ملخص وحل الوحدة الثامنة Diffraction and Interference

Grade 12 General / physics

Chapter 8 – Interference and Diffraction

Incoherent and Coherent Light

Differentiate between incoherent and coherent waves by giving examples like rain or water droplets falling on the surface of water.

1- What led scientists to believe that light has wave properties?

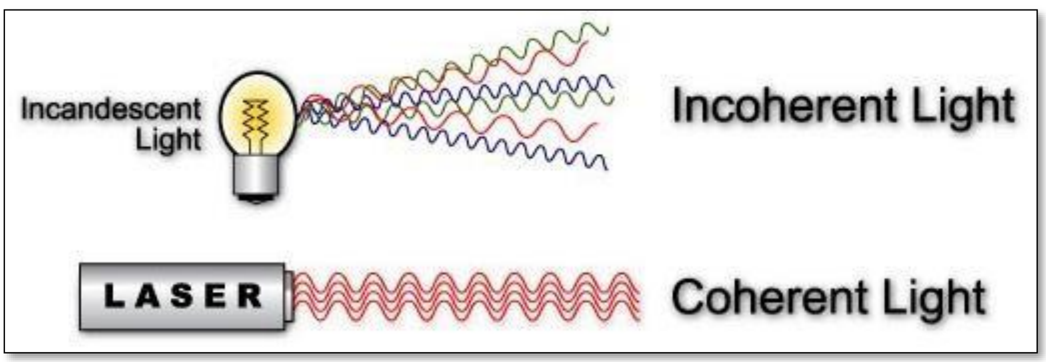
They discovered that light could be made to interfere, which results from the superposition of waves

2- Define the incoherent light?

It is light whose waves are not in phase

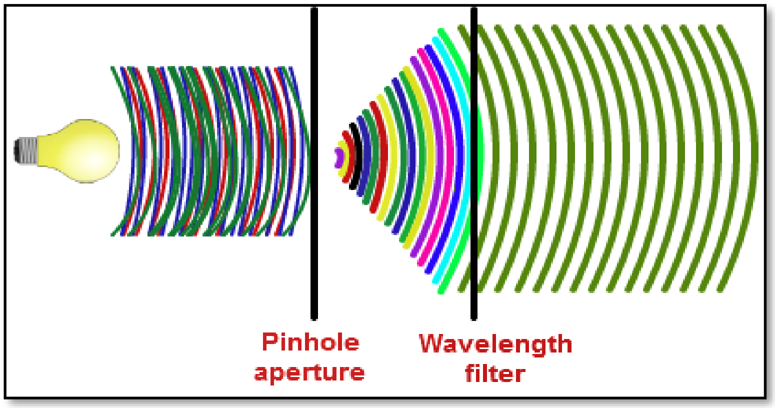
3- Define the coherent light?

It is Light made up of waves of the same wavelength that are in phase with each other



4- How we can create a coherent light?

- ✓ It can be created by a single point source.
- ✓ It can be created by multiple point sources when all point sources are in phase. This type of coherent light is produced by a laser.


Pinhole aperture
Wavelength filter

Interference of Coherent Light

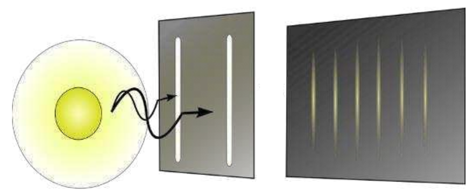
1- What is the prerequisite for a clear interference of light waves?

The light waves should be from coherent sources.

7- Define a monochromatic light.

The light of a single wavelength is called monochromatic light

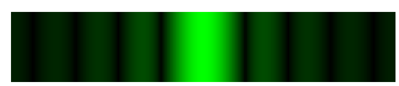
2- What was Thomas Young experiment?



In his experiment, monochromatic light from a small source (single point source). was passed through two closely spaced slits and produced an interference pattern.

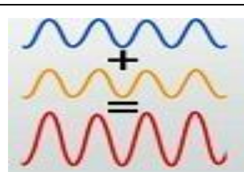
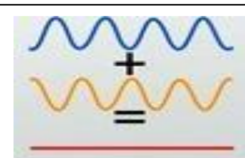
8- Recall the concepts of constructive and destructive interference and define interference fringes of light.

3- Define interference fringes



The pattern of bright and dark band

- **Note1**: There are two types of waves interference (constructive – destructive)

Constructive	Destructiv e
When two waves meet in such a way that their crests line up together.	When two waves meet in such a way that the crest of one wave meets the trough of another.
	

Explain how bright and dark interference fringes are created in a double-slit interference investigation with monochromatic light.

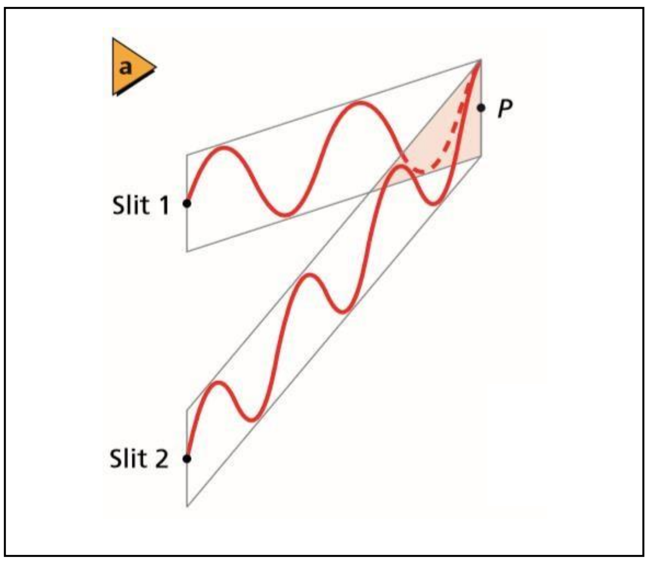
- **Note2:** In the interference pattern:
  - ✓ The Bright band represents an area where a constructive interference occurs.
  - ✓ The dark area represents an area where a destructive interference occurs.

