
θ
O
I = I0
m = −1
m = −2
m = −3


Relative intensity
1.0
0.8
0.6
0.4
0.2
$a = \lambda$
20 15 10 5 0 5 10 15 20
θ (degrees)
(a)
Relative intensity
1.0
0.8
0.6
0.4
0.2
$a = 5\lambda$
$\Delta\theta$
20 15 10 5 0 5 10 15 20
θ (degrees)
(b)
Relative intensity
1.0
0.8
0.6
0.4
0.2
$a = 10\lambda$
20 15 10 5 0 5 10 15 20
θ (degrees)
(c)

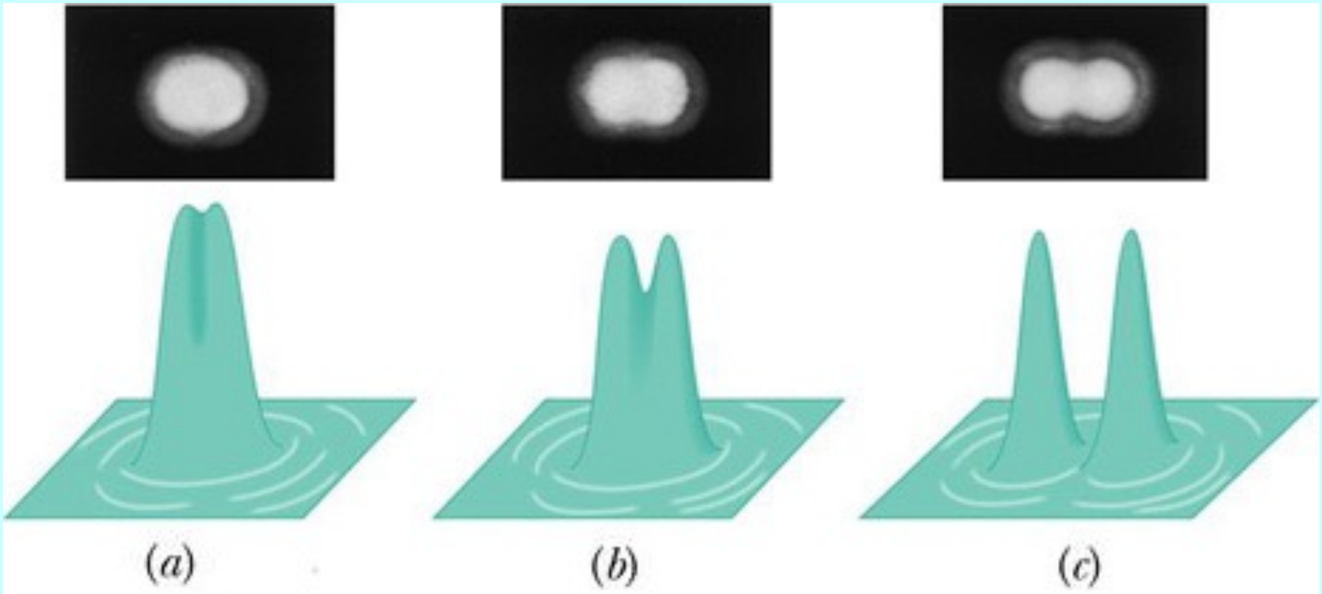
圓孔繞射



狹縫 $a\sin\theta = \lambda$

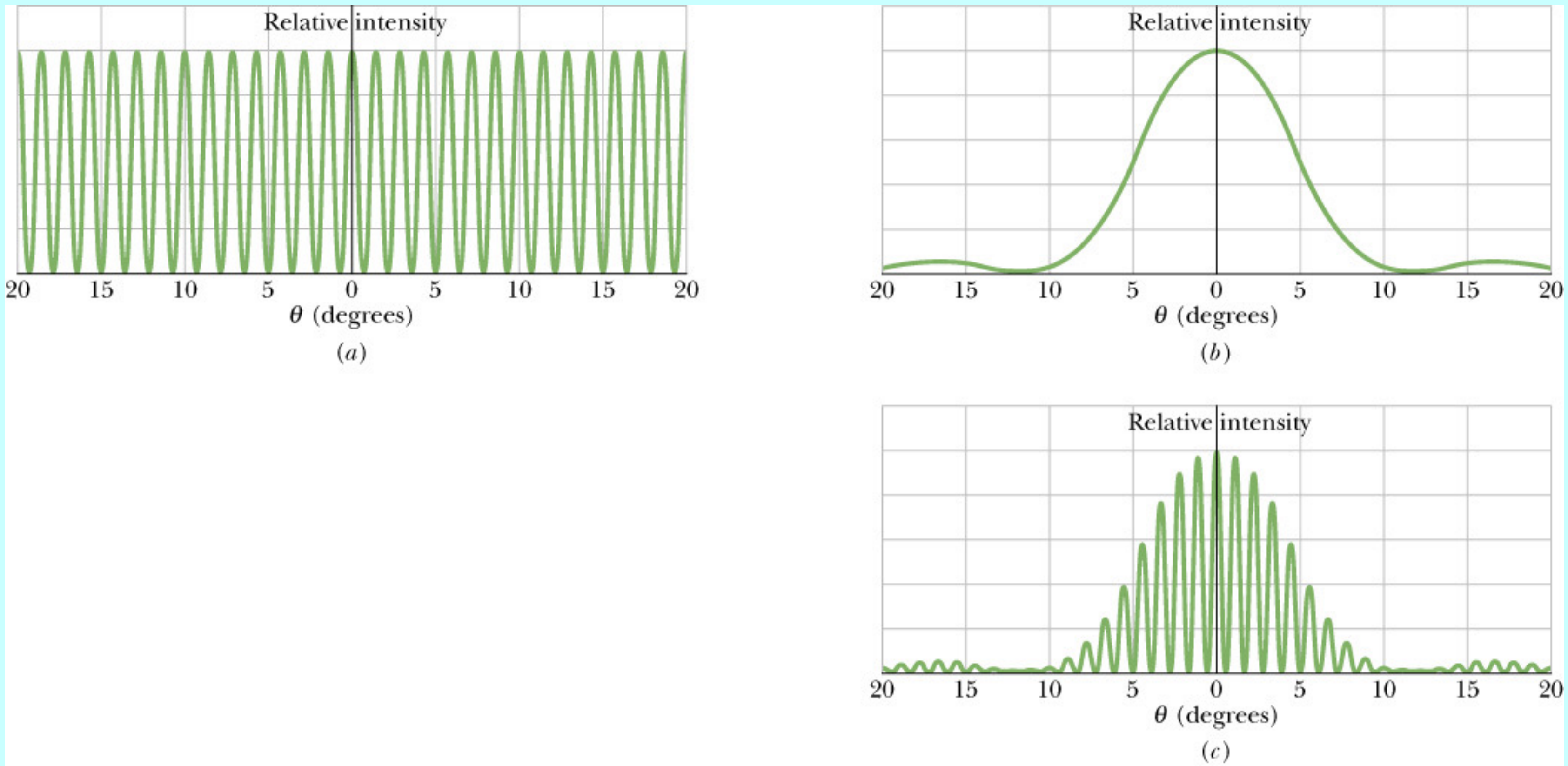
$$\sin\theta = 1.22\frac{\lambda}{a}$$

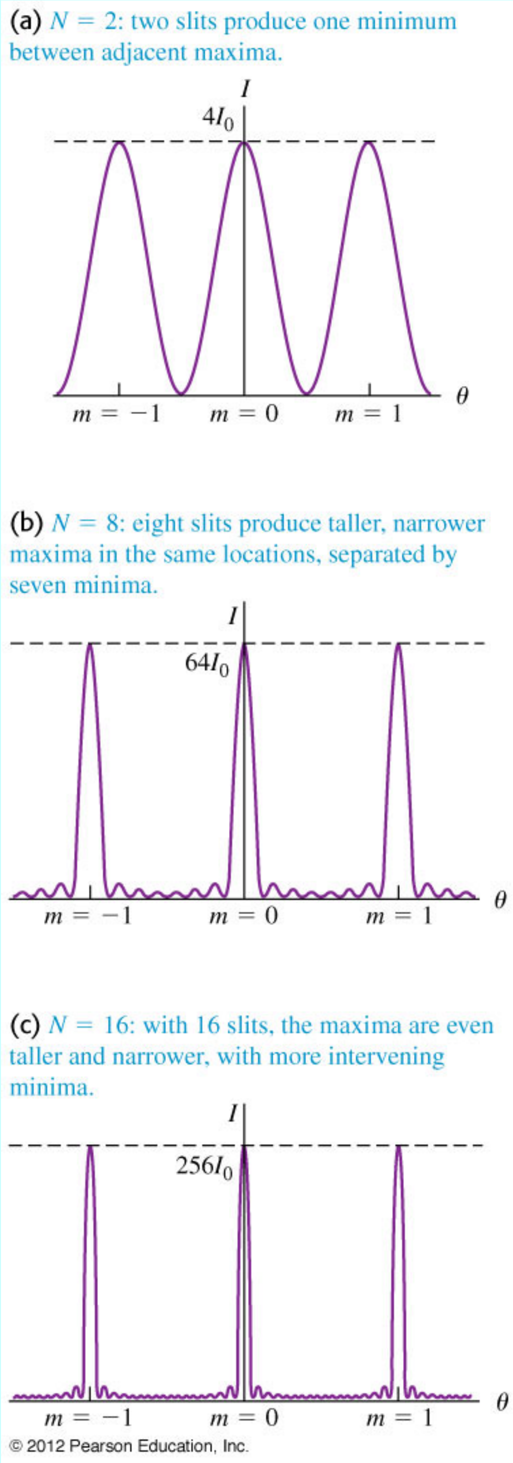
鑑別度



$$\theta_R = \sin^{-1}\frac{1.22\lambda}{d} \approx \frac{1.22\lambda}{d}$$

波長越短，鑑別度越好


Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)
(a)
Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)
(b)
Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)
(c)


(a) N = 2: two slits produce one minimum between adjacent maxima.
I
4I0
θ
m = −1
m = 0
m = 1
(b) N = 8: eight slits produce taller, narrower maxima in the same locations, separated by seven minima.
I
64I0
θ
m = −1
m = 0
m = 1
(c) N = 16: with 16 slits, the maxima are even taller and narrower, with more intervening minima.
I
256I0
θ
m = −1
m = 0
m = 1
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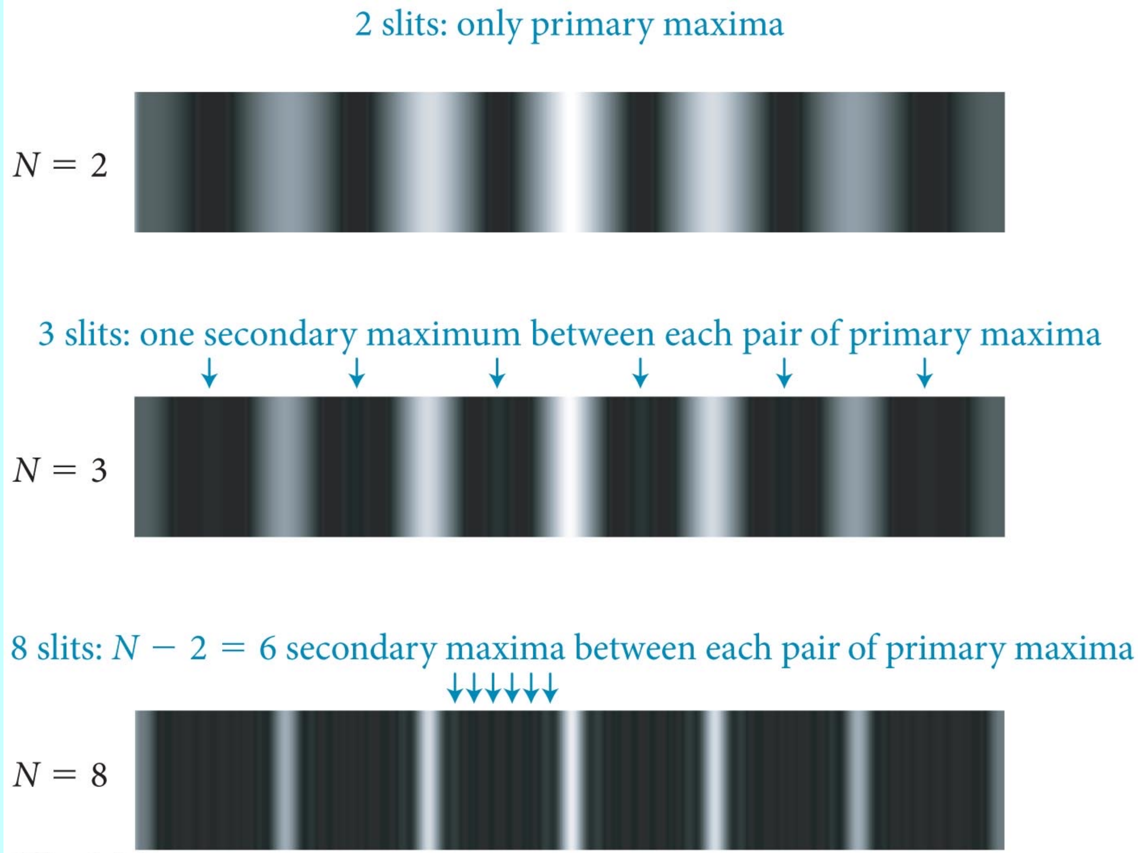
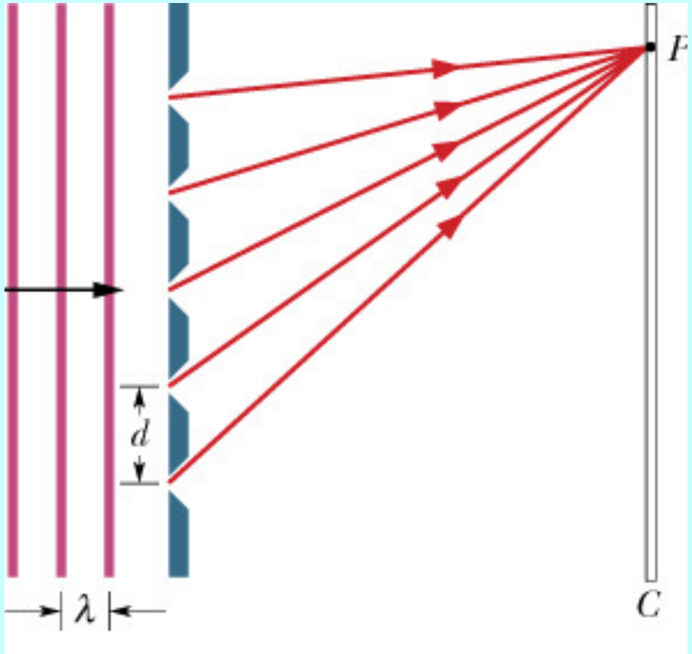
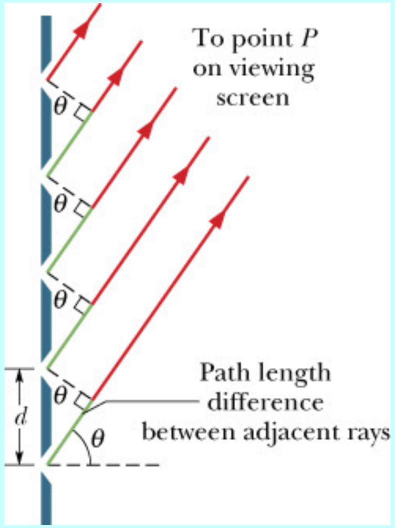

2 slits: only primary maxima
N = 2
3 slits: one secondary maximum between each pair of primary maxima
N = 3
8 slits: N − 2 = 6 secondary maxima between each pair of primary maxima
N = 8

