# Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

**Saptaparna Bhattacharya**

**May 4th, 2026**

**Based on Simon Dalley's lectures taught in Spring 2025**

Labs

Lectures

# Schedule

No class

| Month | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| January | 19 | 20 | 21 ✅ | 22 | 23 ✅ | 24 | 25 |
| | 26 ❄️🌨️❄❄❄ | 27 | 28 ❄️🌨️❄❄❄ | 29 | 30 ✅ | 31 | 1 |
| February | 2 ✅ | 3 | 4 ✅ | 5 | 6 ✅ | 7 | 8 |
| | 9 ✅ | 10 | 11 HWB due ✅ | 12 | 13 ✅ | 14 | 15 |
| | 16 ✅ | 17 | 18 ✅ | 19 | 20 HWC due ✅ | 21 | 22 |
| | 23 Hegi Center ✅ | 24 | 25 HWD due ✅ | 26 | 27 ✅ | 28 | 1 |
| March | 2 ✅ | 3 | 4 HWE due | 5 | 6 ✅ | 7 | 8 |
| | 9 ✅ | 10 | 11 | 12 | 13 Midterm | 14 | 15 |
| | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 ✅ | 24 | 25 | 26 | 27 ✅ | 28 | 29 |
| April | 30 Lecture 11 ✅ | 31 | 1 HWF due | 2 | 3 | 4 | 5 |

Labs

Lectures

# Schedule

No class

| Month | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---|---|---|---|---|---|---|---|
| April | 6 Midterm 2 ✅ | 7 | 8 HWG due | 9 | 10 Lecture 15 ✅ | 11 | 12 |
| | 13 Lecture 16 ✅ | 14 | 15 HWH due | 16 | 17 Lecture 17 ✅ | 18 | 19 |
| | 20 Lecture 18 ✅ | 21 | 22 HWI due | 23 | 24 Lecture 19 ✅ | 25 | 26 |
| May | 27 Lecture 20 ✅ | 28 | 29 HWJ due | 30 | 1 Lecture 21 ✅ | 2 | 3 |
| | 4 Lecture 22 ✅ | 5 Lecture 23 ✅ | 6 | 7 | 8 | 9 | 10 |

# Halliday Resnik: Multiple Sources (Halliday: 36.4 & 36.7), and Black Body Radiation (Halliday: 38.4 & 44.4)

# For the final grade: need all of this to be done

| Homework I<br>Out of 100 | Homework J<br>Out of 100 | Homework H<br>Out of 100 | Homework G<br>Out of 100 | Homework F<br>Out of 100 | Homework E<br>Out of 100 |
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| | – | | | | |

# For the final grade: need all of this to be done

| Lab 11: Radioactivity<br>Out of 100 | Lab 10: Spectrometers<br>Out of 12 | Lab 9: e/m ratio<br>Out of 100 | Lab 8: Ripple Tank<br>Out of 100 | Lab 7: speed of light in a ca<br>Out of 100 |
|---|---|---|---|---|
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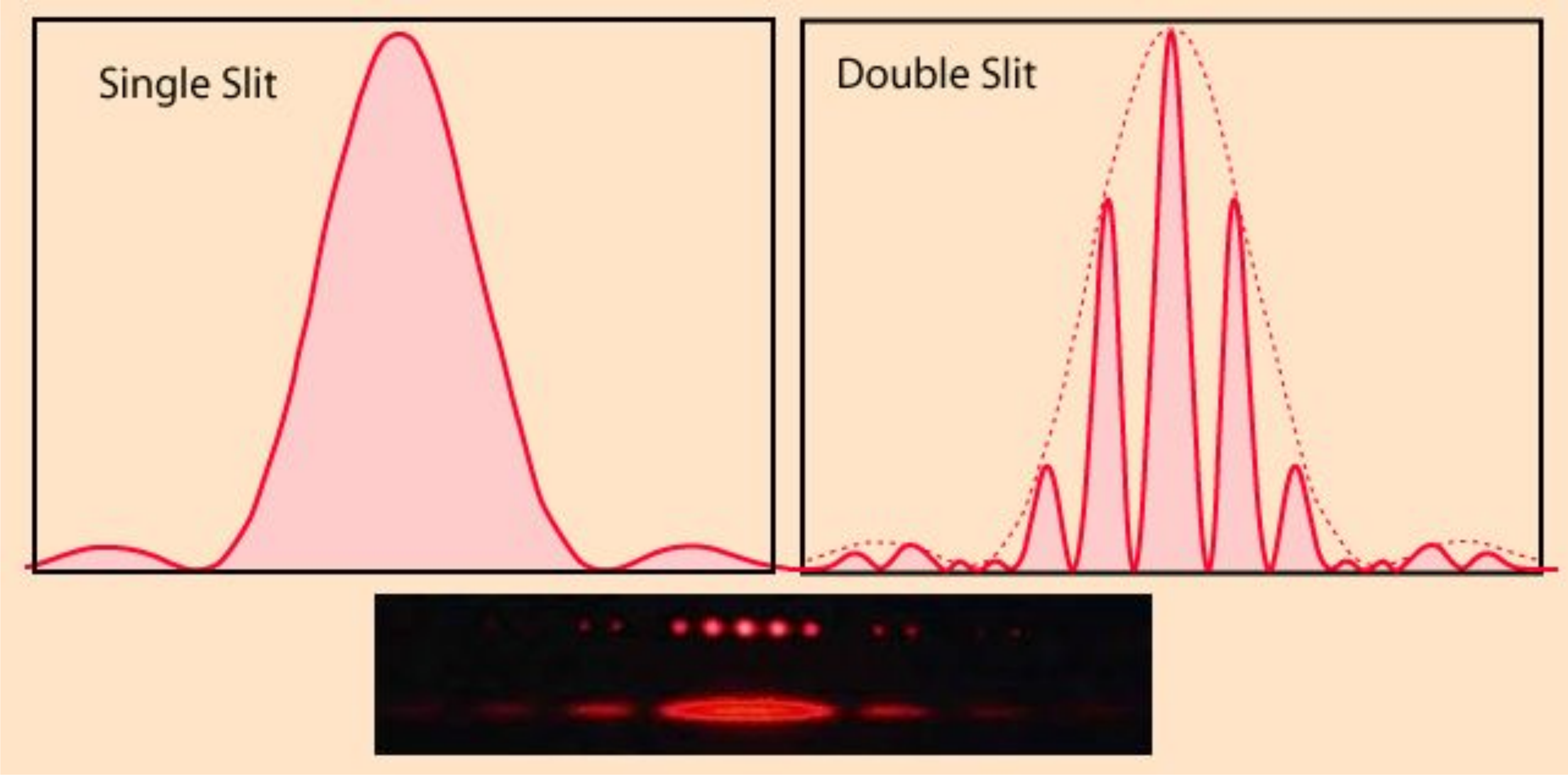
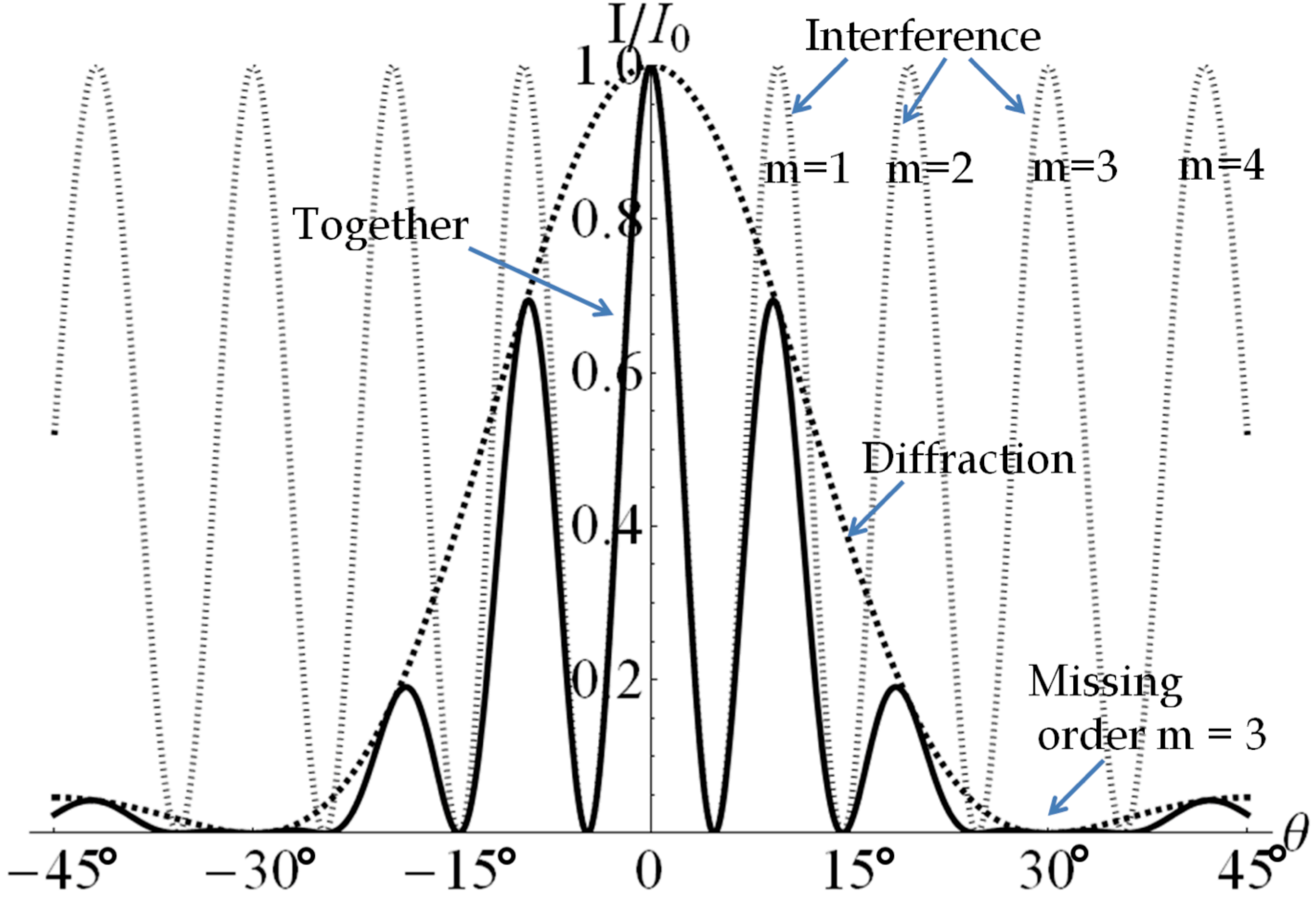
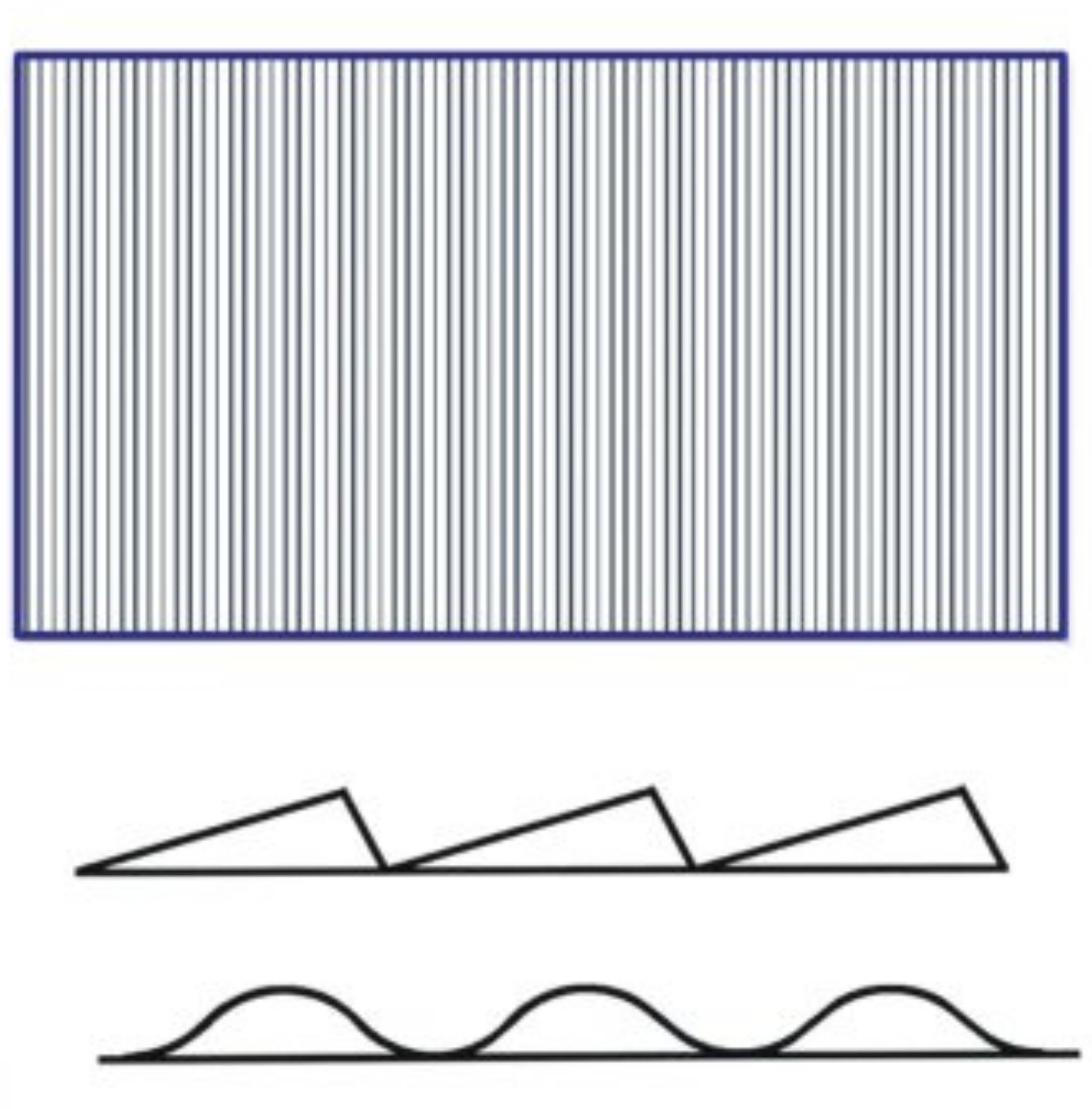
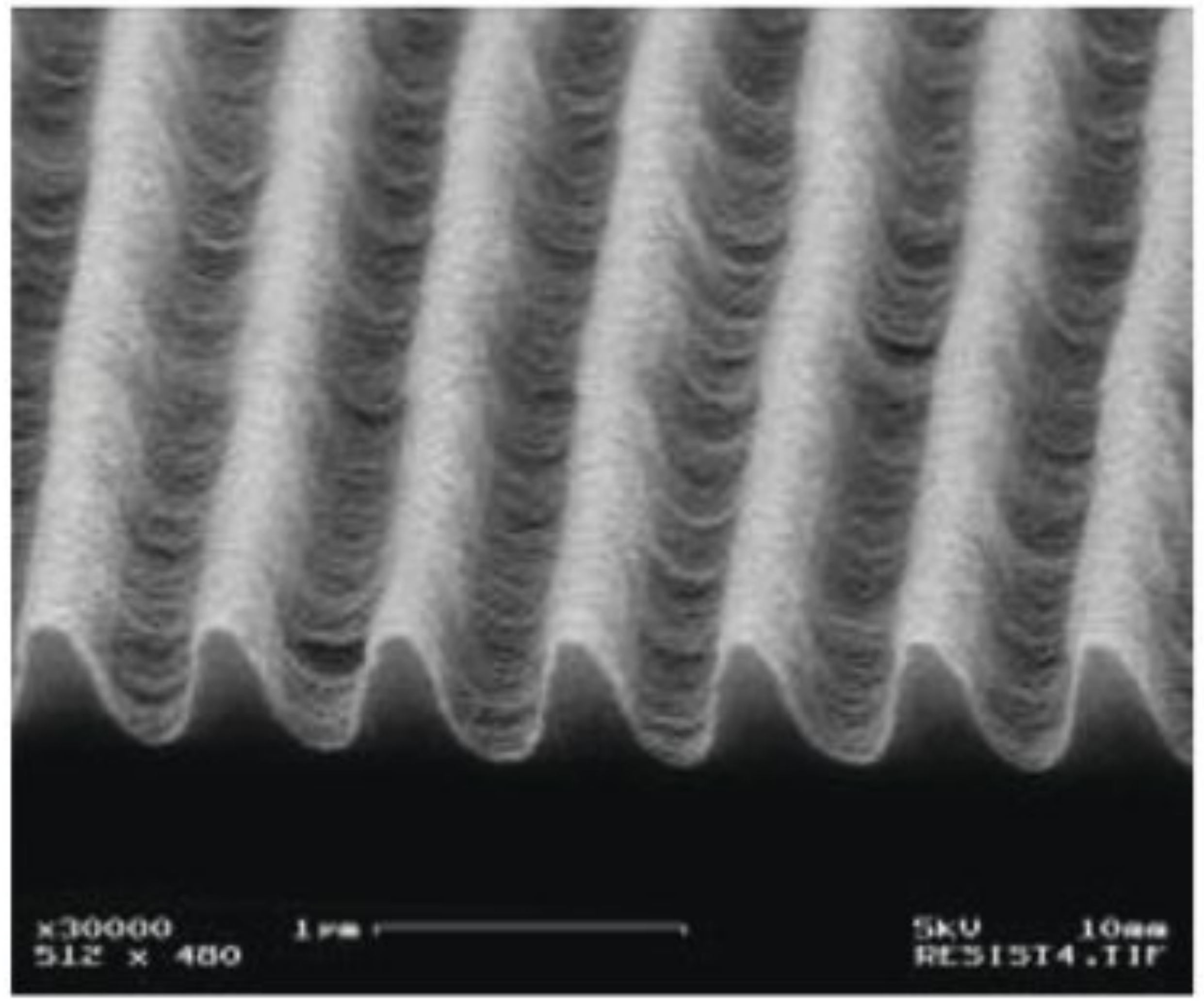