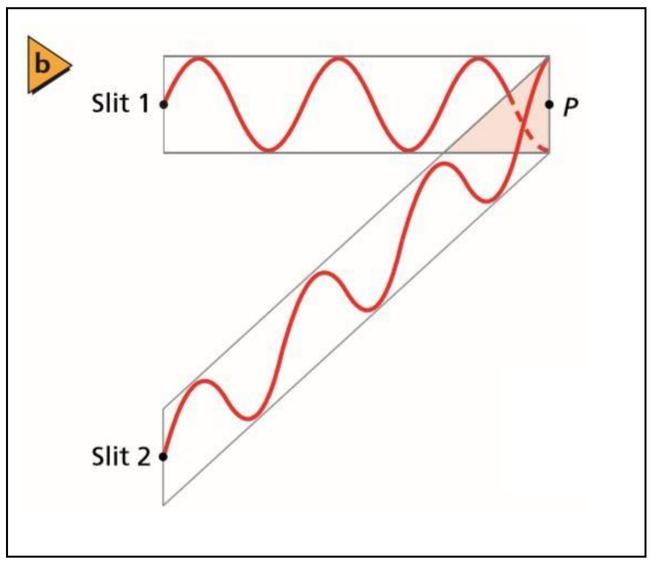
Exercises:

- **Rely on the following figure to fill in the table.**

The areas of constructive interference	The areas of destructive interference

- **Rely on the following figure to fill in the table.**





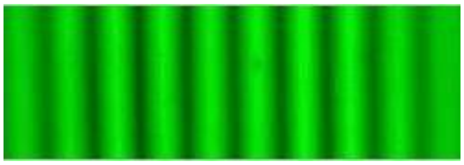
At point "p"	
Case a	Case b
What is the type of interference? Answer:	What is the type of interference? Answer:
What is the type of the band? Answer:	What is the type of the band? Answer:

4- Describe the pattern that Thomas Young gets in his experiment (Double-Slit Interference)

- ✓ A bright central band of the given color on the screen
- ✓ Other bright bands of near-equal spacing and near-equal width on either side
- ✓ The intensity of the bright bands decreases the farther the band is from the central band
- ✓ Between the bright bands are dark areas where destructive interference occurs.

➢ **Note**: The positions of the constructive and destructive interference bands depend on the light's wavelength

5- Describe the changes in the interference pattern when we use a green light instead of a red one.

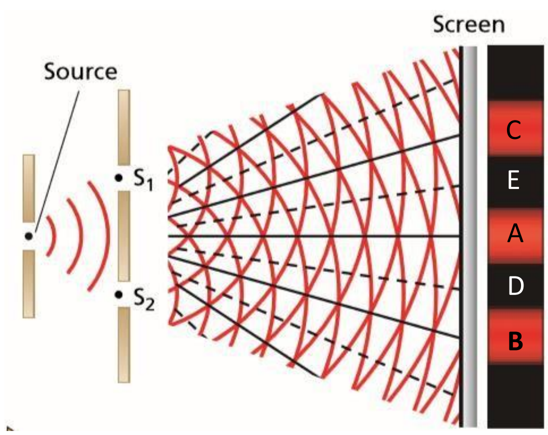


- ✓ The distance between the bright fringes decreases.
- ✓ The width of the bright fringes decreases.

6- Describe the pattern that Thomas Young gets in his experiment (Double-Slit Interference) when he uses a white light.

- ✓ A bright central band of white color on the screen.
- ✓ Colored spectra on either side of the central band.

7- Use the figure to answer the following questions



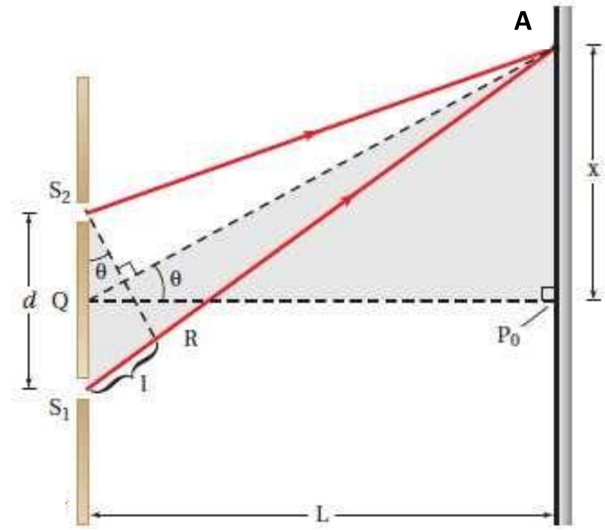
a. What is the useful of each of the single slit and the double slit barriers in the double slit experiment?

The single slit barrier	The double slit barrier

b. Name the following areas?

The area	The name
A	
B,C	
D,E	

8- In the figure, the distance "1" represent the path difference between the two waves coming from the two slits when they met at point A.



➢ What is the value of distance "1" if the two waves meet at point P_0?

…………………………………………………………………
…………………………………………………………………
…………………………………………………………………

➢ If the two waves met at point A, complete the following table

Path difference Distance 1 value	Type of the band (bright- dark)	The order of the band $m = 1, 2, 3, ….$
1λ		
2λ		
$\lambda/2$		
$3\lambda/2$		

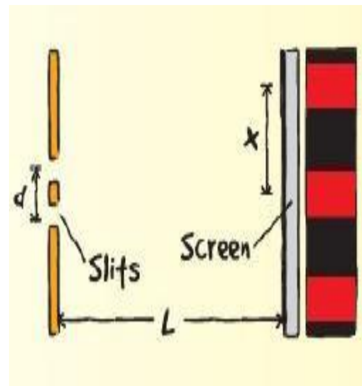
9- What is the equation of the wavelength from the Double-Slit Experiment?

$$m\lambda = \frac{x_m . d}{L}$$

N	The symbol	The physical quantity
1	m	The order of the fringe
2	x_m	The Distance from the central bright band to the bright band
3	λ	The wavelength of the light
4	d	The distance between the slits
5	L	The distance to the screen
Note: all the quantities are measured in meter except m which is dimensionless quantity		

Applications

1- **A double-slit experiment is performed to measure the wavelength of red light. The slits are 0.0190 mm apart. A screen is placed 0.600 m away, and the first-order bright band is found to be 21.1 mm from the central bright band. What is the wavelength of the red light?**



2-

3- **Violet light falls on two slits separated by 1.90×10^{-5} m. A first-order bright band appears 13.2 mm from the central bright band on a screen 0.600 m from the slits. What is λ?**

$$\lambda = \frac{xd}{L}$$

$$= \frac{(13.2\times10^{-3}\ \text{m})(1.90\times10^{-5}\ \text{m})}{0.600\ \text{m}}$$

$$= 418\ \text{nm}$$

4- **Yellow-orange light from a sodium lamp of wavelength 596 nm is aimed at two slits that are separated by 1.90×10−5 m. What is the distance from the central band to the first-order yellow band if the screen is 0.600 m from the slits?**

$$x = \frac{\lambda L}{d}$$

$$= \frac{(13.2\times10^{-3}\ \text{m})(1.90\times10^{-5}\ \text{m})}{0.600\ \text{m}}$$

$$= 1.88\times10^{-2}\ \text{m} = 18.8\ \text{mm}$$

5- **In a double-slit investigation, physics students use a laser with λ = 632.8 nm. A student places the screen 1.000 m from the slits and finds the first-order bright band 65.5 mm from the central line. What is the slit separation?**