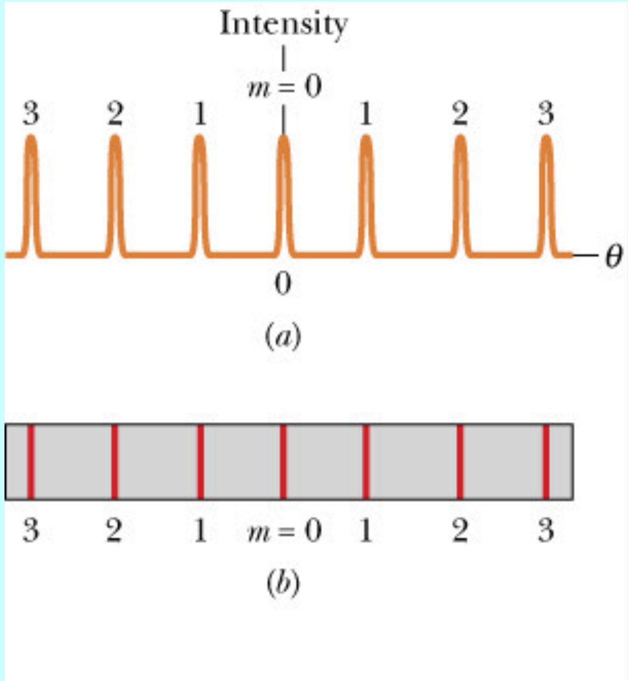
狹縫越多，干涉條紋越細！



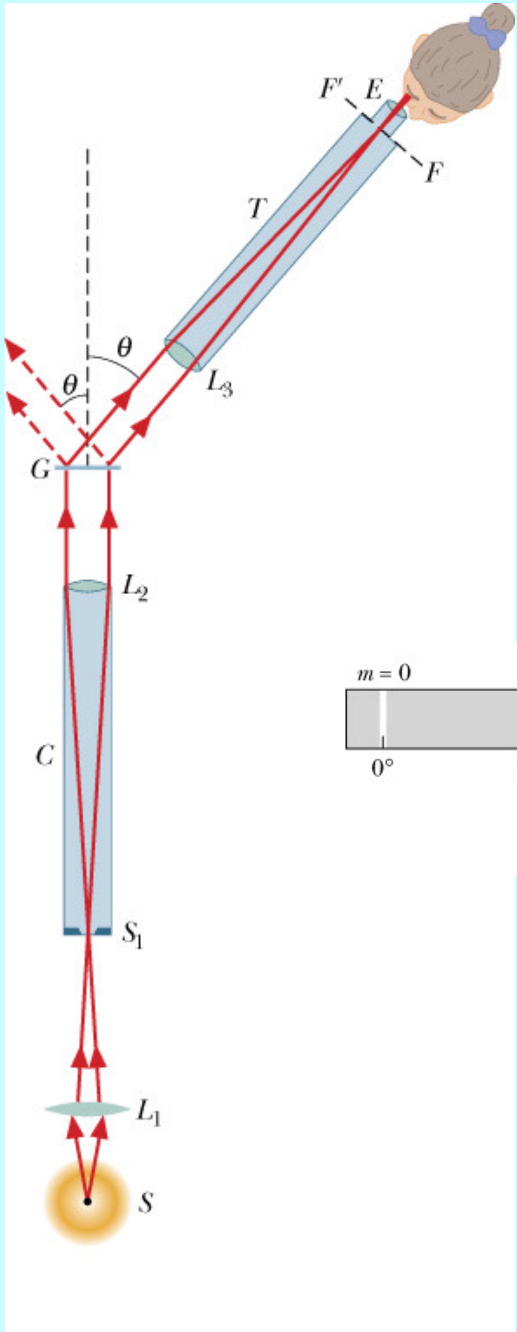


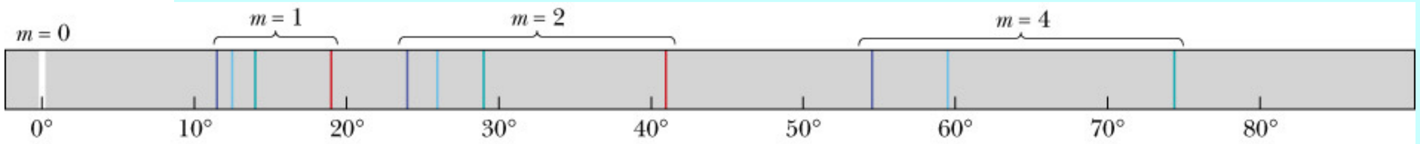
繞射光柵

等同於一系列等距同相光源的干涉疊加！



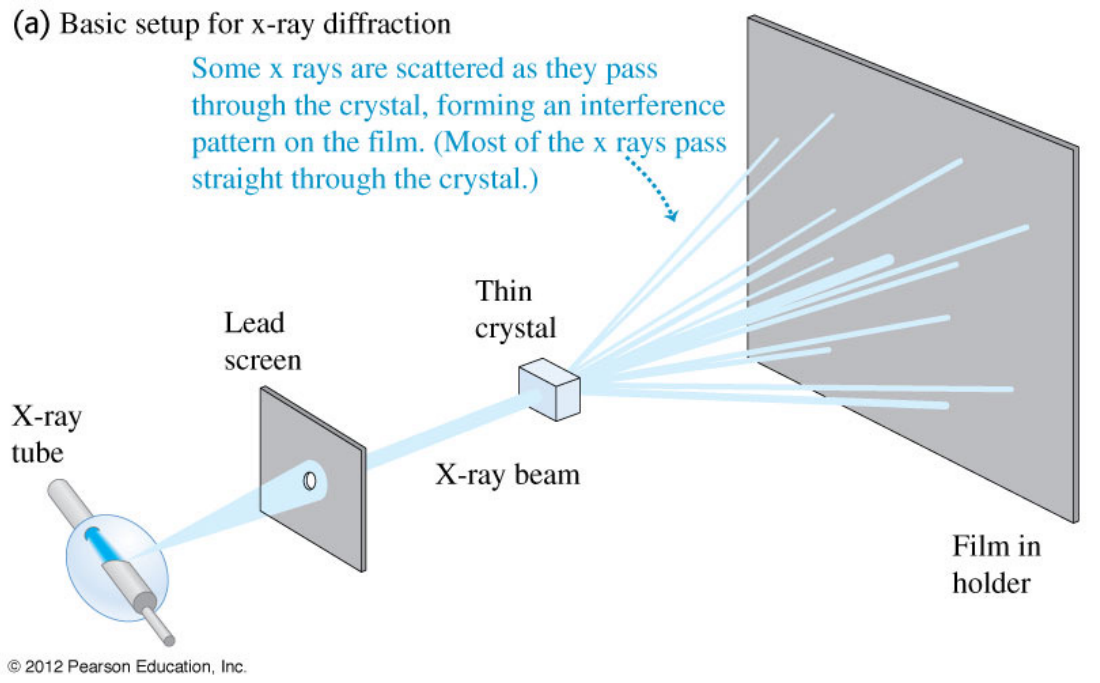
$$d \sin\theta = m\lambda$$

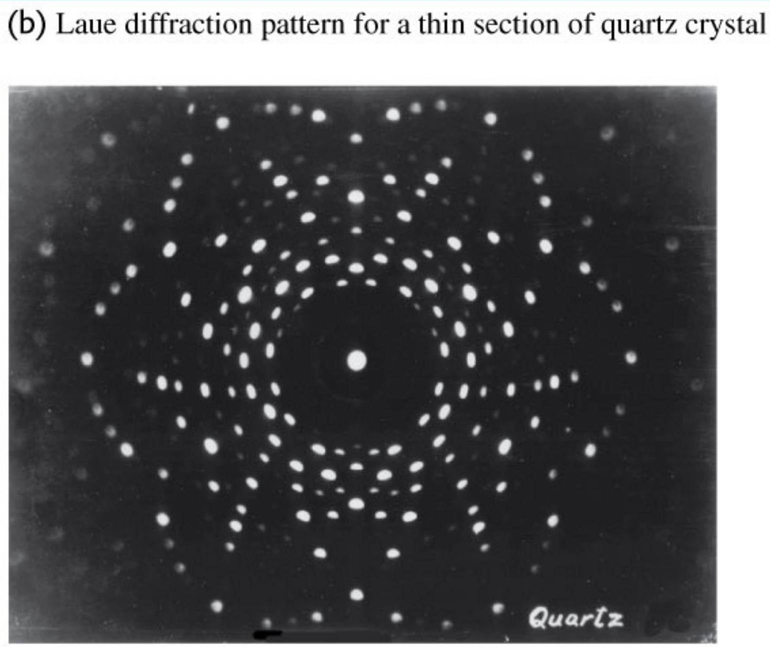


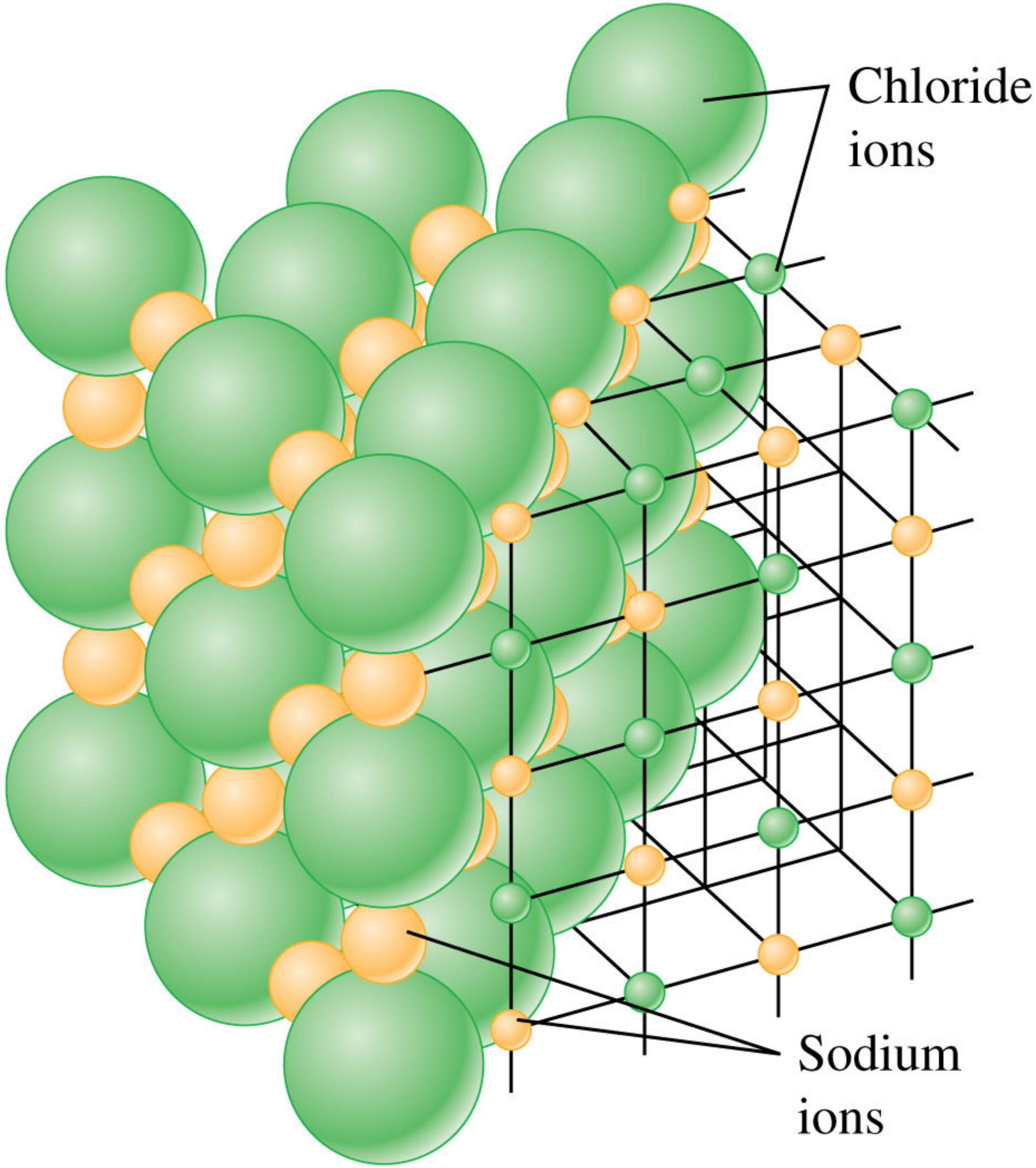


分析光波波長最好的辦法