Single Slit
Double Slit

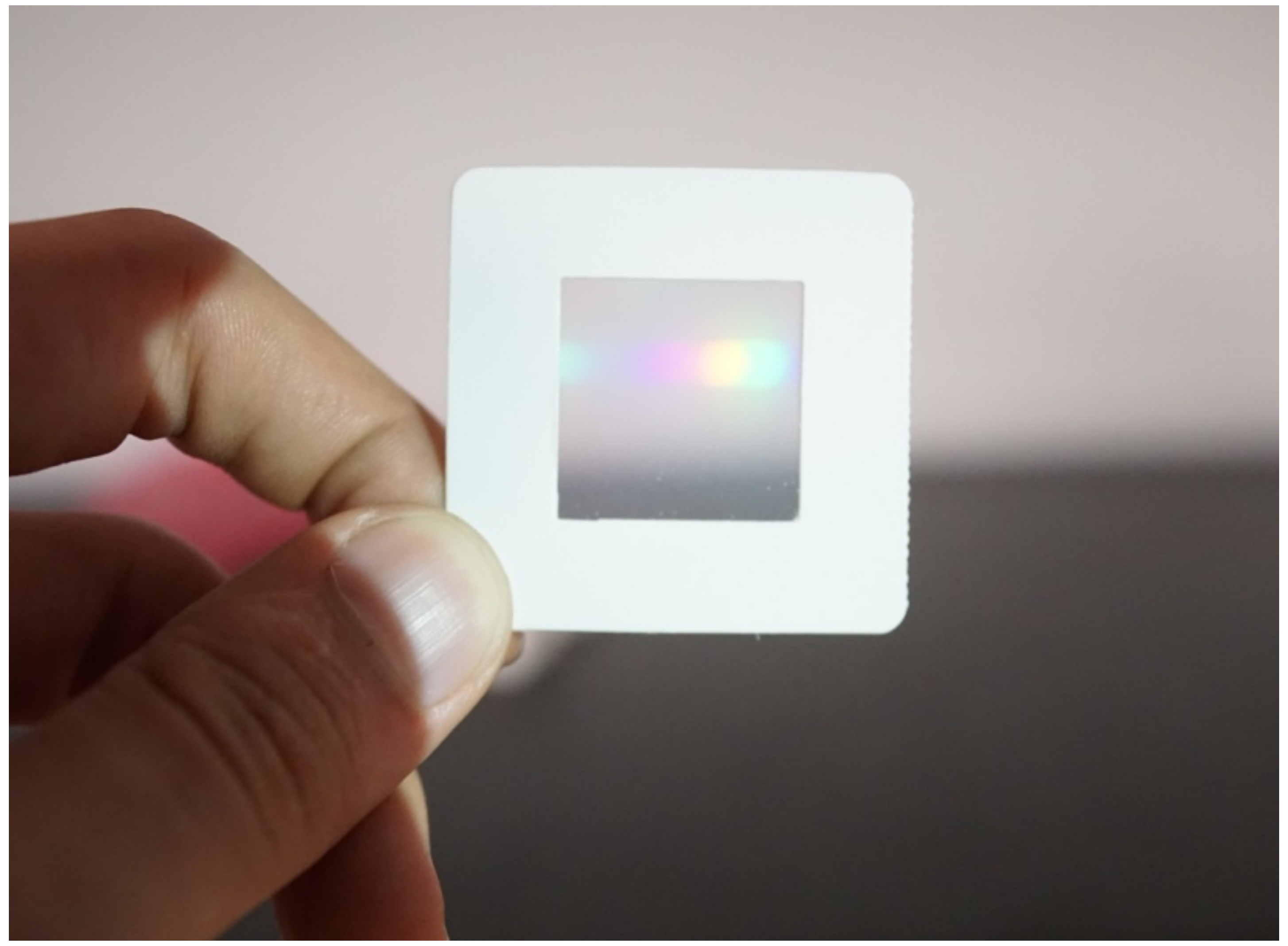


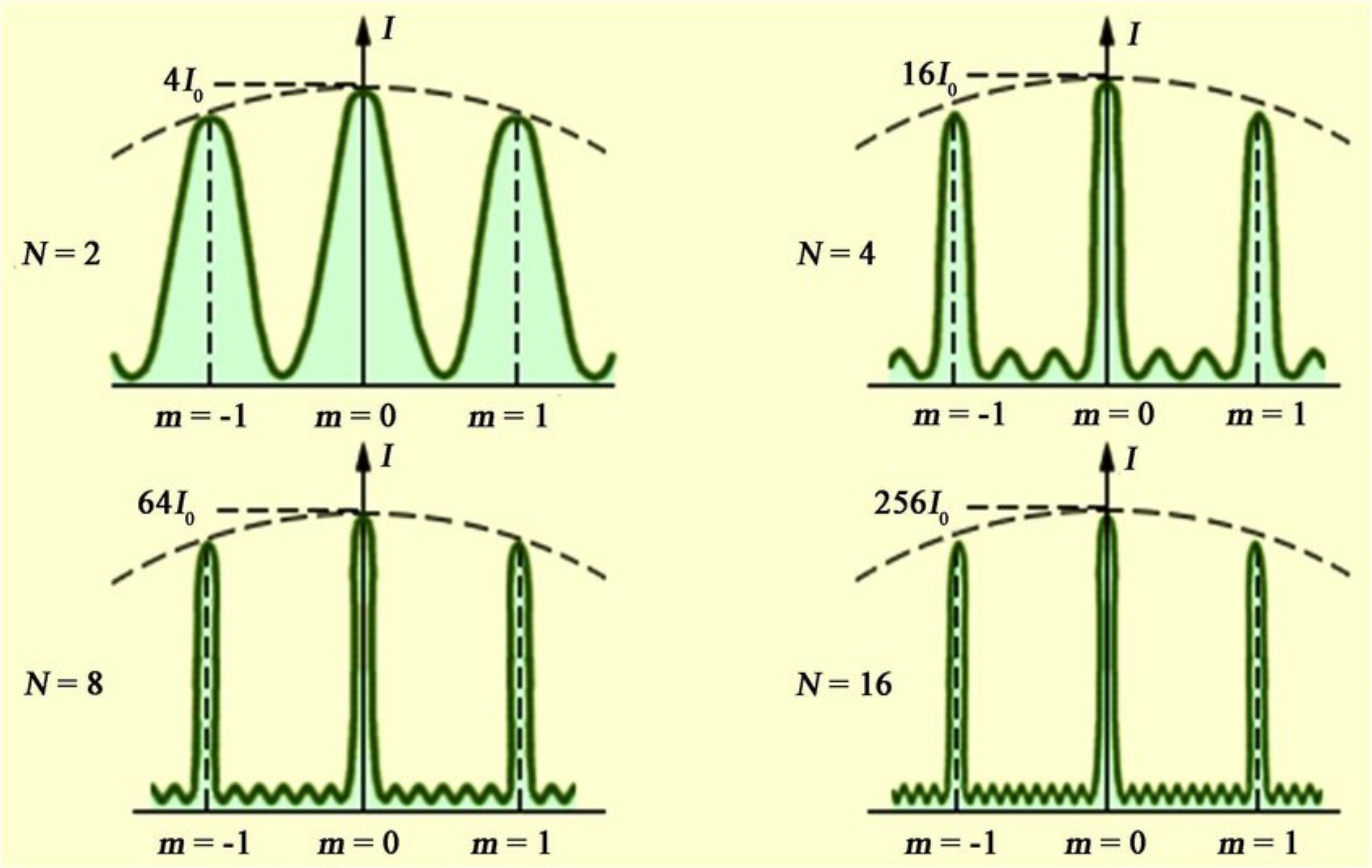
I/$I_0$
Interference
1.0
0.8
0.6
0.4
0.2
m=1
m=2
m=3
m=4
Together
Diffraction
Missing order m = 3
θ
−45°
−30°
−15°
0
15°
30°
45°