$$\lambda = \frac{xd}{L} \qquad d = \frac{\lambda L}{x} = \frac{(632.8\times10^{-9}\ \text{m})(1.000\ \text{m})}{65.5\times10^{-3}\ \text{m}}$$

$$= 9.66\times10^{-6}\ \text{m} = 9.66\ \mu\text{m}$$

6- **Yellow-orange light with a wavelength of 596 nm passes through two slits that are separated by 2.25×10^{-5} m and makes an interference pattern on a screen. If the distance from the central line to the first-order yellow band is 2.00×10^{-2} m, how far is the screen from the slits?**

$$\lambda = \frac{xd}{L} \qquad L = \frac{xd}{\lambda}$$

$$= \frac{(2.00\times10^{-2}\ \text{m})(2.25\times10^{-5}\ \text{m})}{596\times10^{-9}\ \text{m}}$$

$$= 0.755\ \text{m}$$

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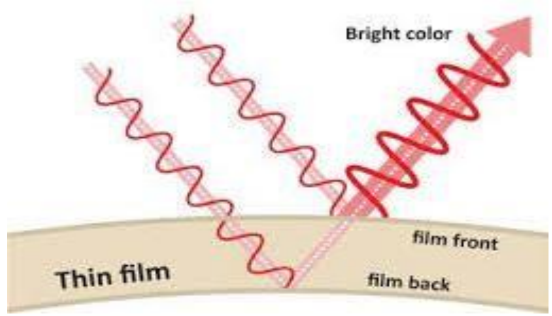
Chapter 8 – Interference and Diffraction

3-Explain the phenomenon of thin-film interference

1- **What is the reason for the emergence of a spectrum of colors on a soap bubble or on the oily film on a water puddle in a parking lot?**
This happen as a result of the constructive and destructive interference when light waves reflect from separate surfaces of a thin film this phenomenon called ***thin-film interference.***

- **Note:** The interference occurs between two reflected waves, one reflects from the outer surface of the thin film and the other from the inner surface of the thin film, and we can get two types of interference (constructive or destructive)

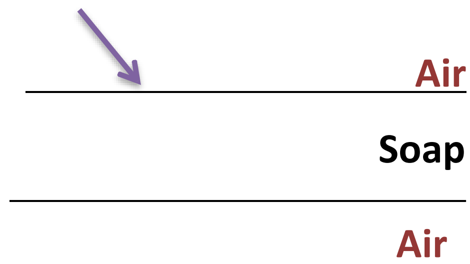


2- **There are two possibilities for the phase difference between the incident and the reflected rays.**

	Possibility	The phase difference
1	The light falls from a medium with a large refractive index to a medium with a small refractive index ($n_1 > n_2$). Slow to fast	The incident and the reflected rays are in phase. The wave does not invert
2	The light falls from a medium with a small refractive index to a medium with a large refractive index ($n_1 < n_2$). Fast to slow	The incident and the reflected rays are out of phase by (π). The wave inverts

Chapter 8 – Interference and Diffraction

- **Note**: In the soap film, the arrangement of the media is as follows:



3- Rely on the following figures to fill in the tables.

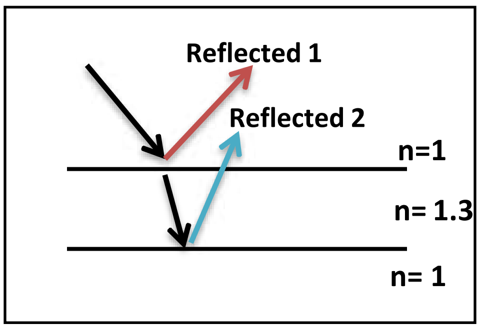


Figure A

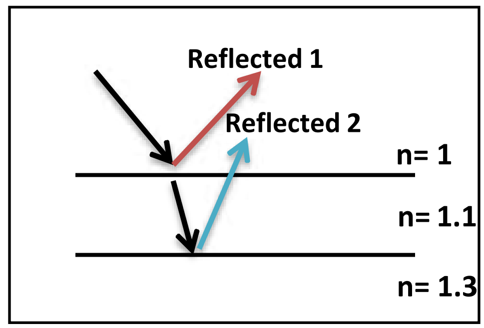


Figure B

Figure A	
The Reflected ray	Does the reflected ray invert?
Reflected ray 1	
Reflected ray 2	

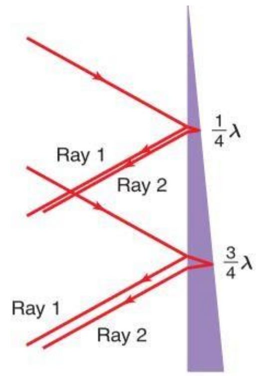
Figure B	
The Reflected ray	Does the reflected ray invert?
Reflected ray 1	
Reflected ray 2	

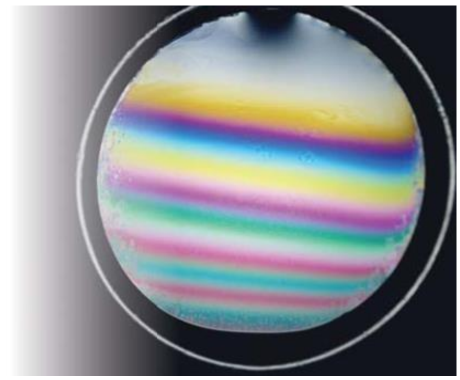
Important note: The type of interference will depend on:
- ✓ The number of inversions
- ✓ The thickness of the thin film

Chapter 8 – Interference and Diffraction

4- In the soap bubble, what are the thicknesses of the film that cause a constructive interference? (one inversion)

The constructive interference occurs on the soap bubble when the thickness of the film is equal to *odd numbers* of a quarter of the wavelength. $1\lambda/4, 3\lambda/4, 5\lambda/4 \; ... etc$





$$d = m\,\lambda/4 \qquad m = 1,3,5,7, ...$$

5- In the thin films (if two inversions or no inversions occurs), what are the thicknesses of the film that cause a constructive interference?

The constructive interference occurs on the thin film when the thickness of the film is equal to *integer numbers* of a halfe of the wavelength. $1\lambda/2, 2\lambda/2, 3\lambda/2, ... etc$

$$d = m\,\lambda/2 \qquad m = 1,2,3,4, ...$$

Important rules to calculate the thickness of the thin film in case of (destructive or constructive) interference.