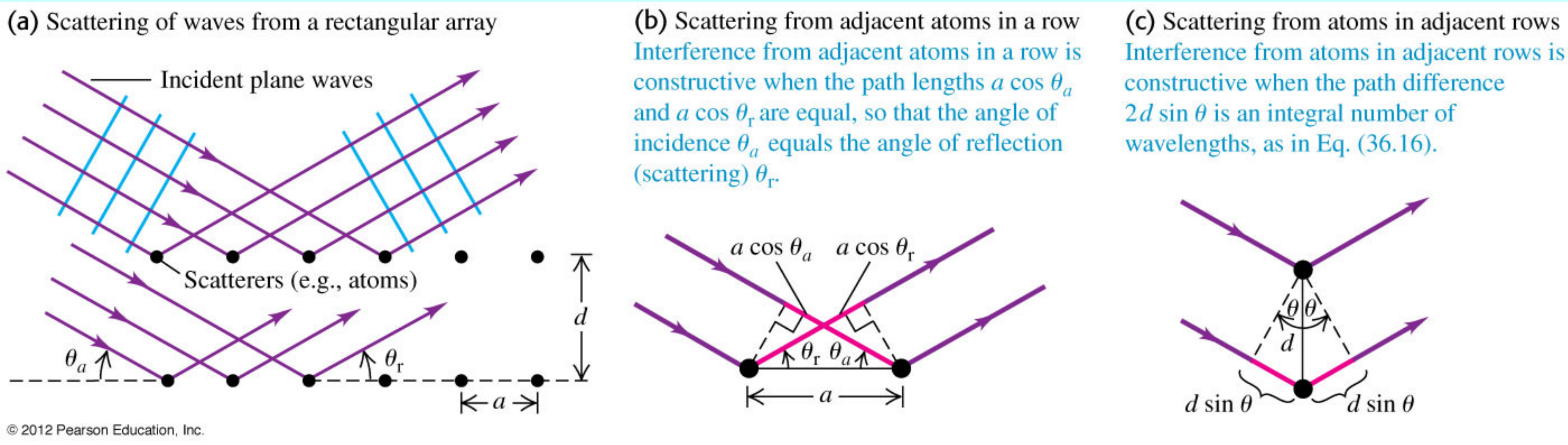
X光繞射


(a) Basic setup for x-ray diffraction
Some x rays are scattered as they pass through the crystal, forming an interference pattern on the film. (Most of the x rays pass straight through the crystal.)
Thin crystal
Lead screen
X-ray tube
X-ray beam
Film in holder
© 2012 Pearson Education, Inc.