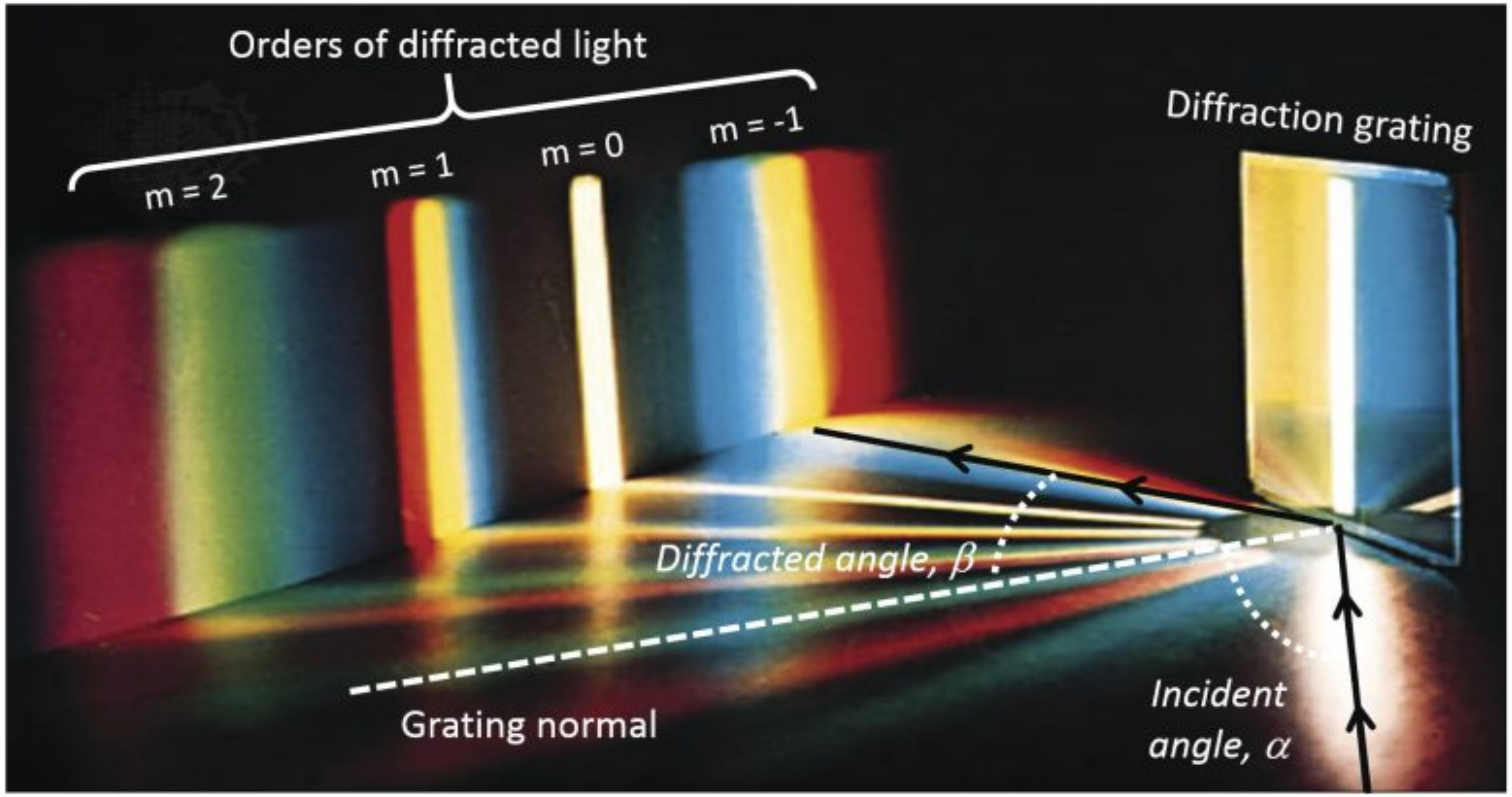
# Diffraction (Reflection or Transmission) Grating






I
4I0
N = 2
m = -1
m = 0
m = 1
I
16I0
N = 4
m = -1
m = 0
m = 1
I
64I0
N = 8
m = -1
m = 0
m = 1
I
256I0
N = 16
m = -1
m = 0
m = 1


Orders of diffracted light
m = 2
m = 1
m = 0
m = -1
Diffraction grating
Diffracted angle, β
Grating normal
Incident
angle, α

# Key concepts: Diffraction by a double slit

- Intensity of a double-slit interference pattern is given by:
- $I(\theta) = I_m(\cos^2 \beta)\left(\frac{\sin \alpha}{\alpha}\right)^2$
- $\beta = \frac{\pi d}{\lambda} \sin \theta$
- $\alpha = \frac{\pi d}{\lambda} \sin \theta$
- $d$ is the distance between the centers of the slits
- $a$ is the slit distance
- Interference factor: $\cos^2 \beta$
- Diffraction factor: $\left(\frac{\sin \alpha}{\alpha}\right)^2$

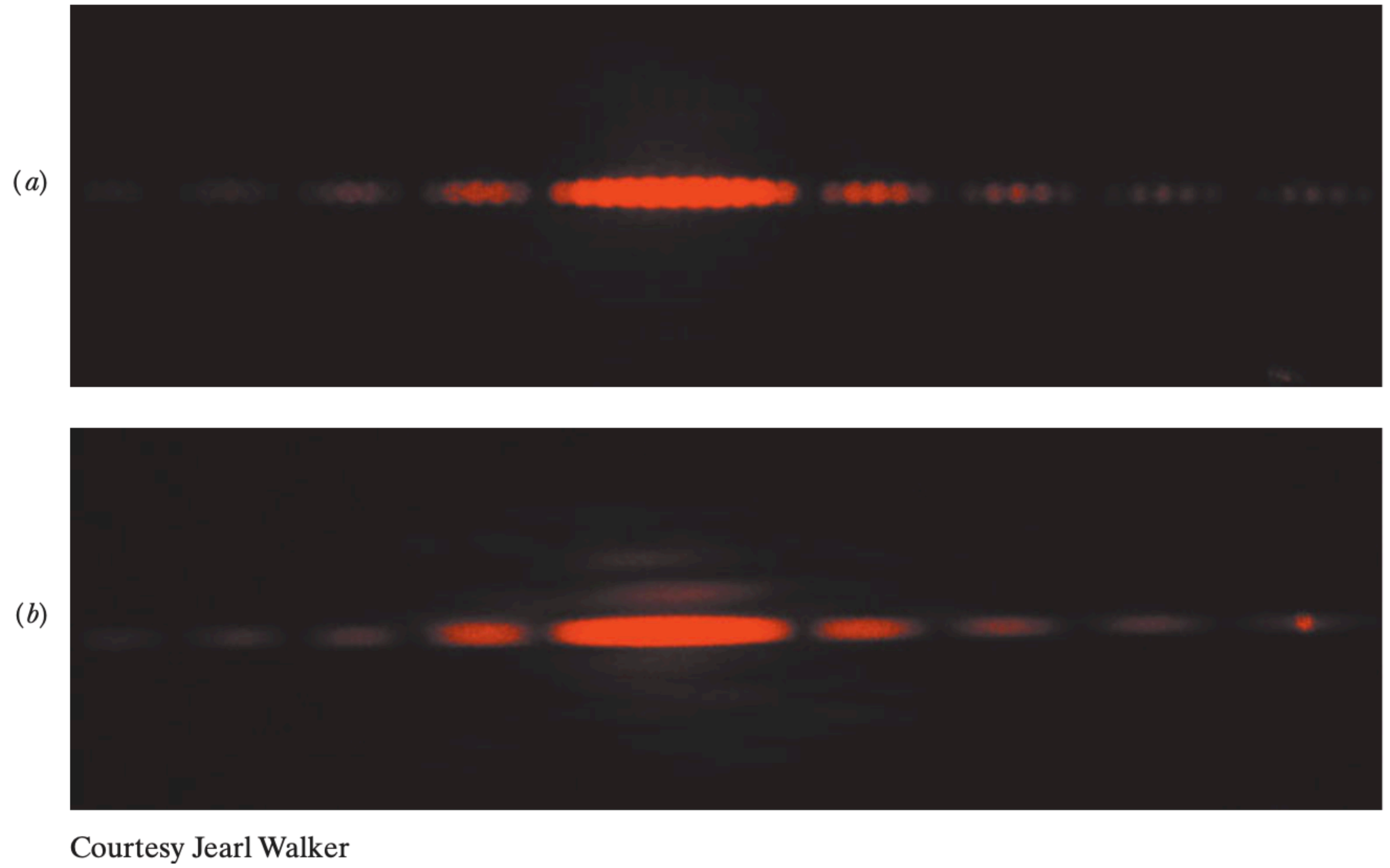



**Figure 36-16** (*a*) Interference fringes for an actual double-slit system; compare with Fig. 36-15*c*. (*b*) The diffraction pattern of a single slit; compare with Fig. 36-15*b*.

# Key concepts: Diffraction gratings

- A diffraction grating is a series of “slits” used to separate an incident wave into its component wavelengths by separating and displaying their diffraction maxima
- Diffraction by $N$ (multiple) slits results in maxima (lines) at angles $\theta$ such that:
  - $d \sin\theta = m\lambda$, $m$ = 0, 1, 2, …
- A line’s half-width is the angle from its center to the point where it disappears into the darkness and is given by:
  - $$\Delta\theta_{hw} = \frac{\lambda}{Nd\cos\theta}$$

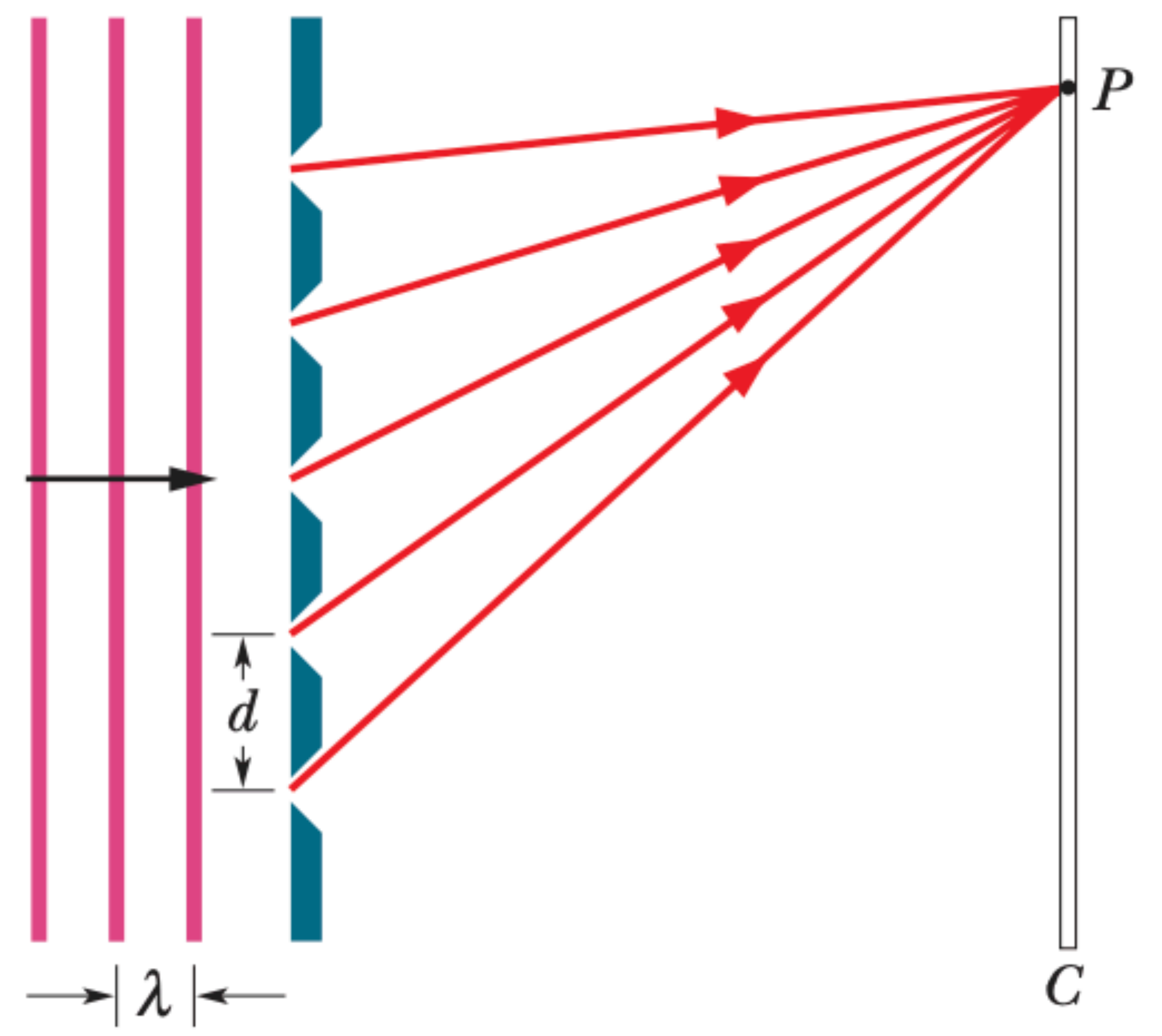



**Figure 36-18** An idealized diffraction grating, consisting of only five rulings, that produces an interference pattern on a distant viewing screen *C*.