In case of constructive interference	
One of the reflected waves inverted.	$2d = (m + \frac{1}{2})\frac{\lambda}{n_{film}}$ $m = 0,1,2,3,4, ...$
Both reflected waves inverted or not	$2d = m\frac{\lambda}{n_{film}}$ $m = 1,2,3,4, ...$

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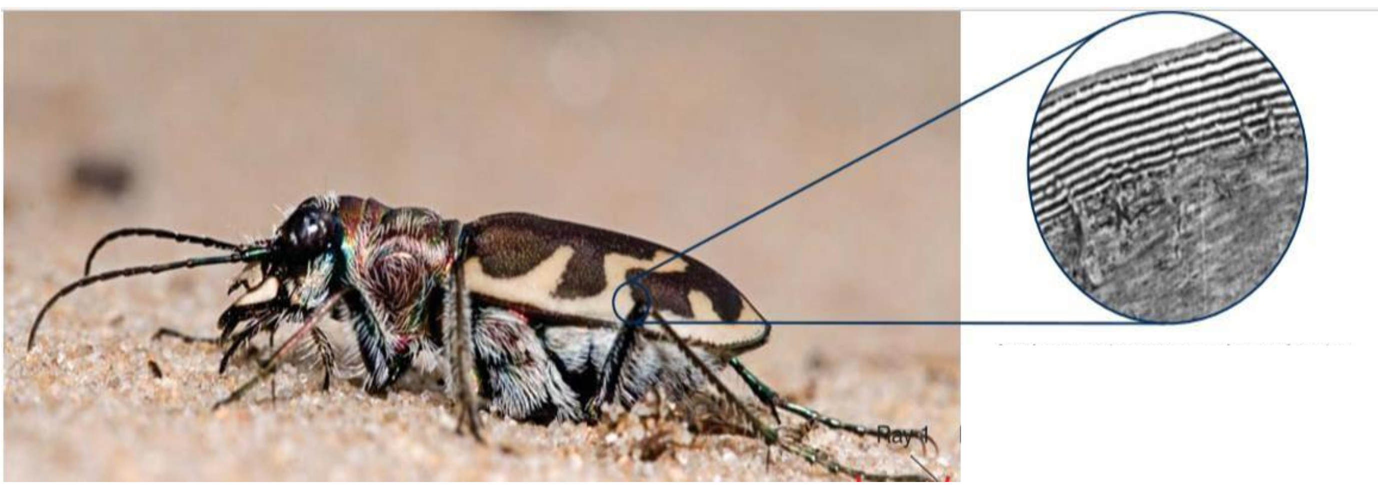
In case of Destructive interference	
One of the reflected waves inverted.	$2d = m\dfrac{\lambda}{n_{film}}$ $m = 1,2,3,4, \ldots.$
Both reflected waves inverted or not	$2d = (m + \dfrac{1}{2})\dfrac{\lambda}{n_{film}}$ $m = 0,1,2,3,4, \ldots.$

6- Light interference also occurs naturally in the outer layer of the shells of many beetles, as shown in the figure. The shimmering green of the tiger beetle is the result of reflection from thin, parallel layers of chitin and sometimes other materials that differ in refractive index.



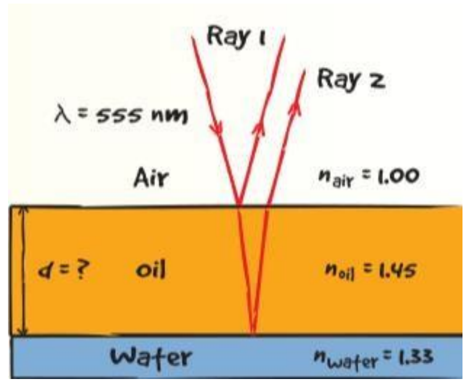
7- To solve the thin film problems, follow these steps:

A. Determine the type of the interference.
B. Determine the number of the inversions.
C. Chose the correct rule from the table.

Chapter 8 – Interference and Diffraction

Applications

1- You observe colored rings on a puddle and conclude that there must be an oil slick on the water. You look directly down at the puddle and see a yellow green (λ = 555 nm) region. If the refractive index of oil is 1.45 and that of water is 1.33, what is the minimum thickness of oil that could cause this color?



Because $n_{oil} > n_{air}$, the wave is inverted on the first reflection. Because $n_{water} < n_{oil}$, there is no inversion on the second reflection. Thus, there is one wave inversion. The wavelength in oil is less than it is in air.

Follow the problem-solving strategy to construct the equation.

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

Because you want the minimum thickness, $m = 0$.

$$d = \frac{\lambda}{4n_{oil}}$$ ◄ Substitute $m = 0$.

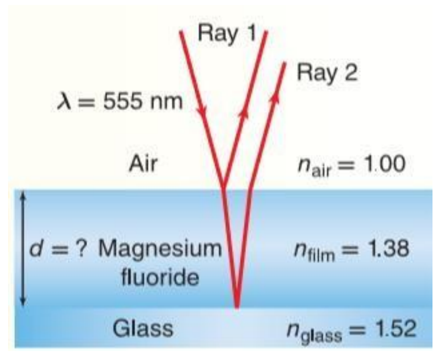
$$= \frac{555\text{ nm}}{(4)(1.45)}$$ ◄ Substitute $\lambda = 555$ nm, $n_{oil} = 1.45$.

$$= 95.7\text{ nm}$$

2- In the previous problem, what would be the thinnest film that would create a reflected red (λ = 635 nm) band

3- A glass lens has a nonreflective coating of magnesium fluoride placed on it. How thick should the nonreflective layer be to keep yellow-green light with a wavelength of 555 nm from being reflected? See the sketch in the figure.

Because $n_{film} > n_{air}$, there is a phase change on the first reflection. Because $n_{air} < n_{film}$, there is no phase change on the second reflection.



For destructive interference to get a black stripe

$$2t = \frac{m\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{555 \text{ nm}}{(4)(1.38)}$$

$$= 101 \text{ nm}$$

Chapter 8 – Interference and Diffraction

4- **You can observe thin-film interference by dipping a bubble wand into some bubble solution and holding the wand in the air. What is the thickness of the thinnest soap film at which you would see a black stripe if the light illuminating the film has a wavelength of 521 nm? Use n = 1.33 for the bubble solution**

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection.

Because $n_{glass} > n_{film}$, there is a phase inversion on the second reflection.

For destructive interference to keep yellow-green from being reflected:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 1$.

$$t = \frac{\lambda}{2n_{film}}$$

$$= \frac{521\text{ nm}}{(2)(1.33)}$$

$$= 196\text{ nm}$$

5- **What is the thinnest soap film (n = 1.33) for which light of wavelength 521 nm will constructively interfere with itself?**

For constructive interference

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{521\ \text{nm}}{(4)(1.33)}$$

$$= 97.9\ \text{nm}$$

6- **A silicon solar cell has a nonreflective coating placed on it. If a film of silicon monoxide, n = 1.45, is placed on the silicon, n = 3.5, how thick should the layer be to keep yellow-green light (λ = 555 nm) from being reflected?**

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection.