(b) Laue diffraction pattern for a thin section of quartz crystal
Quartz

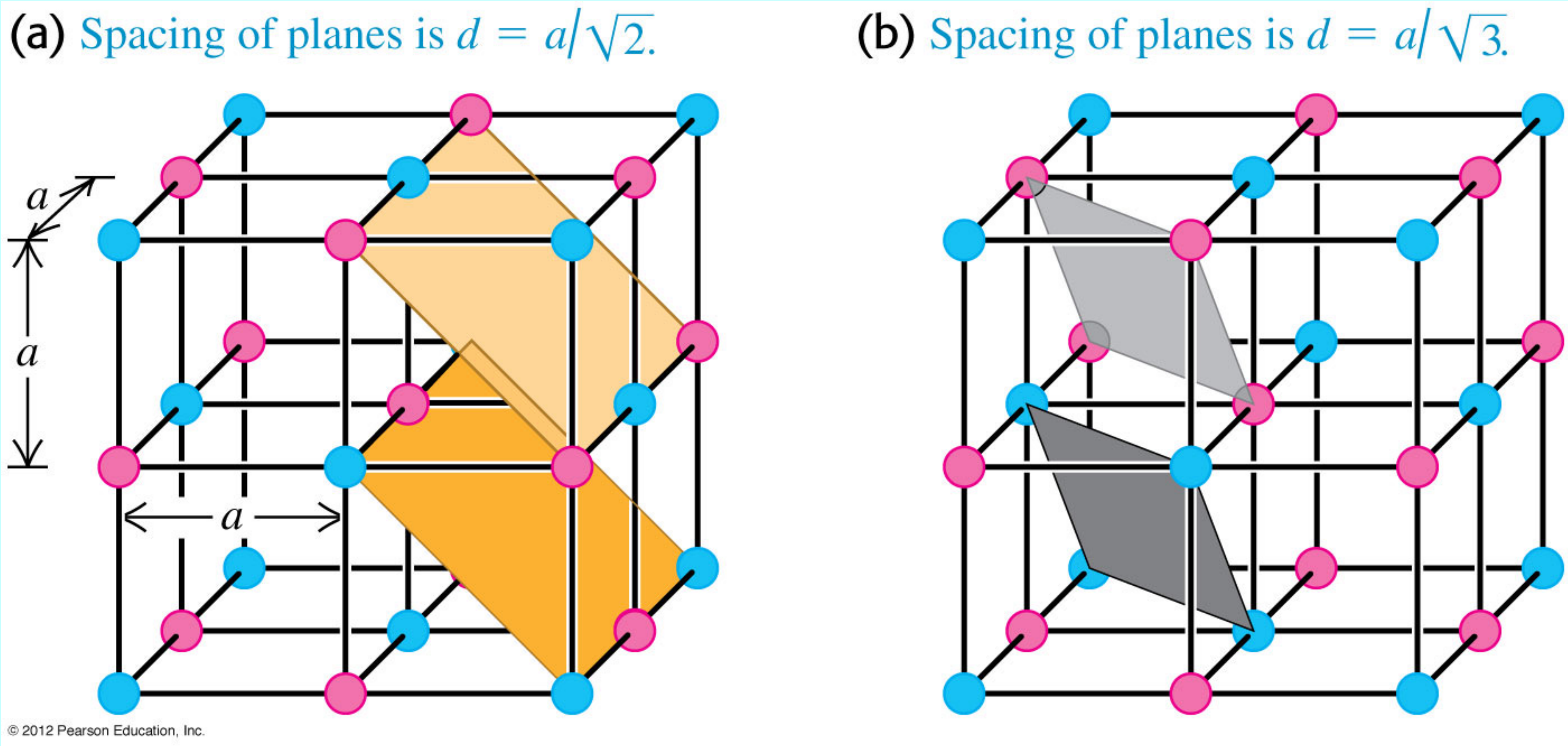


Chloride
ions
Sodium
ions



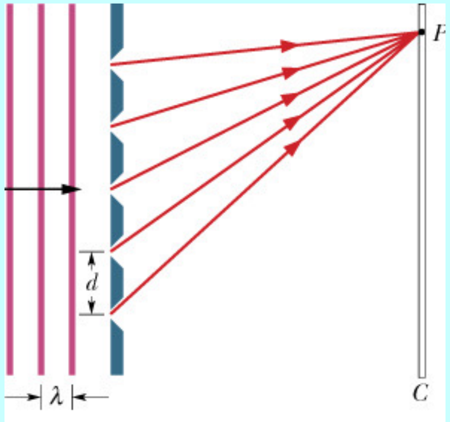
亮點條件 $2d \sin\theta = m\lambda$

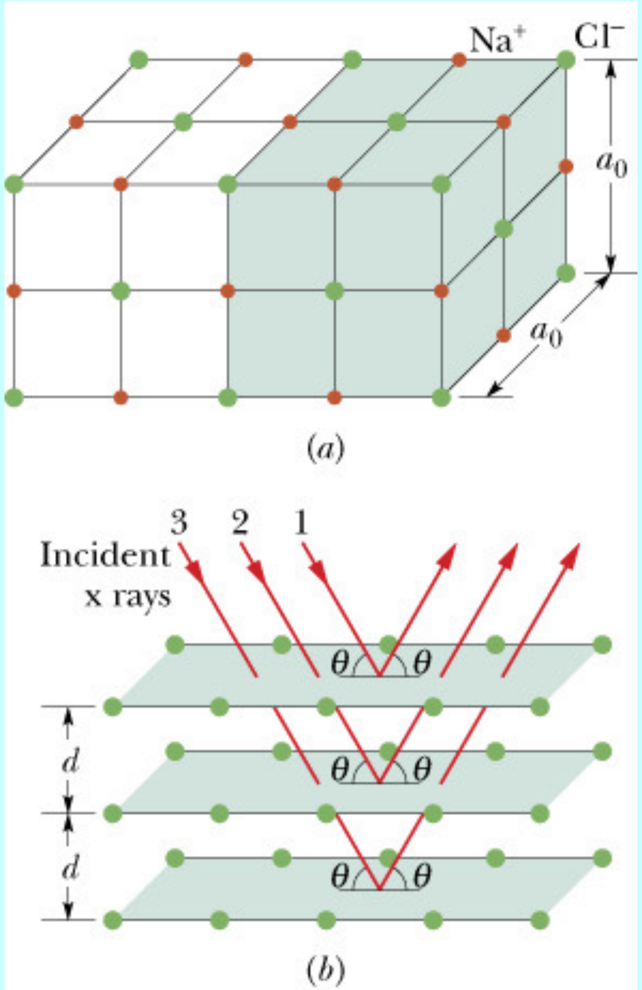
晶體的重複結構保證有一系列有秩序的反射平面，

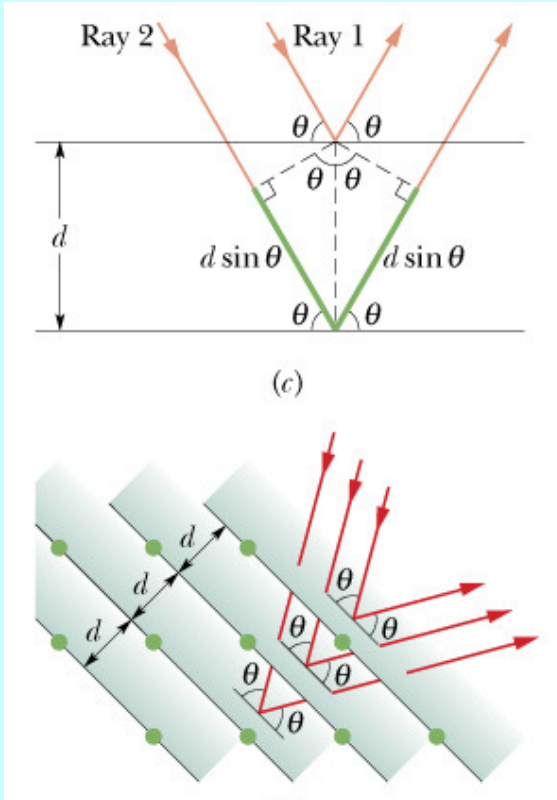


晶體的重複結構保證有一系列有秩序的反射平面，

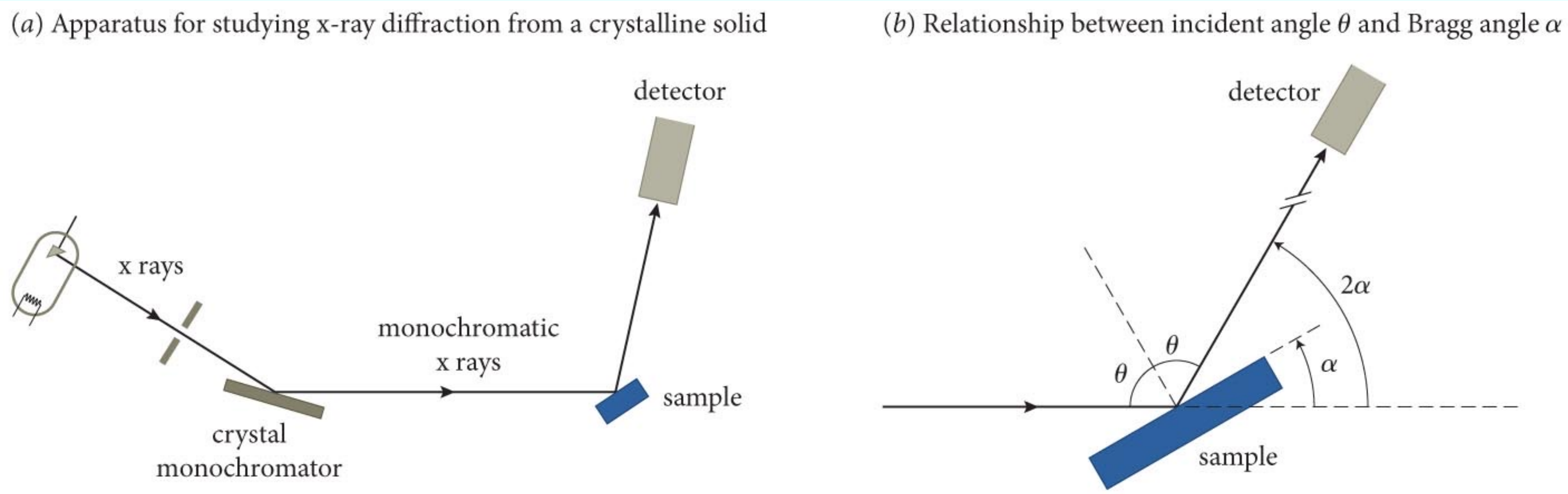