# Key concepts: Diffraction gratings

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- A line’s half-width is the angle from its center to the point where it disappears into the darkness and is given by:
    - $$\Delta\theta_{hw} = \frac{\lambda}{Nd\cos\theta}$$
    - $N$ rays from $N$ slits cancel one another

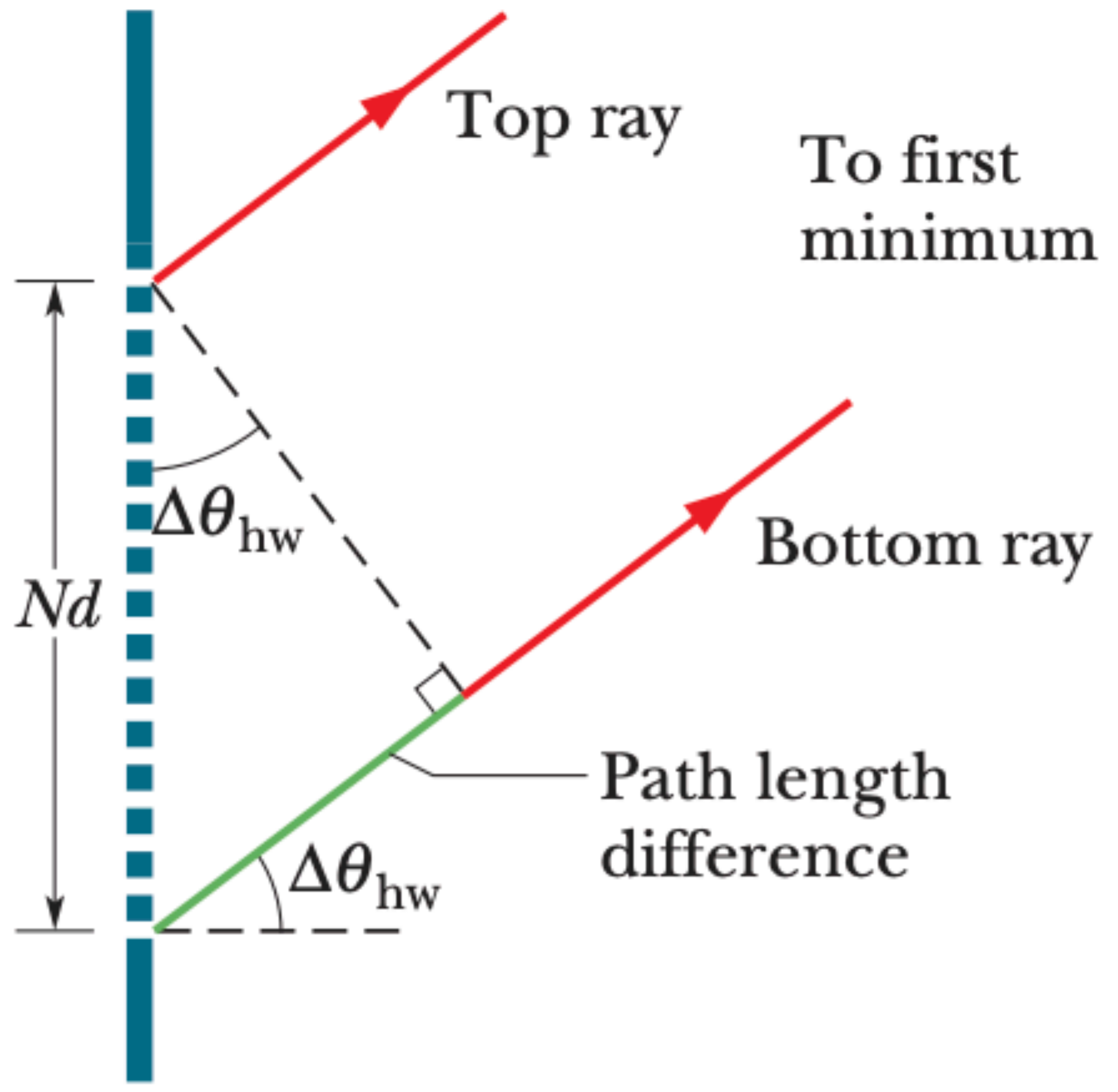


**Figure 36-22** The top and bottom rulings of a diffraction grating of $N$ rulings are separated by $Nd$. The top and bottom rays passing through these rulings have a path length difference of $Nd \sin\Delta\theta_{hw}$, where $\Delta\theta_{hw}$ is the angle to the first minimum. (The angle is here greatly exaggerated for clarity.)

# Key concepts: Diffraction gratings and resolving power

- The dispersion $D$ of a diffraction grating is a measure of the angular separation $\Delta\theta$ of the lines it produces for two wavelengths differing by $\Delta\lambda$. For order number $m$, at angle $\theta$, the dispersion is given by:
  - $D = \frac{\Delta\theta}{\Delta\lambda} = \frac{m}{d\cos\theta}$ (can be derived by taking differential of $d\sin\theta = m\lambda$)
- Resolving power of a diffraction grating is a measure of its ability to make the emission lines of two close wavelengths distinguishable
- For two wavelengths differing by $\Delta\lambda$ and with an average value of $\lambda_{\text{avg}}$, the resolving power is given by ($N$ = number of rulings):
  - $R = \frac{\lambda_{\text{avg}}}{\Delta\lambda} = Nm$

What is the separation between successive lines (slits) in a diffraction grating if the density of lines is 1400/cm.

A. 1400 cm
B. 2.14 cm
C. 0.47 cm
D. 7.14 μm
E. 3.33 μm

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A. 1400 cm
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C. 0.47 cm
D. 7.14 μm
E. 3.33 μm

$$d = \frac{1}{N} = \frac{1}{1400} \approx 0.00071428 \text{ cm}$$

Is the half-width of spectral lines produced by green monochromatic light sent through a diffraction grating

a)Less than that of red light?

b)More than that of red light?

c)The same as that of red light?

Is the half-width of spectral lines produced by green monochromatic light sent through a diffraction grating

a) Less than that of red light?

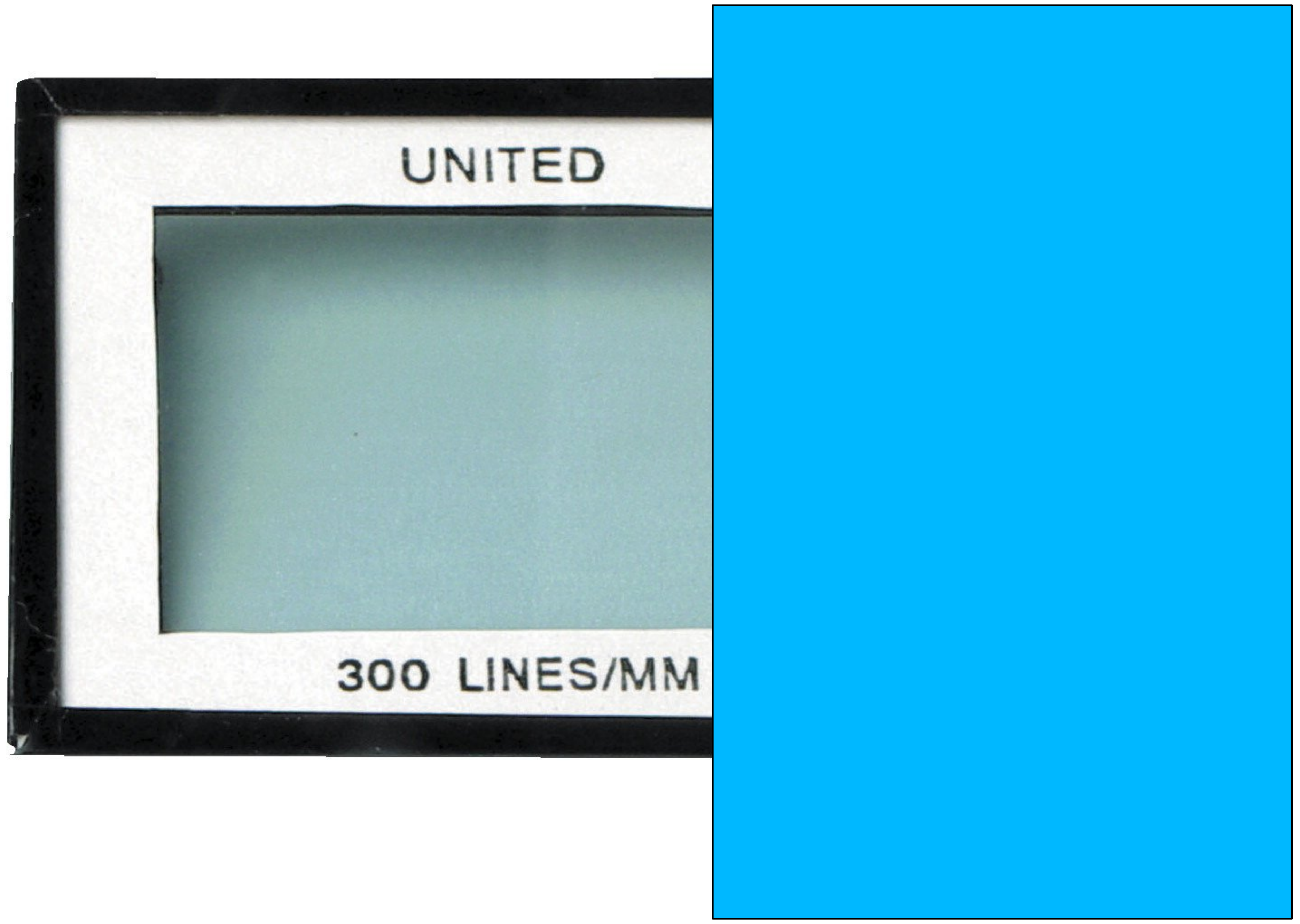
b) More than that of red light?

c) The same as that of red light?

- Green has a shorter wavelength than red ($\lambda_{green} < \lambda_{red}$)
- Half-width formula: $\Delta\theta_{hw} = \dfrac{\lambda}{Nd\cos\theta}$
- Standard equation: $d\sin\theta = m\lambda$

If we cover part of the grating with opaque tape, what happens to the resolving power?