Because $n_{silicon} > n_{film}$, there is a phase inversion on the second reflection.

For destructive interference to keep yellow-green from being reflected:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

For the thinnest film, $m = 0$.

$$t = \left(\frac{1}{4}\right)\frac{\lambda}{n_{film}}$$

$$= \frac{555\text{ nm}}{(4)(1.45)}$$

$$= 95.7\text{ nm}$$

Compare the bright and dark bands from Young's Double Slit investigation with the diffraction pattern from Single Slit Diffraction
regarding the band spacing, light sources, width of bands, and intensity of created bands.

What is Diffraction?

The process of bending light around corners such that it spreads out and illuminates regions where a shadow is anticipated is known as diffraction of light.

What Is Single Slit Diffraction?

The curving of light waves around a tight turn of an obstacle or an opening is known as the diffraction of light.
The single slit diffraction's meaning is that an alternating dark and bright pattern can be seen when light is imposed on a slit with a size corresponding to the wavelength of light.
When light strikes the gap, secondary wavelets form at each point, as per Huygens' rule.
These wavelets start out in a phased manner and then disperse on all sides.
Each one of them covers a specific path to reach any location on the screen.
Due to the path difference, they reach diverse phases and may interact either constructively or destructively.

16. Monochromatic green light of wavelength 546 nm falls on a single slit with a width of 0.095 mm. The slit is located 75 cm from a screen. How wide will the central bright band be?

$$2x_{min} = \frac{2\lambda L}{w}$$

$$= \frac{2(5.46 \times 10^{-7}\ \text{m})(0.75\ \text{m})}{9.5 \times 10^{-5}\ \text{m}}$$

$$= 8.6\ \text{mm}$$

17. Yellow light with a wavelength of 589 nm passes through a slit of width 0.110 mm and makes a pattern on a screen. If the width of the central bright band is 2.60×10^{-2} m, how far is it from the slits to the screen?

SOLUTION:

$$2x_1 = \frac{2\lambda L}{w}$$

$$L = \frac{(2x_1)w}{2\lambda}$$

$$= \frac{(2.60 \times 10^{-2}\ \text{m})(0.110 \times 10^{-3}\ \text{m})}{(2)(589 \times 10^{-9}\ \text{m})}$$

$$= 2.43\ \text{m}$$

18. Light from a He-Ne laser ($\lambda = 632.8$ nm) falls on a slit of unknown width. A pattern is formed on a screen 1.15 m away, on which the central bright band is 15.0 mm wide. How wide is the slit?

SOLUTION:

$$2x_1 = \frac{2\lambda L}{w}$$

$$w = \frac{2\lambda L}{2x_1}$$

$$= \frac{(2)(632.8 \times 10^{-9}\ \text{m})(1.15\ \text{m})}{15 \times 10^{-3}\ \text{m}}$$

$$= 9.7 \times 10^{-5}\ \text{m} = 97\ \mu\text{m}$$

19. Yellow light falls on a single slit 0.0295 mm wide. On a screen that is 60.0 cm away, the central bright band is 24.0 mm wide. What is the wavelength of the light?

SOLUTION:

$$2x_1 = \frac{2\lambda L}{w}$$

$$\lambda = \frac{(2x_1)w}{2L}$$

$$= \frac{(24.0 \times 10^{-3}\ \text{m})(0.0295 \times 10^{-3}\ \text{m})}{(2)(60.0 \times 10^{-2}\ \text{m})}$$

$$= 5.90 \times 10^{2}\ \text{nm}$$

20. **CHALLENGE** White light falls on a single slit that is 0.050 mm wide. A screen is placed 1.00 m away. A student first puts a blue-violet filter ($\lambda = 441$ nm) over the slit, then a red filter ($\lambda = 622$ nm). The student measures the width of the central bright band.

a. Which filter produced the wider band?
b. Calculate the width of the central bright band for both filters.

SOLUTION:
a. Red, because the width of the central bright band is proportional to wavelength.

b.

$$2x_1 = \frac{2\lambda L}{w}$$

For blue,

$$2x_1 = \frac{2(4.41\times10^{-7}\ \text{m})(1.00\ \text{m})}{5.0\times10^{-5}\ \text{m}} = 18\ \text{mm}$$

For red,

$$2x_1 = \frac{2(6.22\times10^{-7}\ \text{m})(1.00\ \text{m})}{5.0\times10^{-5}\ \text{m}} = 25\ \text{mm}$$

47. Monochromatic light passes through a single slit 0.010-cm wide and falls on a screen 100 cm away, as shown in **Figure 25.** If the width of the central band is 1.20 cm, what is the wavelength of the light? (Level 1)

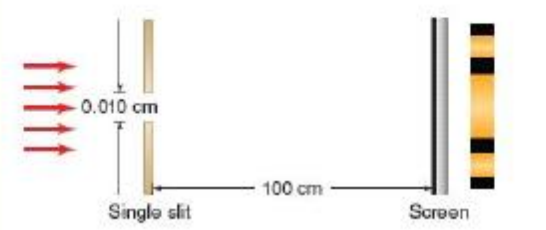


Figure 25

SOLUTION:

$$2x_1 = \frac{2\lambda L}{w}$$

$$\lambda = \frac{xw}{L}$$

$$= \frac{(0.60\text{ cm})(0.010\text{ cm})}{100\text{ cm}}$$

$$= 600\text{ nm}$$

A **diffraction grating**
is a device that is made up of many small slits that diffract light and form a pattern that is an overlap of single-slit diffraction patterns.
This pattern is similar to that of a two-slit interference pattern, but with much narrower and brighter bands.
Diffraction gratings can have as many as 10,000 slits per centimeter, which means the spacing between the slits can be as small as 10−6 m. A diffraction grating is a useful tool for the study of light and objects that emit or absorb light.One type of diffraction grating is called a transmission grating.
A transmission grating can be made by scratching very fine lines with a diamond point on glass that transmits light. The spaces between the scratched lines act like slits.Diffraction gratings can be used to enhance the appearance of dia-monds. The gratings are etched into certain surfaces of the diamond to improve the dispersion of light and make the gems appear more brilliant

12 Explain diffraction through circular appertures and discuss resolving of images using the Rayleigh criterion

Rayleigh criterion
states that if the center of the bright spot of one source's image falls on the first dark ring of the second, the two images are at the limit of resolution. If the images of two stars are at the limit of resolution, a viewer can tell that there are two stars rather than only one.

RAYLEIGH CRITERION
The separation distance between objects that are at the limit of resolution is equal to 1.22, times the wavelength of light, times the distance from the circular aperture to the objects, divided by the diameter of the circular aperture.