如光柵一樣，為一系列等間距的光源的光的干涉疊加



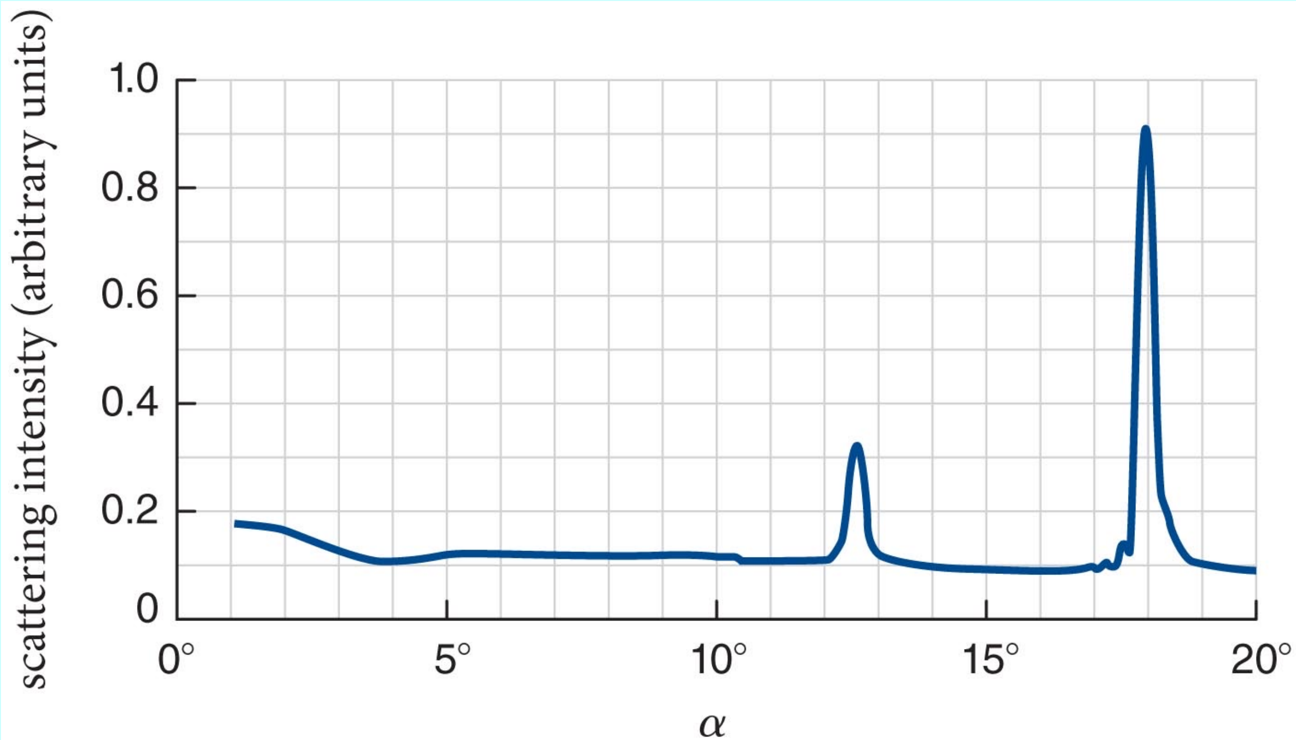




亮點條件 $2d\sin\theta = m\lambda$

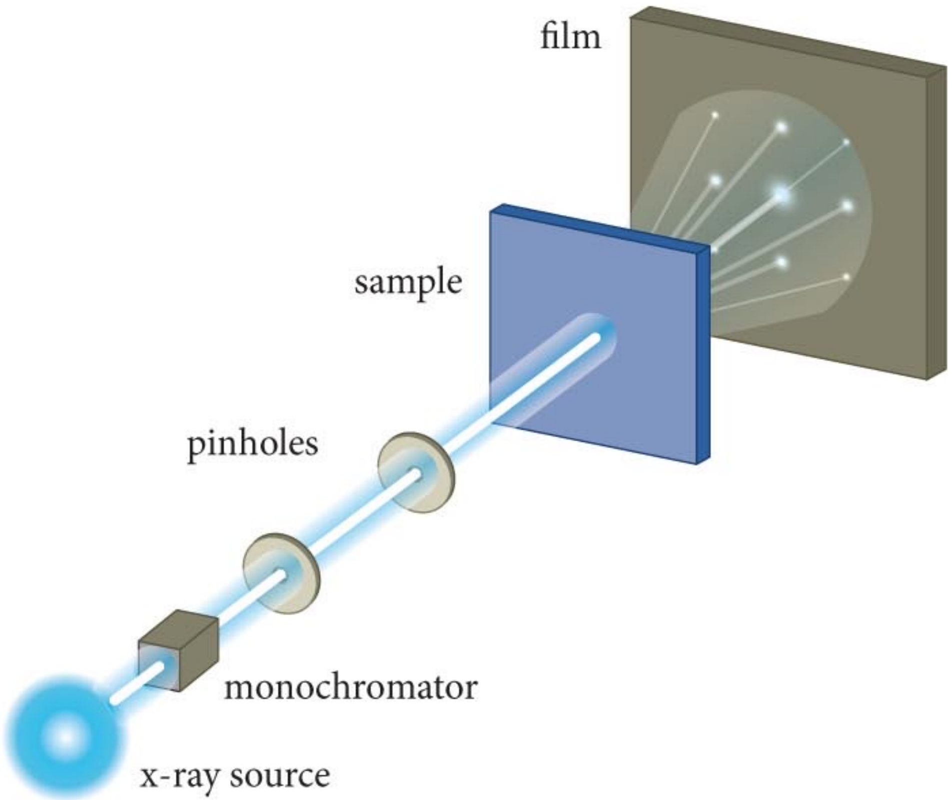


(a) Apparatus for studying x-ray diffraction from a crystalline solid
detector
x rays
monochromatic
x rays
sample
crystal
monochromator
(b) Relationship between incident angle θ and Bragg angle α
detector
2α
θ
θ
α
sample