A. It stays the same
B. It increases
C. It decreases



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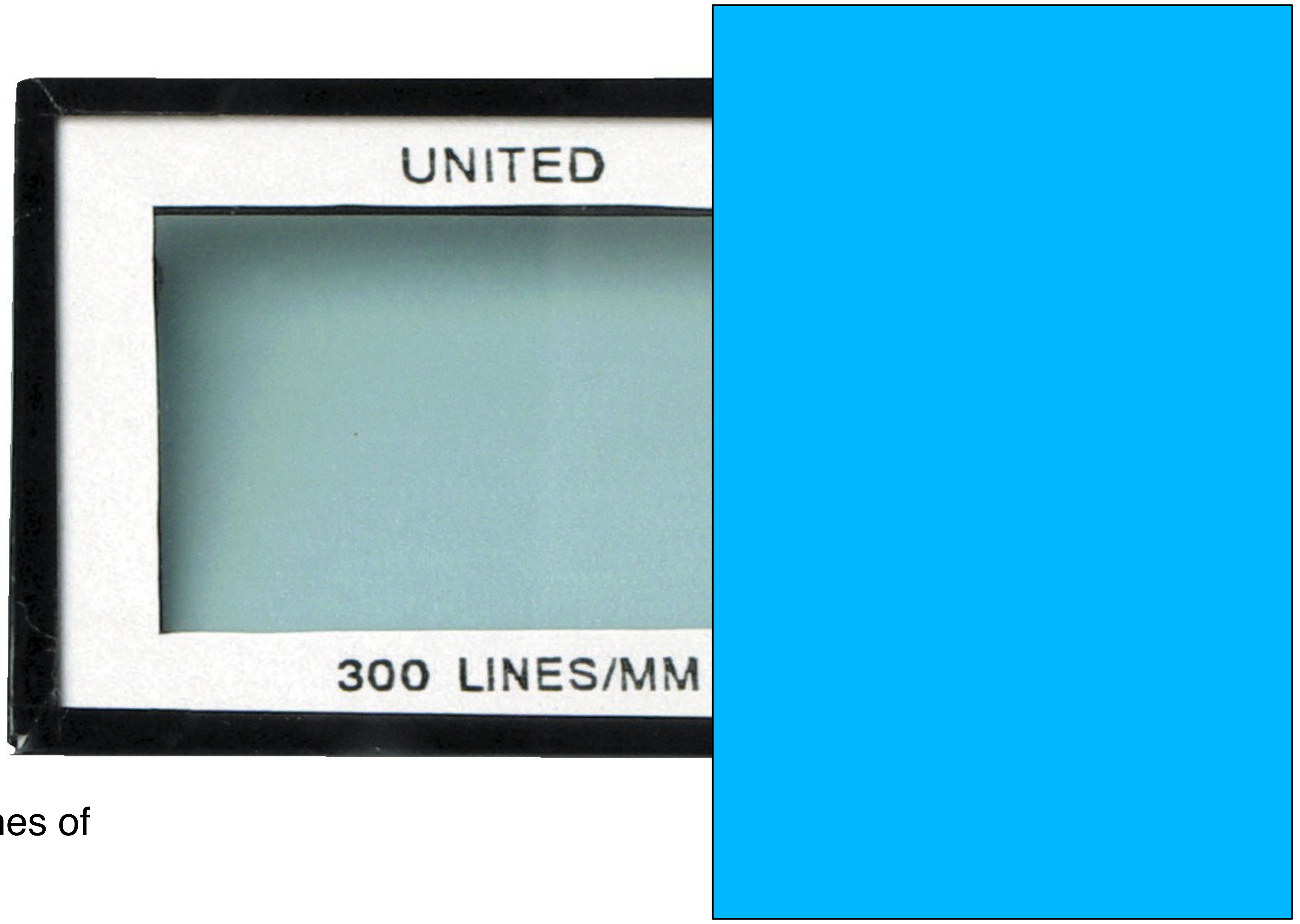



The resolving power ($R$) of a diffraction grating is its ability to separate adjacent spectral lines of slightly different wavelengths. The formula for resolving power is:

$$R = N \cdot m$$

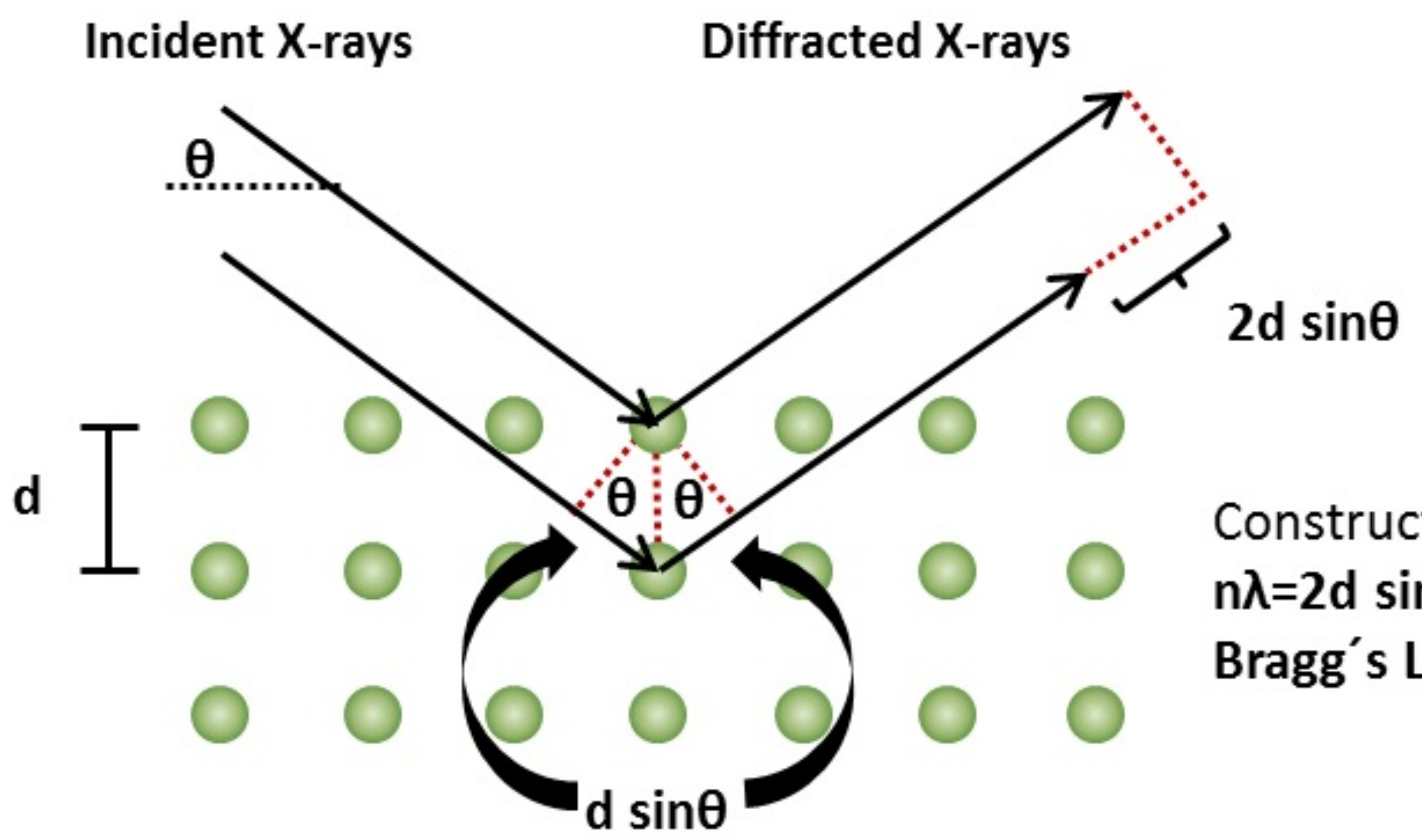
Where:

- **$N$** is the total number of illuminated slits (lines) on the grating.
- **$m$** is the spectral order of the diffraction pattern.

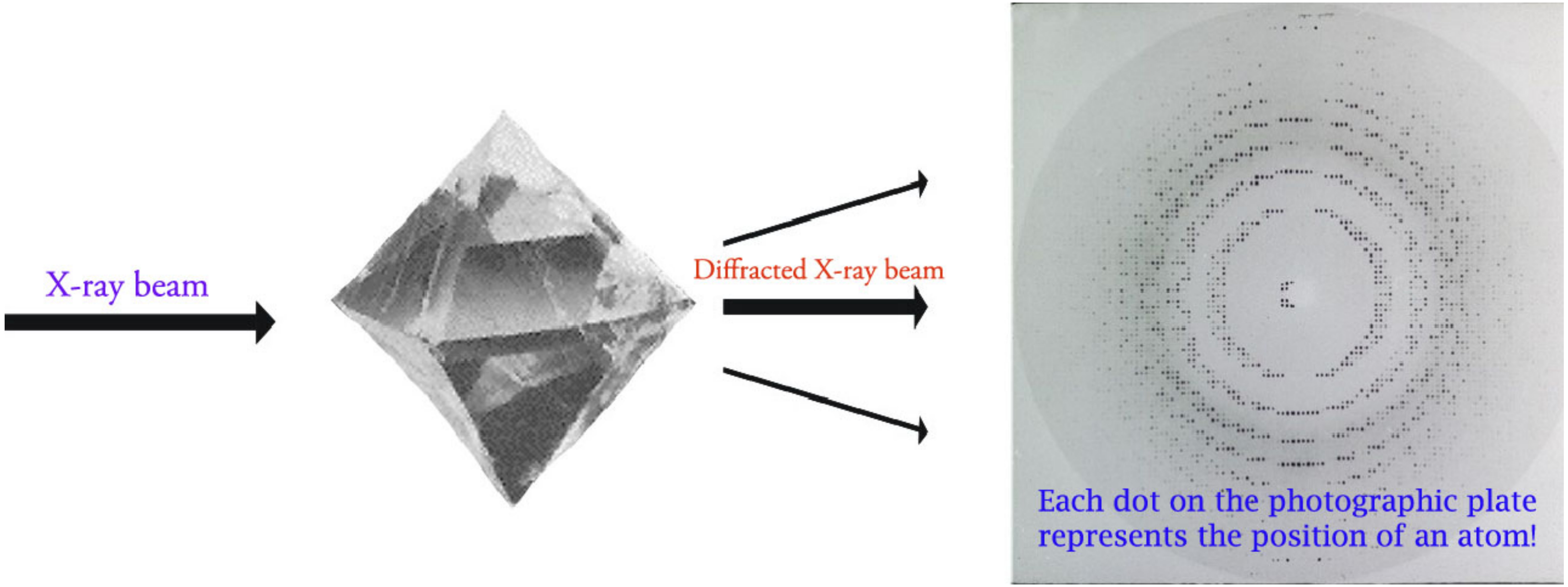
When you cover part of the grating with opaque tape, you are physically blocking light from passing through a portion of the slits. This reduces the total number of illuminated slits ($N$). Because resolving power is directly proportional to the number of exposed slits, decreasing $N$ will proportionally decrease the grating's resolving power $R$.

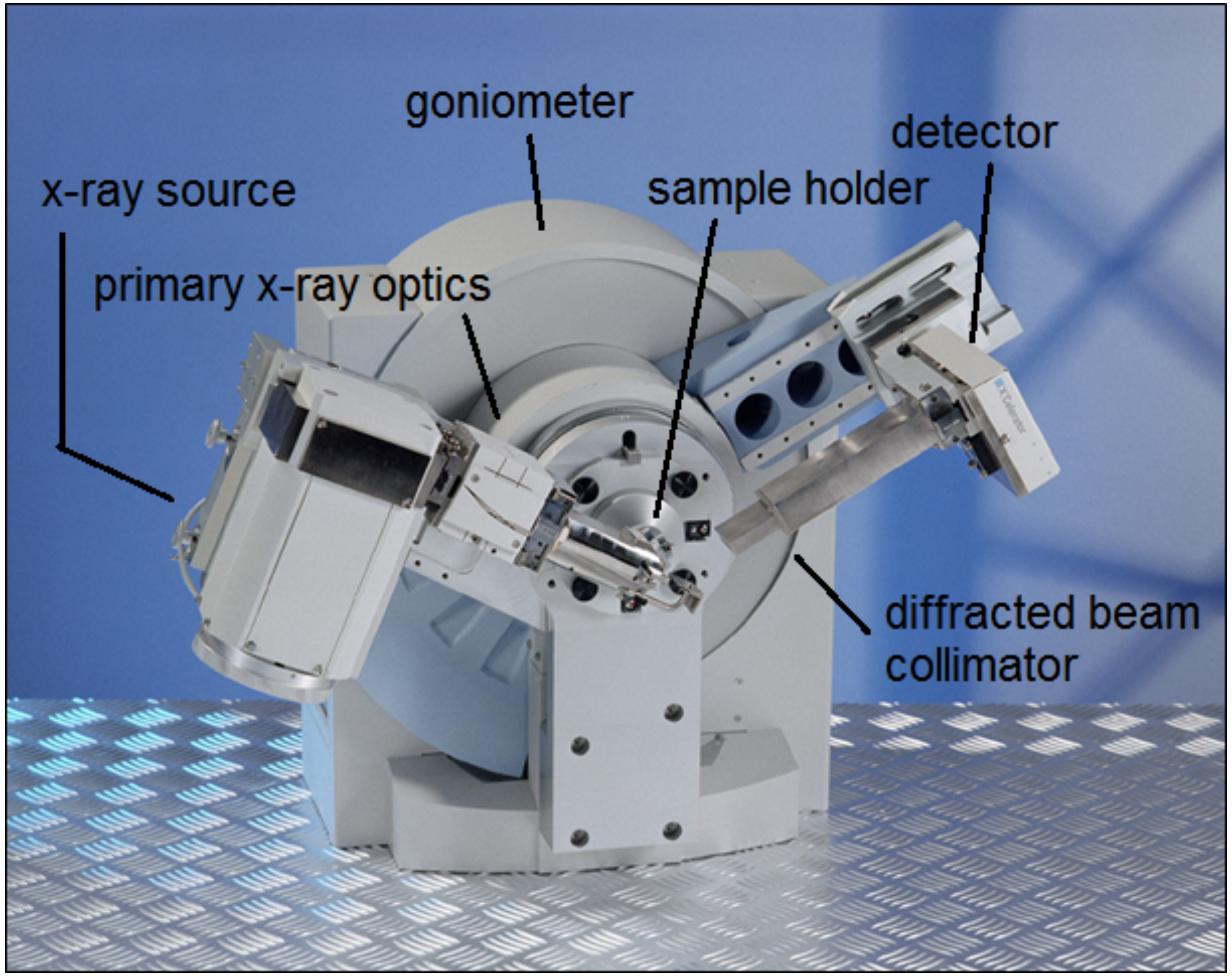
In practical terms, this means the spectral lines will become broader and blurrier, making it harder to distinguish between two closely spaced wavelengths.