SECTION 2 Diffraction

MAIN IDEA Light waves diffract when they pass through a single slit and diffract and interfere when they encounter a diffraction grating.

- Light passing through a narrow slit is diffracted, which means spread out from a straight-line path, producing a diffraction pattern on a screen. The width of the bright central band of a single-slit diffraction pattern is related to the wavelength of light used.
- Diffraction gratings consist of large numbers of slits that are very close together and produce narrow spectral lines that result from interference of light diffracted by all the slits.
- Diffraction gratings can be used to measure the wavelength of light precisely or to separate light composed of different wavelengths.

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

- Diffraction limits the ability of an aperture to distinguish two closely spaced objects, because the resulting image contains a diffuse central bright spot. If two bright spots are closer than the limit of resolution, they will overlap and the objects cannot be distinguished.

القسم 2 الحيود

الفكرة الرئيسة تحيد الموجات الضوئية عندما تمرّ عبر شق أحادي، وتحيد وتتداخل عندما تسقط على محزوز حيود.

- يحيد الضوء الذي يمر من خلال شق ضيق، وهذا يعني انتشاره من مسار في خط مستقيم ليُحدث نمط حيود على الشاشة. يرتبط عرض الحزمة المركزية المضيئة في نمط حيود الشق الأحادي بطول موجة الضوء المستخدم.
- تتكوّن محزوزات الحيود من أعداد كبيرة من الشقوق القريبة جدًا من بعضها وتُحدث خطوطًا طيفية ضيقة تنشأ من تداخل الضوء الذي يحيد من جميع الشقوق.
- يمكن استخدام محزوزات الحيود لقياس طول موجة الضوء بدقة أو لفصل الضوء المكون من أطوال موجة مختلفة.

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

- يحدّ الحيود من قدرة الفتحة على التمييز بين جسمين متقاربين لأنّ الصورة الناتجة تحوي نقطة مركزية مضيئة منتشرة. إذا كانت نقطتان مضيئتان أقرب من حد الدقة، فستتداخل النقطتان ولا يمكن تمييز الأجسام.

14 **Calculate the energy emitted or absorbed by a vibrating atom using the equation (E=nhf) where n is an integer, h is Planck's constant**

(h = 6.63 × 10"31J/Hz), and f is the frequency of vibration.

ENERGY OF VIBRATION

The energy emitted or absorbed by a vibrating atom is equal to the product of an integer, Planck's constant, and the frequency of vibration.

$$E = nhf$$

In the equation, f is the frequency of vibration of the atom, h is a constant called Planck's constant, which has a value of 6.626×10^{-34} J/Hz, and n is an integer such as 0, 1, 2, 3 . . .

$n = 0$: $E = (0)hf = 0$
$n = 1$: $E = (1)hf = hf$
$n = 2$: $E = (2)hf = 2hf$

quantized

The energy of the radiation (E) can have values of

A	3/4 hf	B	1/2 hf	C	6/2 hf	D	5/2 hf

15	Define the work function of a metal, and calculate its value

Work function
is a property of a material, which is defined as the minimum quantity of energy which is required to remove an electron to infinity from the surface of a given solid

The work function of iron is 4.7 eV.

a. What is the threshold wavelength of iron?

$$W = \frac{hc}{\lambda_0} = \frac{1240 \text{ eV}\cdot\text{nm}}{\lambda_0}$$

$$\lambda_0 = \frac{1240 \text{ eV}\cdot\text{nm}}{W} = \frac{1240 \text{ eV}\cdot\text{nm}}{4.7 \text{ eV}}$$

$$= 2.6\times10^2 \text{ nm}$$

The threshold wavelength of zinc is 310 nm. Find the threshold frequency, in Hz, and the work function, in eV, of zinc.

$$f_0 = \frac{c}{\lambda_0} = \frac{3.00\times10^{8}\ \text{m/s}}{310\times10^{-9}\ \text{m}} = 9.7\times10^{14}\ \text{Hz}$$

$$W = hf_0$$

$$= (6.63\times10^{-34}\ \text{J/Hz})$$

$$(9.7\times10^{14}\ \text{Hz})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 4.0\ \text{eV}$$

The work function for cesium is 1.96 eV. What is the kinetic energy, in eV, of photoelectrons ejected when 425-nm violet light falls on the cesium?

$$KE_{max} = \frac{1240\ \text{eV}\cdot\text{nm}}{\lambda} - hf_0$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{425\ \text{nm}} - 1.96\ \text{eV}$$

$$= 0.960\ \text{eV}$$

When a metal is illuminated with 193-nm ultraviolet radiation, electrons with energies of 3.5 eV are emitted. What is the work function of the metal?

$$KE = hf - hf_0$$

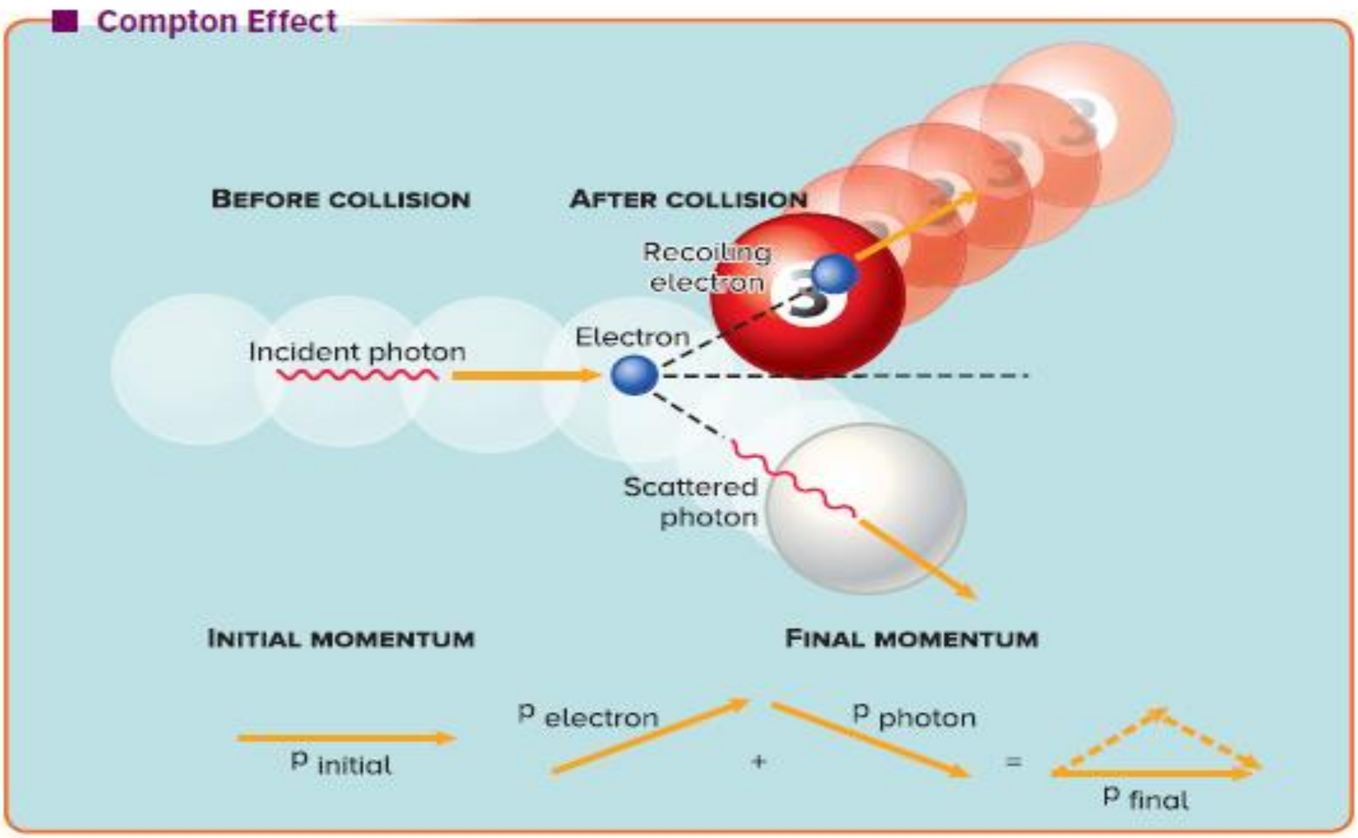
$$hf_0 = hf - KE = \frac{hc}{\lambda} - KE$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{\lambda} - KE$$