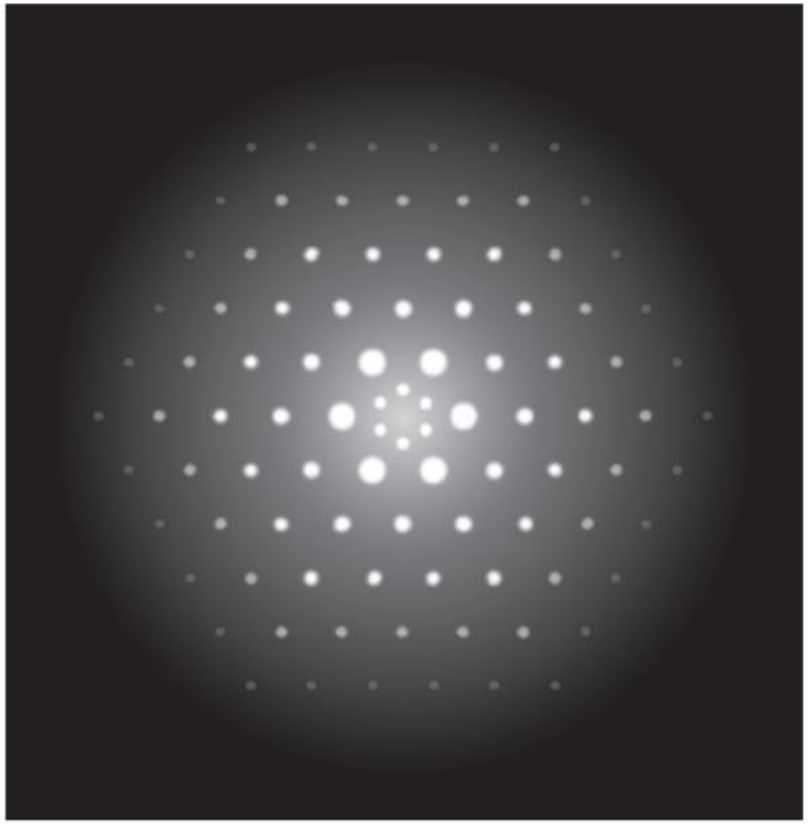


scattering intensity (arbitrary units)
1.0
0.8
0.6
0.4
0.2
0
0°
5°
10°
15°
20°
α

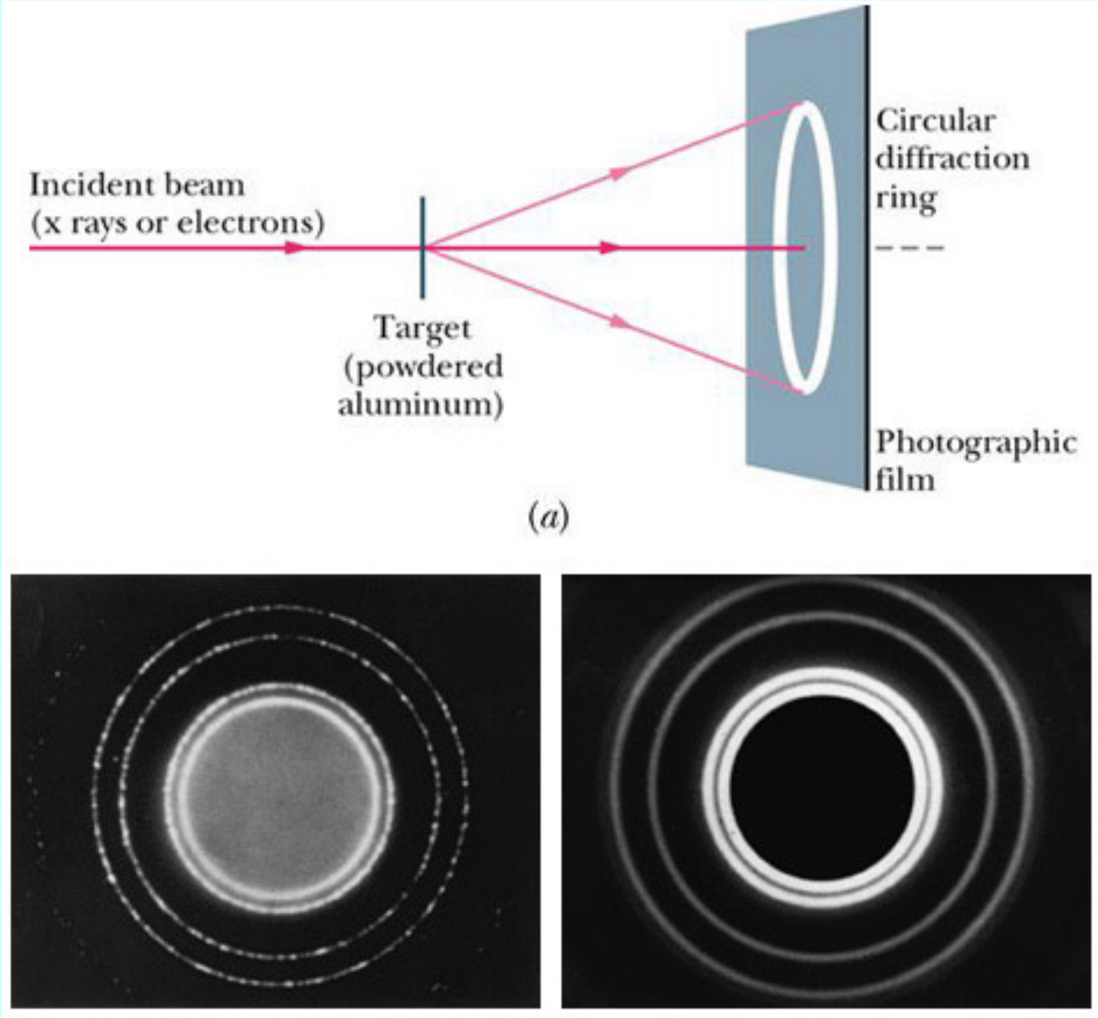
(*a*) Schematic apparatus for x-ray crystallography



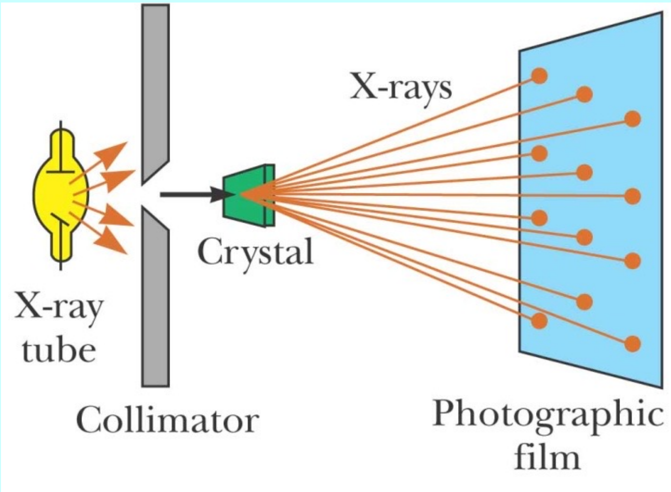
(*b*) X-ray diffraction pattern of diamond lattice