# X-Ray Diffraction




Constructive interference when
**nλ=2d sinθ**
**Bragg´s Law**


X-ray beam
Diffracted X-ray beam
Each dot on the photographic plate
represents the position of an atom!


goniometer
detector
x-ray source
sample holder
primary x-ray optics
diffracted beam
collimator

First-order monochromatic X rays reflect from a particular family of crystal planes at angles 17°, 35°, and 59° to the planes.

Rank them according to the associated path length difference of the X rays, greatest first

a)17°, 35°, 59°
b)17°, 59°, 35°
c)59° , 35°, 17°
d)35°, 17°, 59°

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Rank them according to the associated path length difference of the X rays, greatest first

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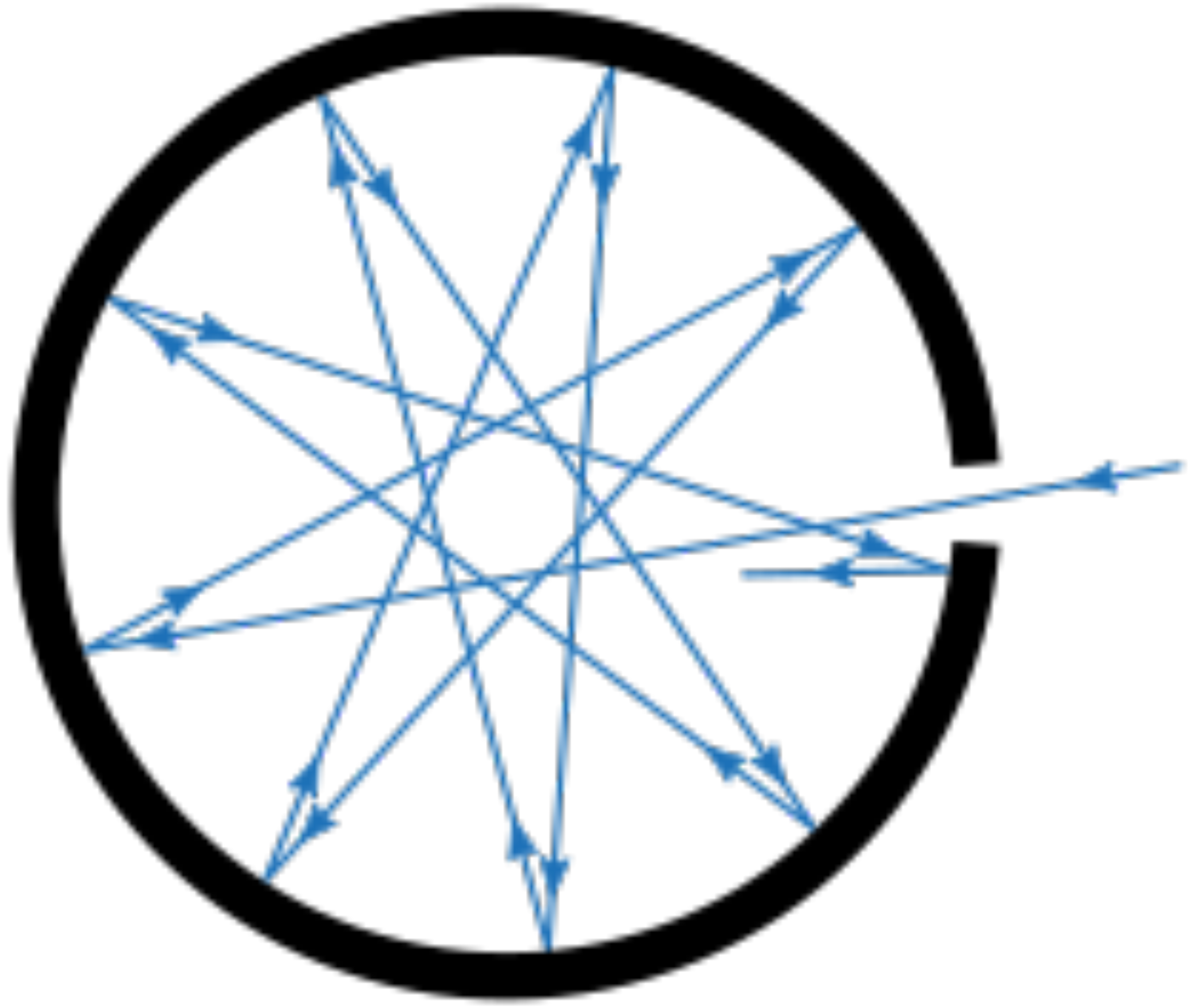
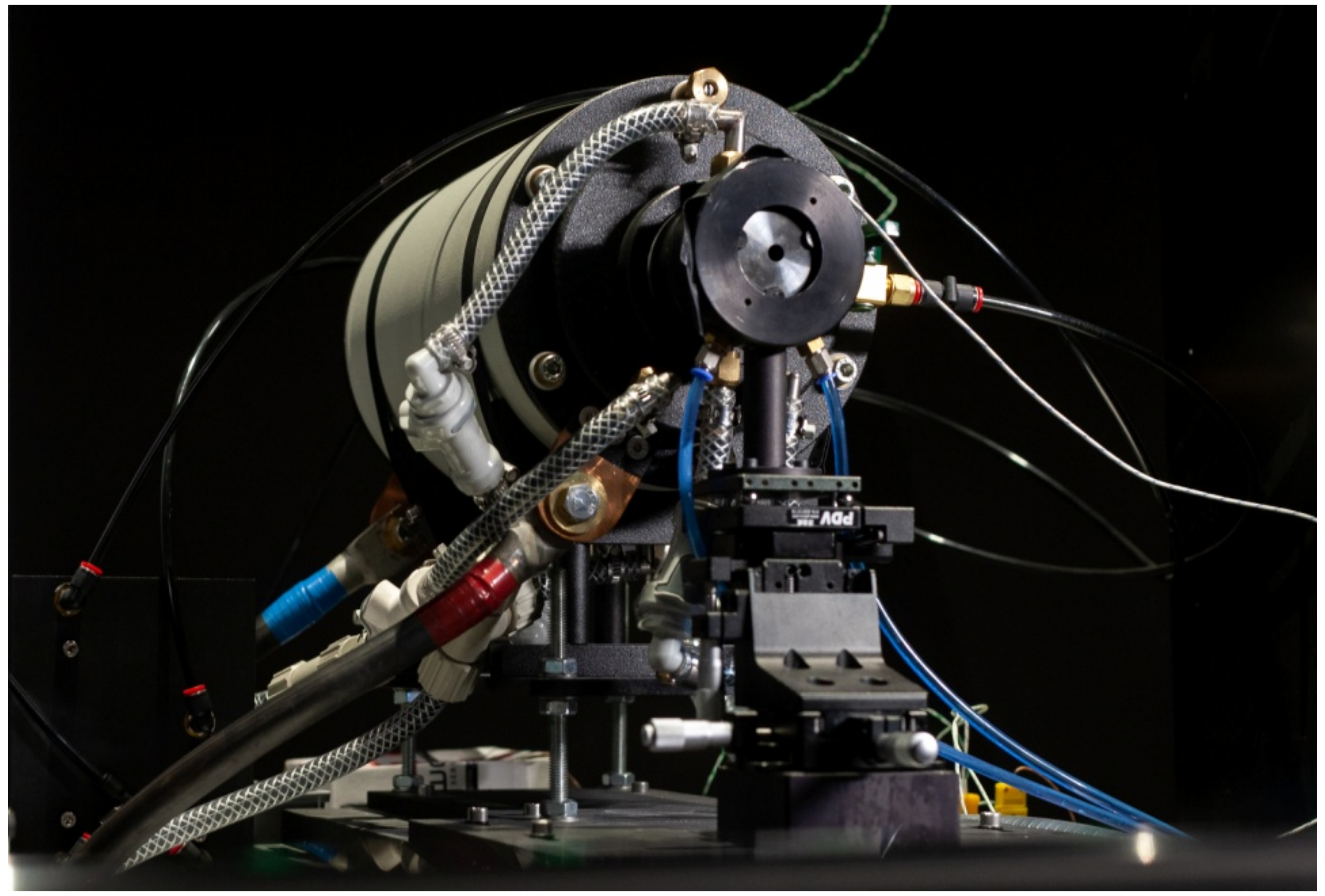
d)35°, 17°, 59°

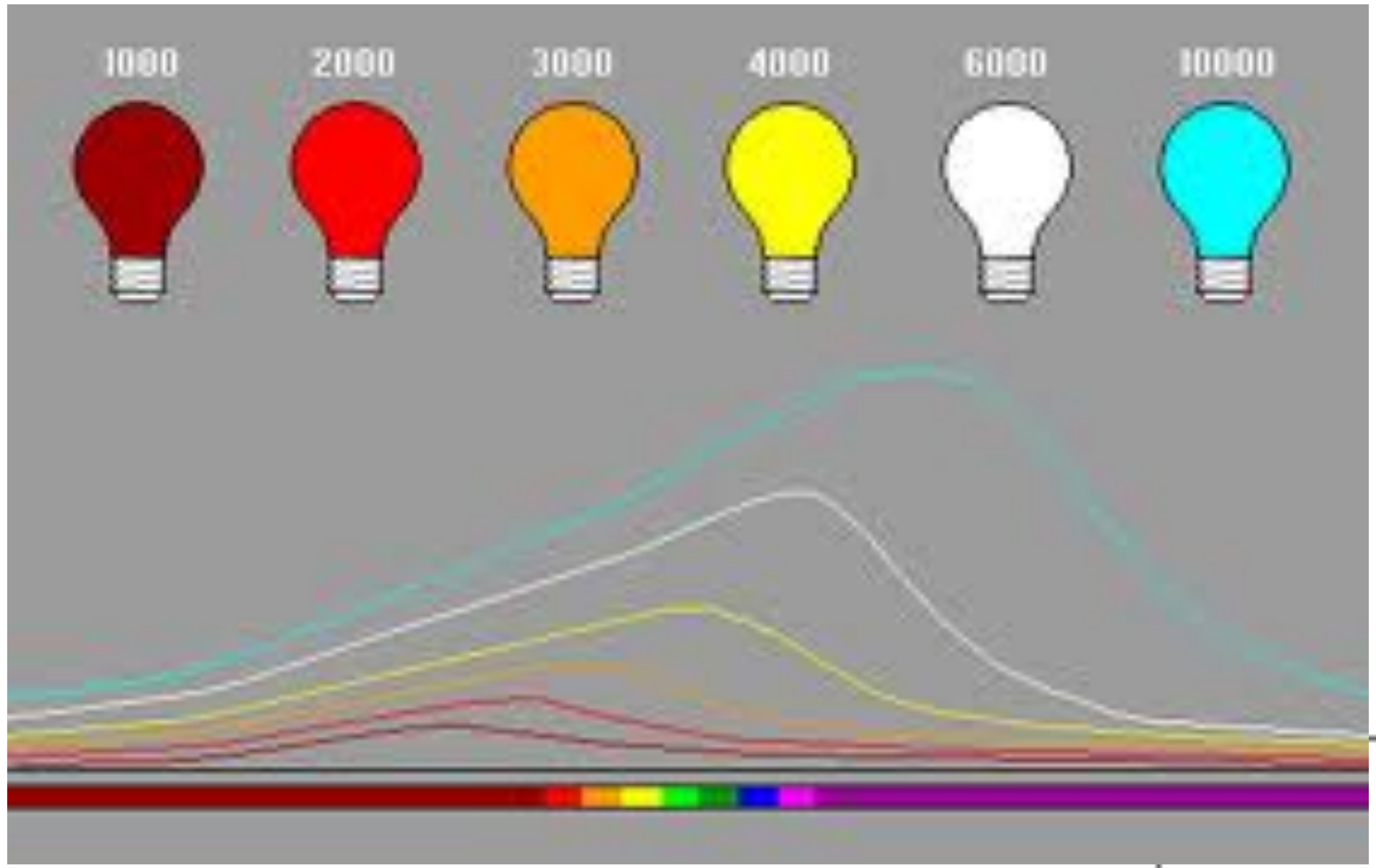
In X-ray diffraction, the path length difference between waves reflecting from adjacent crystal planes is given by the formula: $2d \sin\theta$