$$= \frac{1240\ \text{eV}\cdot\text{nm}}{193\ \text{nm}} - 3.5\ \text{eV}$$

$$= 2.9\ \text{eV}$$

16 -Describe that collisions between photons and particle obey the laws of conservation of energy and momentum



Photons and conservation of energy and momentum In later experiments, Compton observed that electrons were ejected from the graphite block during the experiment. He suggested that the X-ray photons collided with electrons in the graphite target and transferred energy and momentum to them. Compton thought these photon-electron collisions were similar to the elastic collisions experienced by billiard balls He tested this idea by measuring the energies of the electrons ejected from the graphite block. Compton found that the energy and momentum gained by the ejected electrons equaled the energy and momentum lost by the photons. Thus, photons obey the laws of conservation of energy and momentum when they collide with other particles.

17-

Apply the relation of the wavelength from double-slit investigation (λ=xd/L) where 'x' is the distance on the screen from the central bright fringe to the first bright band, 'd' is the distance between the slits, and 'L' is the distance from the slits to the screen.

1. Violet light falls on two slits separated by 1.90×10^{-5} m. A first-order bright band appears 13.2 mm from the central bright band on a screen 0.600 m from the slits. What is λ?

$$\lambda = \frac{xd}{L}$$

$$= \frac{(13.2\times10^{-3}\ \text{m})(1.90\times10^{-5}\ \text{m})}{0.600\ \text{m}}$$

$$= 418\ \text{nm}$$

2. Yellow-orange light from a sodium lamp of wavelength 596 nm is aimed at two slits that are separated by 1.90×10^{-5} m. What is the distance from the central band to the first-order yellow band if the screen is 0.600 m from the slits?

$$x = \frac{\lambda L}{d}$$

$$= \frac{(13.2\times10^{-3}\ \text{m})(1.90\times10^{-5}\ \text{m})}{0.600\ \text{m}}$$

$$= 1.88\times10^{-2}\ \text{m} = 18.8\ \text{mm}$$

3. In a double-slit experiment, physics students use a laser with $\lambda = 632.8$ nm. A student places the screen 1.000 m from the slits and finds the first-order bright band 65.5 mm from the central line. What is the slit separation?

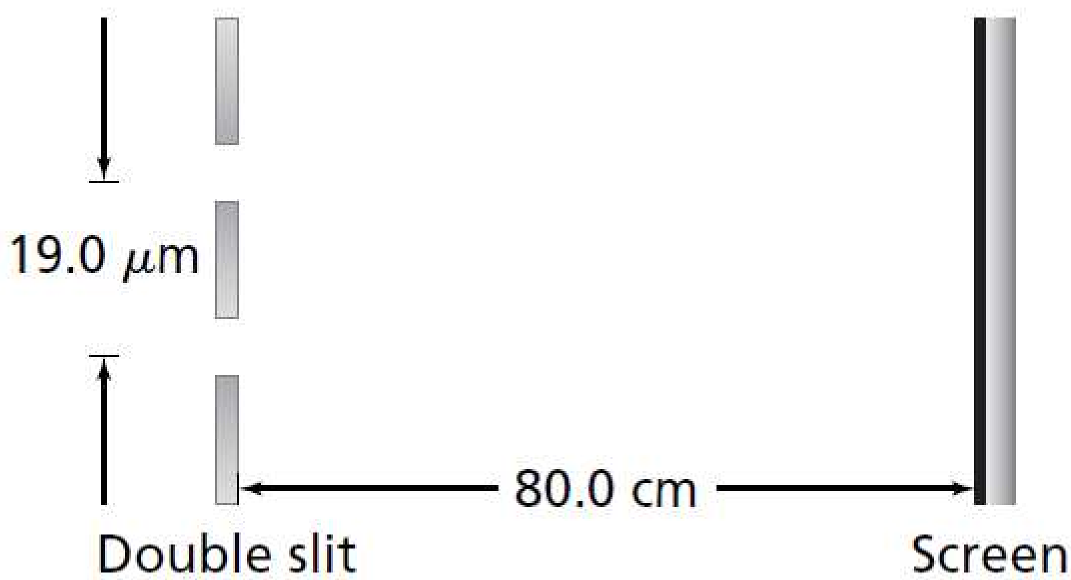
$$\lambda = \frac{xd}{L}$$

$$d = \frac{\lambda L}{x}$$

$$= \frac{(632.8\times10^{-9}\ \text{m})(1.000\ \text{m})}{65.5\times10^{-3}\ \text{m}}$$

$$= 9.66\times10^{-6}\ \text{m} = 9.66\ \mu\text{m}$$

Light falls on a pair of slits 19.0 μm apart and 80.0 cm from a screen, as shown in **Figure 19-17.** The first-order bright band is 1.90 cm from the central bright band. What is the wavelength of the light?