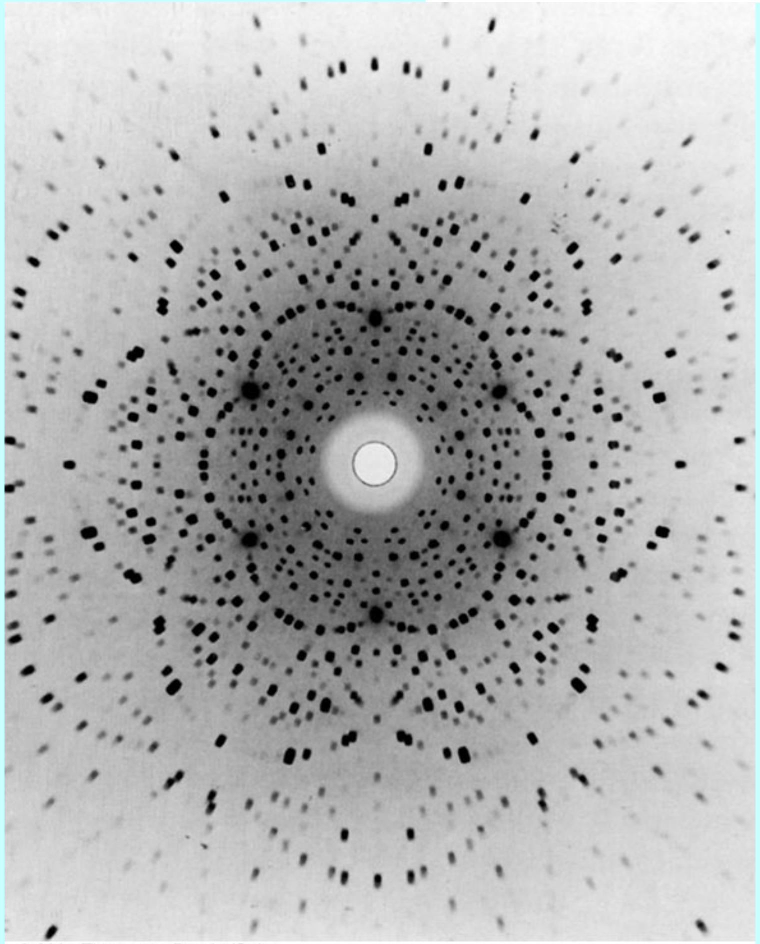


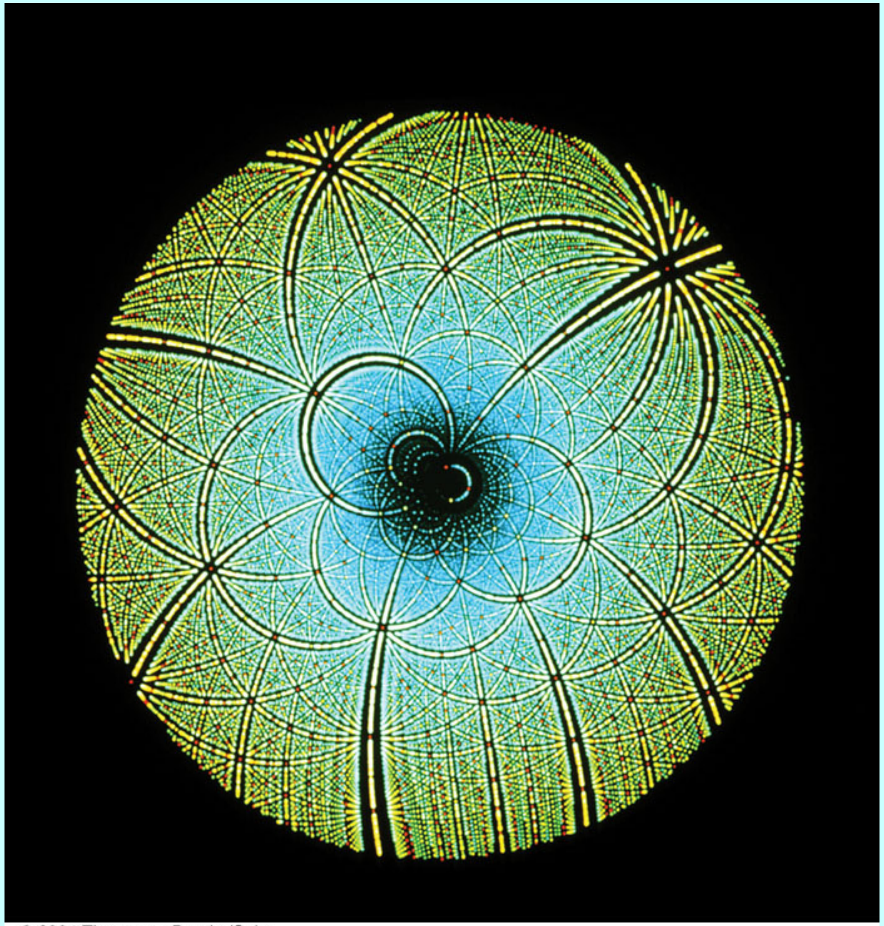
電子的繞射實驗證實了物質波的存在！

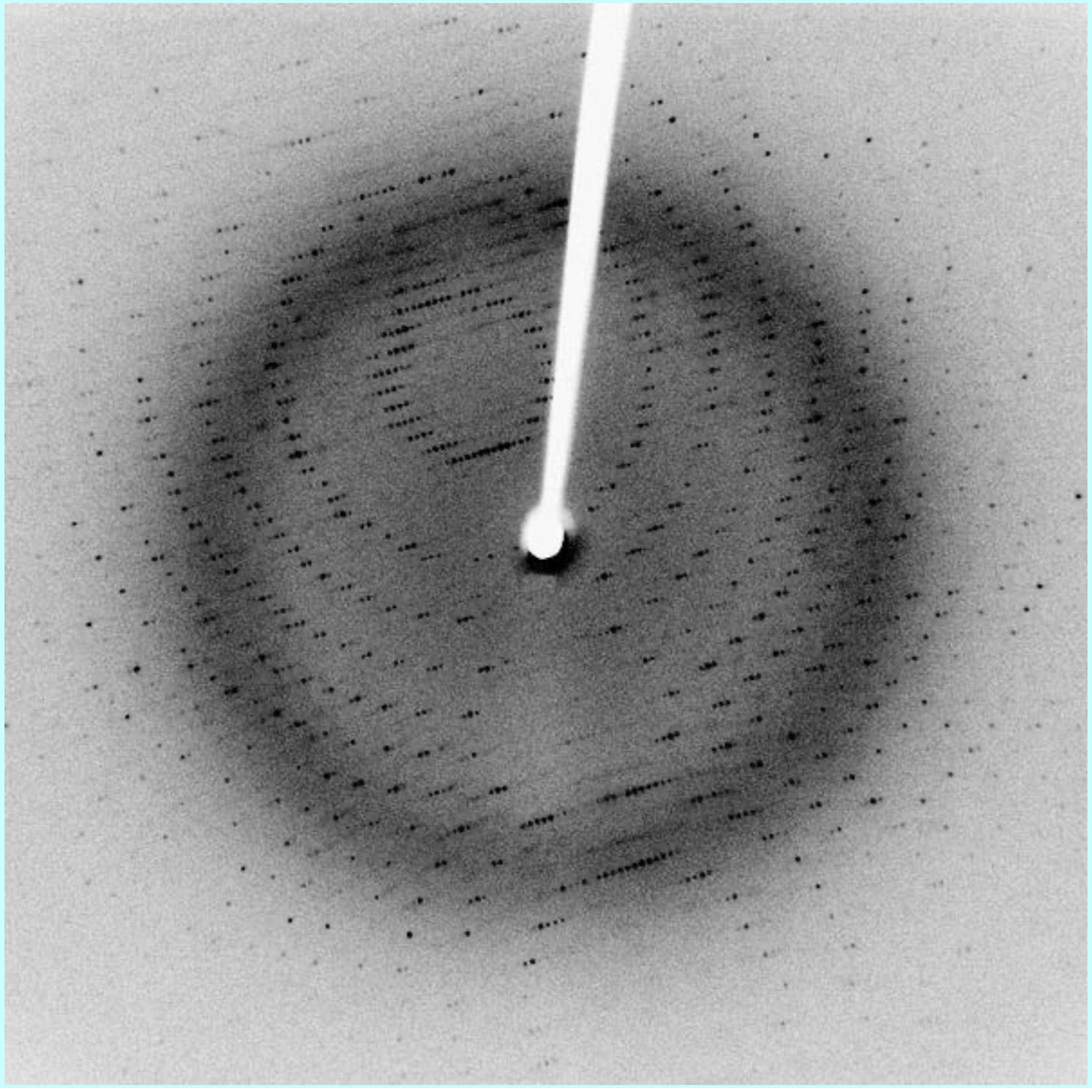


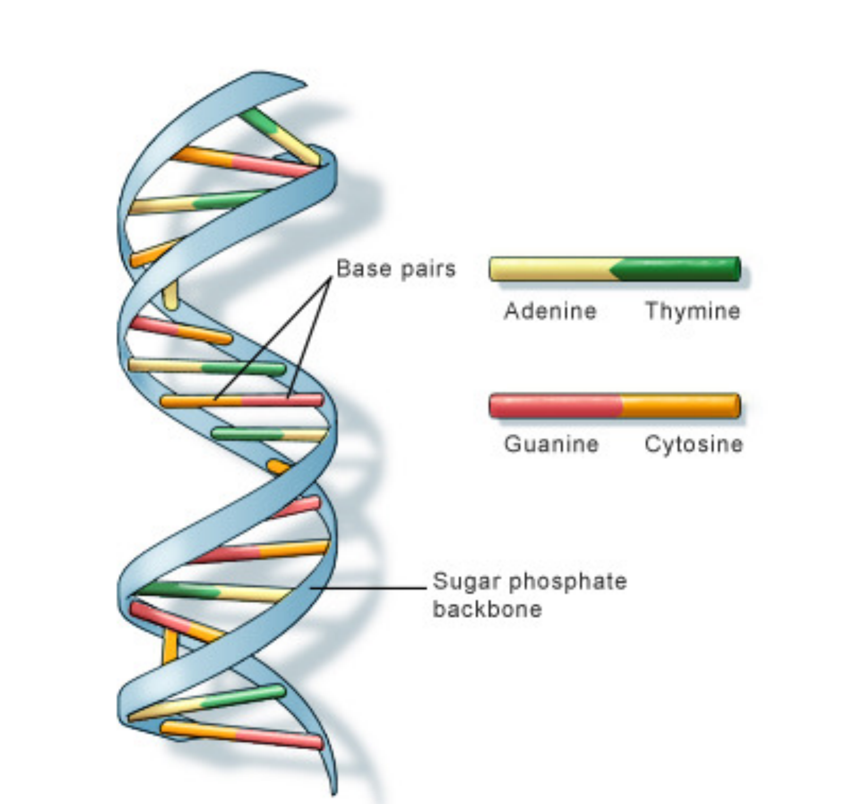
粉末狀樣本


X-rays
X-ray
tube
Crystal
Collimator
Photographic
film









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