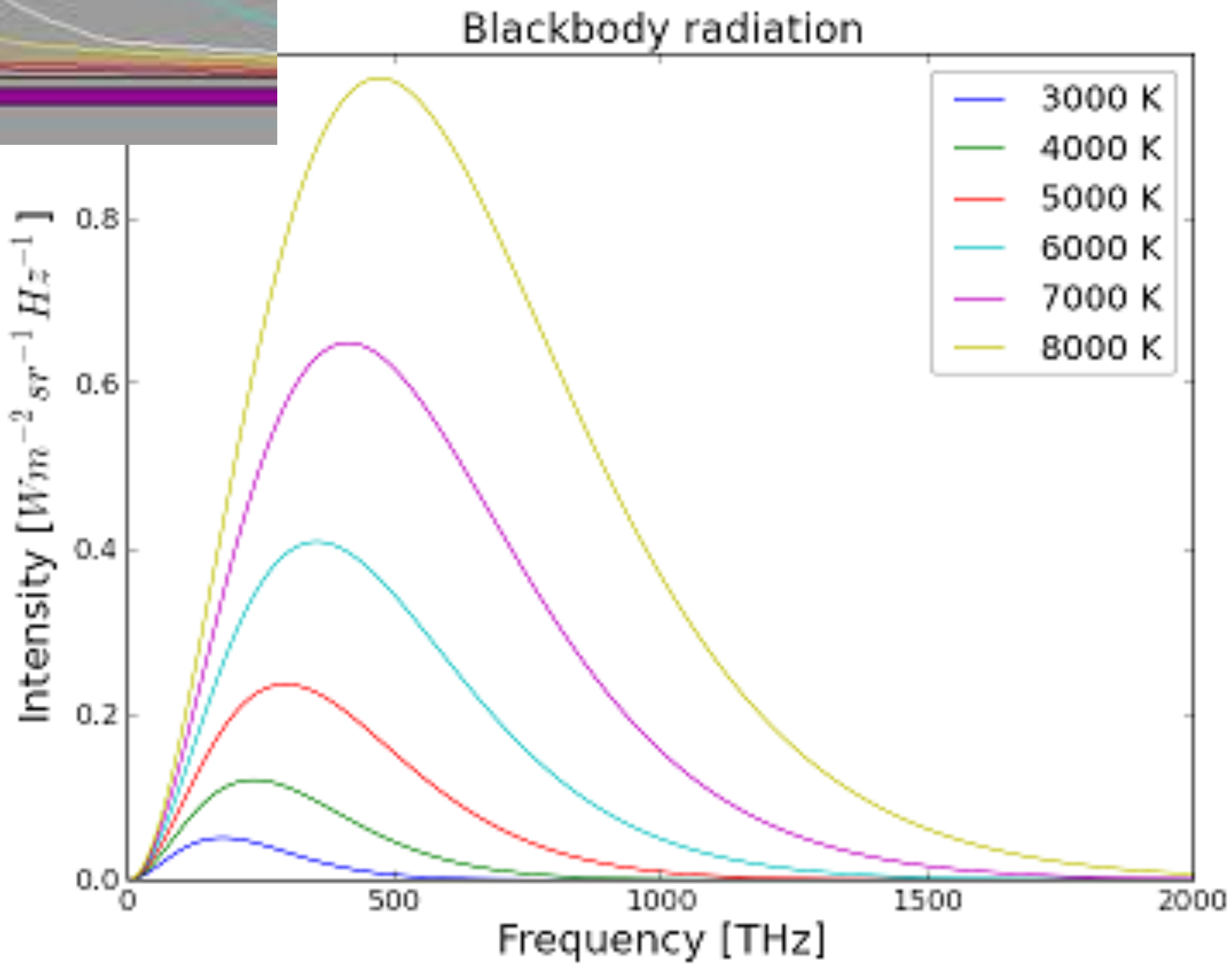




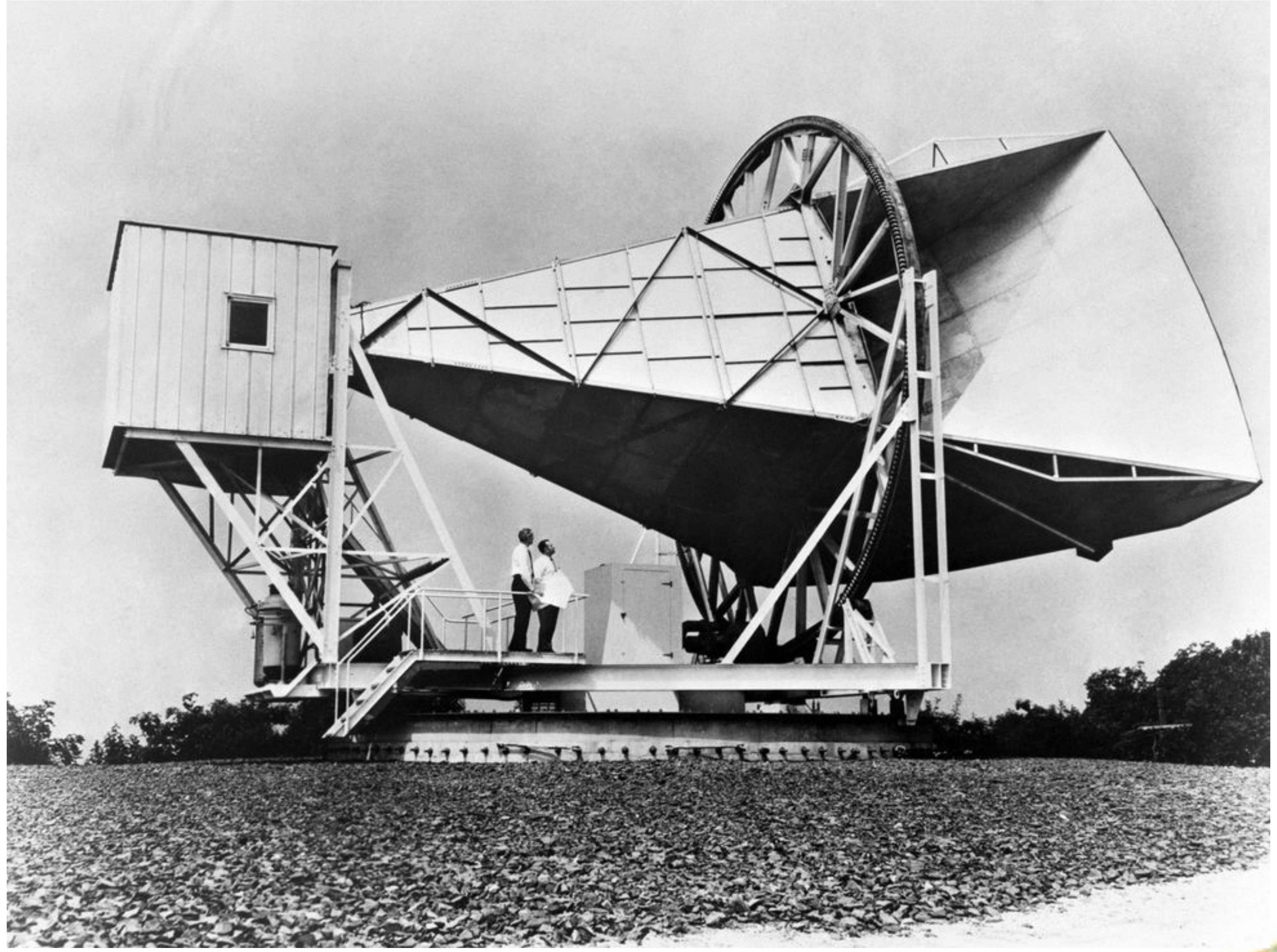
# Key concepts: Black Body Radiation

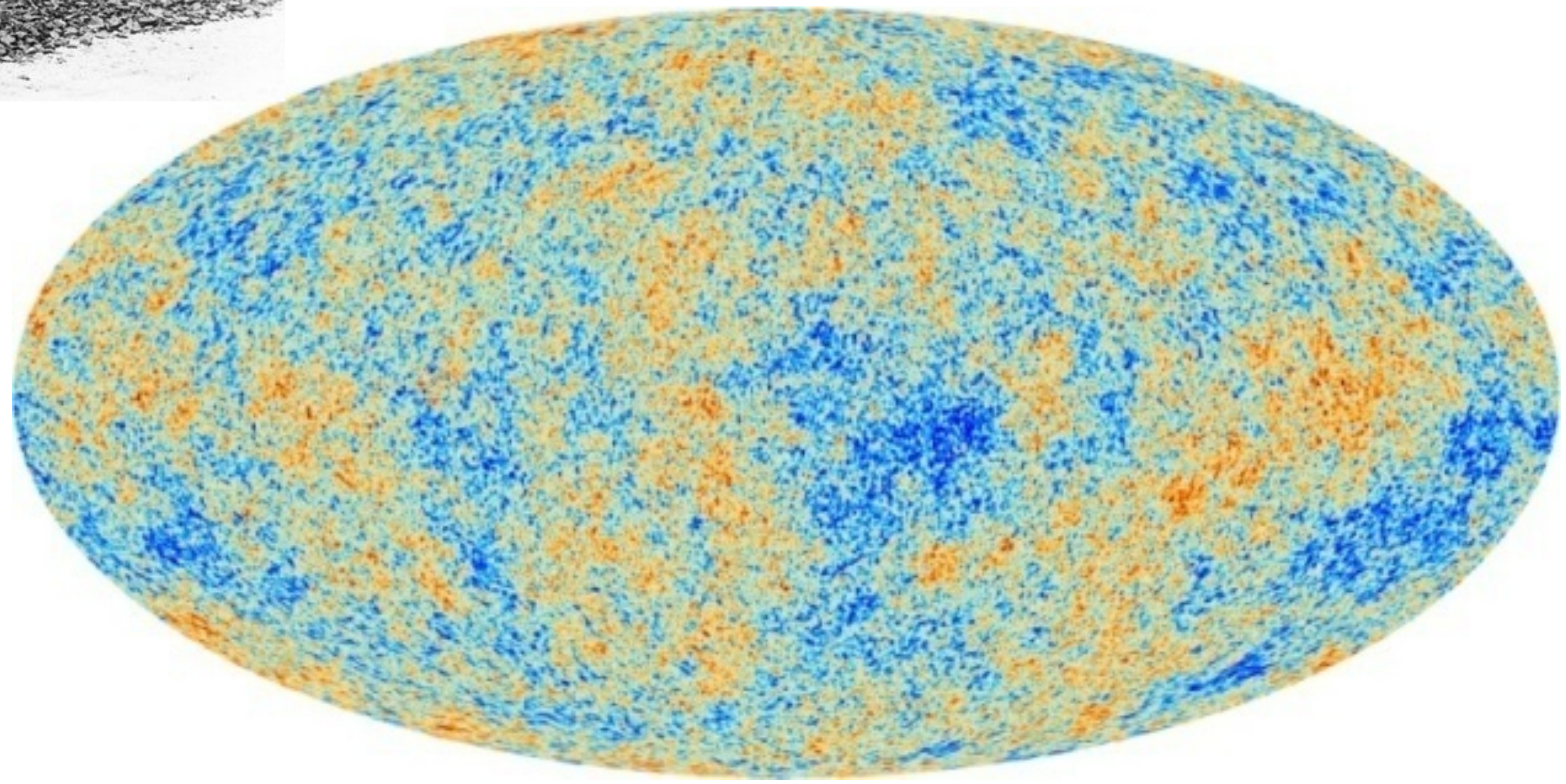
- As a measure of the emission of thermal radiation by an ideal blackbody radiator, we define the spectral radiancy in terms of the emitted intensity per unit wavelength at a given wavelength $\lambda$:
  - $S(\lambda) = \dfrac{\text{intensity}}{\text{unit wavelength}}$
- Planck's radiation law, in which atomic oscillators produce the thermal radiation:
  - $S(\lambda) = \dfrac{2\pi c^2 h}{\lambda^5} \dfrac{1}{e^{\frac{hc}{\lambda kT}} - 1}$
  - $h$ = Planck's constant
  - $k$ = Boltzmann constant
  - $T$ = temperature
- Planck's law was the first suggestion that the energies of the atomic oscillators producing the radiation are quantized
- Wavelength $\lambda_{\max}$ at which $S(\lambda)$ is maximum: $\lambda_{\max} T = 2898\ \mu m \cdot K$ (Wien's law)
- Radiated power: $P = \sigma \epsilon A T^4$


1000
2000
3000
4000
6000
10000


Blackbody radiation
3000 K
4000 K
5000 K
6000 K
7000 K
8000 K
Intensity $[Wm^{-2}sr^{-1}Hz^{-1}]$
0.0
0.2
0.4
0.6
0.8
0
500
1000
1500
2000
Frequency [THz]

# Cosmic Microwave Background





The Stefan-Boltzmann constant σ has SI units of

a) J/$m^2$ s $K^4$

b) J/m s $K^4$

c) J/s $K^4$

d) J/s $K^3$

e) J/$m^2$ $K^4$

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d) $J/s\ K^3$

e) $J/m^2\ K^4$

The relationship at which the maximum value of monochromatic emissive power of a black body occurs is termed

a) Planck's law

b) Wien's law

c) Stefan's law

d) Kirchoff's law

e) Einstein's law

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Similar pieces of copper were heated to the same temperature and then left in the environment to cool. Also, these pieces were painted with different colors of paints.

Which among the following paints will give the fastest cooling?

a) White

b) Black

c) Red

d) Blue

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As the wavelength declines, the intensity of black body radiation

a) Increases

b) Decreases

c) First decreases then increases

d) First increases then decreases

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a) Increases

b) Decreases

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The graph forms a characteristic curve with a distinct peak:

1. **Long Wavelengths:** At very long wavelengths (like infrared or radio waves), the intensity of the emitted radiation is relatively low, forming a long, slowly sloping tail on the right side of the graph.
2. **The Peak:** There is a specific wavelength where the emission intensity reaches its absolute maximum. (This peak shifts depending on the temperature of the object).
3. **Short Wavelengths:** At very short wavelengths (like ultraviolet or X-rays), the intensity drops rapidly toward zero.

What is the relation between absorptive power fraction $a$ and the emissive power fraction (emissivity) $e$ of the electromagnetic radiation from any body

a) $e < a$

b) $e = a$

c) $e > a$

d) no specific relation

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An iron rod is heated and the colors at different temperatures are noted.

Which among the following colors indicates that the rod is at the lowest temperature?

a) Red

b) White

c) Orange

d) Blue

e) Yellow

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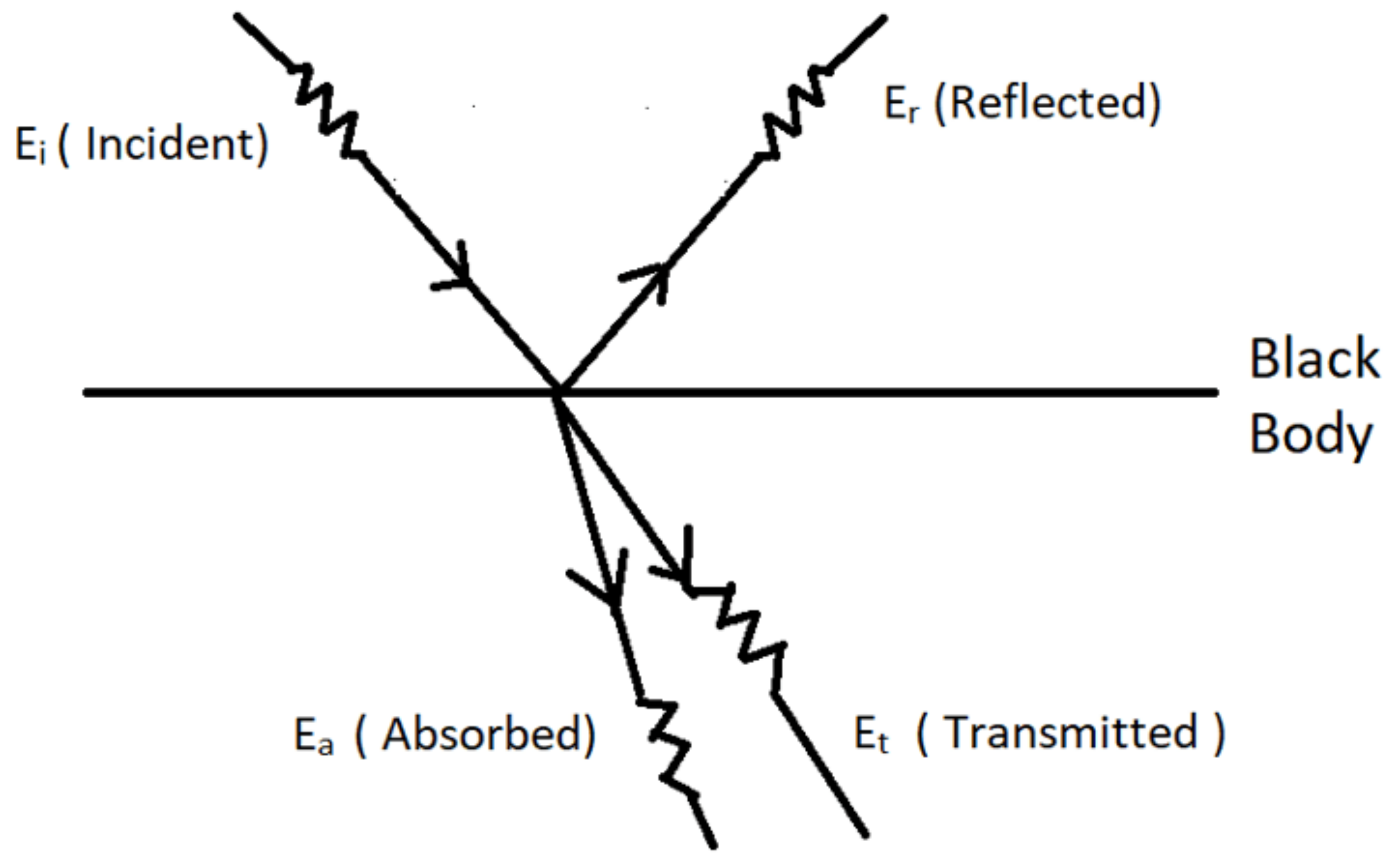
What is the relation between the energies E as shown when electromagnetic radiation is incident on the interface with a black-body ?




a) $E_r = 0$

b) $E_a = 0$

c) $E_t = E_i$

d) $E_i = E_r$

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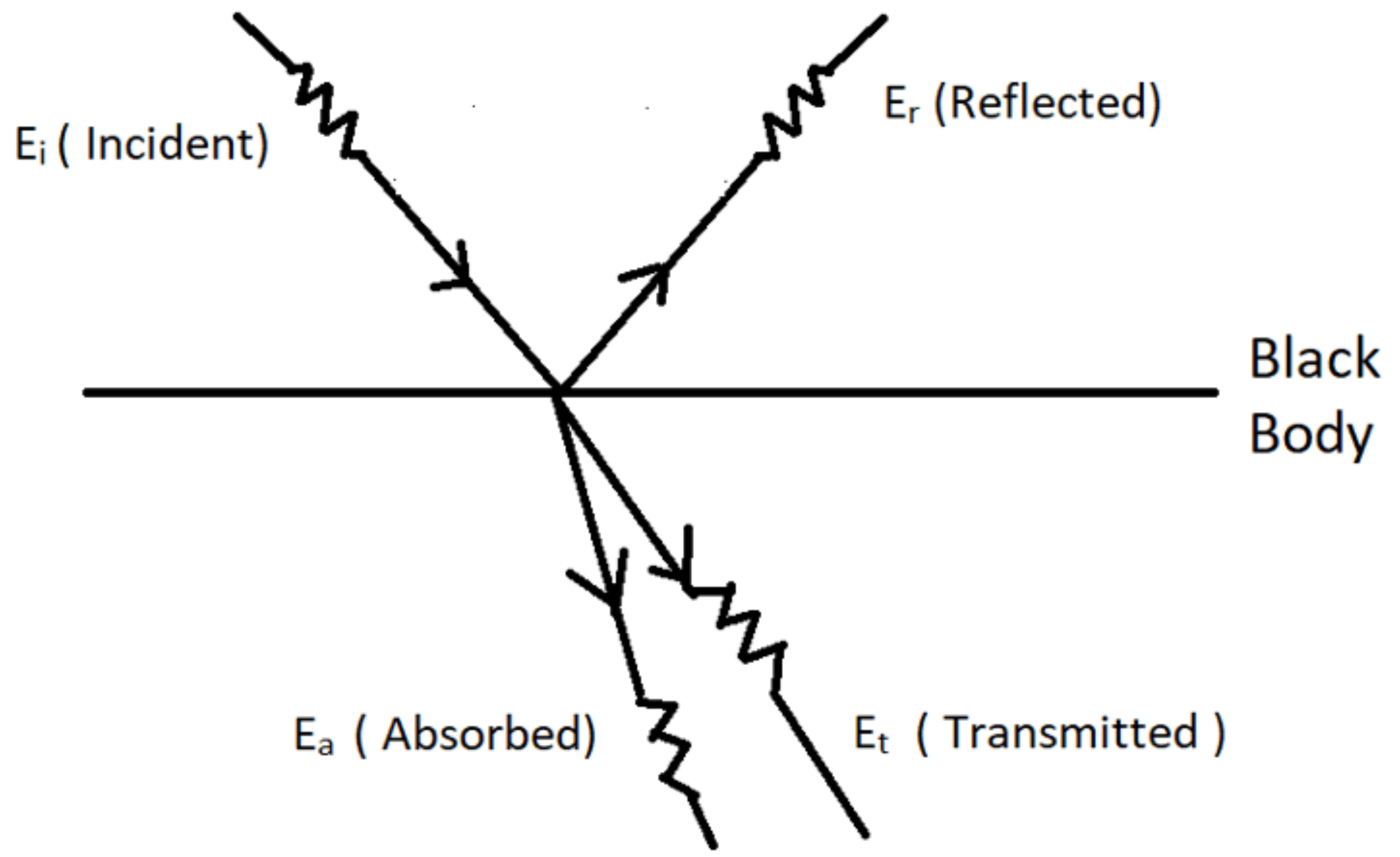


a) $E_r = 0$

b) $E_a = 0$

c) $E_t = E_i$

d) $E_i = E_r$

What is the approximate nature of the Cosmic Microwave Background radiation now?

A) It is a bright, uniform, x-ray glow.

B) It is a faint, uniform, radio signal.

C) It is a faint, uniform, x-ray glow.

D) It is a weak and very patchy glow at visible wavelengths.

E) It is a weak background of cosmic neutrinos.

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How was the Cosmic Microwave Background first created?

A) The radiation emitted by the first stars.

B) The radioactive decay of uranium.

C) The formation of quarks in the big bang.

D) The combined effect of distant quasars.

E) The formation of atoms after the big bang.

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Why is the CMB so cold now?

A) The expansion of the Universe has cooled the radiation and stretched its wavelengths.

B) Dense clouds of dust have blocked most of it.

C) The acceleration of the expansion of the Universe has cooled the radiation and stretched its wavelengths.

D) Hydrogen atoms have condensed on it and chilled it.

E) It was cold when it was produced.

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