■ **Figure 19-17** (Not to scale)

$$\lambda = \frac{xd}{L}$$

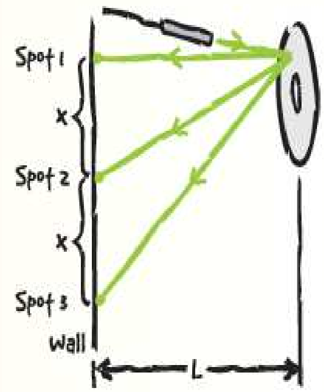
$$= \frac{(19.0\times10^{-6}\ \text{m})(1.90\times10^{-2}\ \text{m})}{80.0\times10^{-2}\ \text{m}}$$

$$= 451\ \text{nm}$$

18-Explain that constrcuctive interference from a diffraction grating occurs at angles on either side of the central bright line given by the equation mλ= dsinθ where m=1,2,3.

EXAMPLE 3

USING A DVD AS A DIFFRACTION GRATING A student noticed the beautiful spectrum reflected off a rented DVD. She directed a beam from her teacher's green laser pointer at the DVD and found three bright spots reflected on the wall. The label on the pointer indicated that the wavelength was 532 nm. The student found that the spacing between the spots was 1.29 m on the wall, which was 1.25 m away. What is the spacing between the rows on the DVD?



1 ANALYZE AND SKETCH THE PROBLEM

- Sketch the investigation, showing the DVD as a grating and the spots on the wall.
- Identify and label the knowns.

KNOWN	UNKNOWN
$x = 1.29$ m	$d = ?$
$L = 1.25$ m	
$\lambda = 532$ nm	

2 SOLVE FOR THE UNKNOWN

Find the angle between the central bright spot and the one next to it using $\tan\theta = \frac{x}{L}$.

$$\theta = \tan^{-1}\left(\frac{x}{L}\right)$$

$$= \tan^{-1}\left(\frac{1.29 \text{ m}}{1.25 \text{ m}}\right)$$ ◀ Substitute $x = 1.29$ m, $L = 1.25$ m.

$$= 45.9°$$

Use the diffraction grating wavelength and solve for *d*.

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

$$d = \frac{\lambda}{\sin\theta}$$

$$= \frac{532\times10^{-9} \text{ m}}{\sin 45.9°}$$ ◀ Substitute $\lambda = 532\times10^{-9}$ m, $\theta = 45.9°$.

$$= 7.41\times10^{-7} \text{ m} = 741 \text{ nm}$$

3 EVALUATE THE ANSWER

- **Are the units correct?** The answer is in meters, which is correct for separation.
- **Is the magnitude realistic?** With *x* and *L* almost the same size, *d* is close to λ.

22. If blue light of wavelength 434 nm shines on a diffraction grating and the spacing of the resulting lines on a screen that is 1.05 m away is 0.55 m, what is the spacing between the slits in the grating?

$\lambda = d \sin \theta$

$d = \frac{\lambda}{\sin \theta}$ where $\theta = \tan^{-1}\left(\frac{x}{L}\right)$

$= \frac{\lambda}{\sin\left(\tan^{-1}\left(\frac{x}{L}\right)\right)}$

$= \frac{434\times10^{-9}}{\sin\left(\tan^{-1}\left(\frac{0.55\text{ m}}{1.05\text{ m}}\right)\right)}$

$= 9.4\times10^{-7}\text{ m}$

23. A diffraction grating with slits separated by 8.60×10^{-7} m is illuminated by violet light with a wavelength of 421 nm. If the screen is 80.0 cm from the grating, what is the separation of the lines in the diffraction pattern?

$\lambda = d \sin \theta$

$\sin \theta = \frac{\lambda}{d}$

$\tan \theta = \frac{x}{L}$

$x = L \tan \theta$

$= L \tan\left(\sin^{-1}\left(\frac{\lambda}{d}\right)\right)$

$= (0.800\text{ m})\left(\tan\left(\sin^{-1}\left(\frac{421\times10^{-9}\text{ m}}{8.60\times10^{-7}\text{ m}}\right)\right)\right)$

$= 0.449\text{ m}$

24. Blue light shines on the DVD in Example Problem 3. If the dots produced on a wall that is 0.65 m away are separated by 58.0 cm, what is the wavelength of the light?

$$\lambda = d\sin\theta = d\sin\left(\tan^{-1}\left(\frac{x}{L}\right)\right)$$

$$= (7.41\times10^{-7}\text{ m})\left(\sin\left(\tan^{-1}\left(\frac{0.58\text{ m}}{0.65\text{ m}}\right)\right)\right)$$

$$= 490\text{ nm}$$

61. Camera When a camera with a 50-mm lens is set at f/8, its aperture has an opening 6.25 mm in diameter.

a. For light with λ = 550 nm, what is the resolution of the lens? The film is 50.0 mm from the lens.

$$x_{obj} = \frac{1.22\lambda L_{obj}}{D}$$

$$= \frac{(1.22)(5.5\times10^{-4}\text{ mm})(50.0\text{ mm})}{6.25\text{ mm}}$$

$$= 5.4\times10^{-3}\text{ mm}$$

b. The owner of a camera needs to decide which film to buy for it. The expensive one, called fine-grained film, has 200 grains/mm. The less costly, coarse-grained film has only 50 grains/mm. If the owner wants a grain to be no smaller than the width of the central bright spot calculated in part a, which film should he purchase?

Central bright band width

$2x' = 10.7\times10^{-3}$ mm

The 200 grains/mm film has $\frac{1}{200\text{ mm}}$ between grains $= 5\times10^{-3}$ mm, so this film will work.

The 50 grains/mm has $\frac{1}{50\text{ mm}}$ between grains $= 20\times10^{-3}$ mm, so this film won't work.

19-Calculate the kinetic energy of an electron ejected due to the photoelectric effect KE=hf-hf o

1. An electron has an energy of 2.3 eV. What is the energy of the electron in joules?

$$(2.3\ \text{eV})\left(\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right) = 3.7\times10^{-19}\ \text{J}$$

2. What is the energy in eV of an electron with a velocity of 6.2×10^{6} m/s?

$$KE = \frac{1}{2}mv^2$$

$$= \left(\frac{1}{2}\right)(9.11\times10^{-31}\ \text{kg})(6.2\times10^{6}\ \text{m/s})^2$$

$$= (1.75\times10^{-17}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 1.1\times10^{2}\ \text{eV}$$

3. What is the velocity of the electron in problem 1?

$$m = 9.11\times10^{-31}\ \text{kg},\ KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(3.7\times10^{-19}\ \text{J})}{9.11\times10^{-31}\ \text{kg}}}$$

$$= 9.0\times10^{5}\ \text{m/s}$$

4. The stopping potential for a photoelectric cell is 5.7 V. Calculate the maximum kinetic energy of the emitted photoelectrons in eV.

$$KE = -qV_0$$

$$= -(-1.60\times10^{-19}\ \text{C})(5.7\ \text{J/C})$$

$$\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right)$$

$$= 5.7\ \text{eV}$$

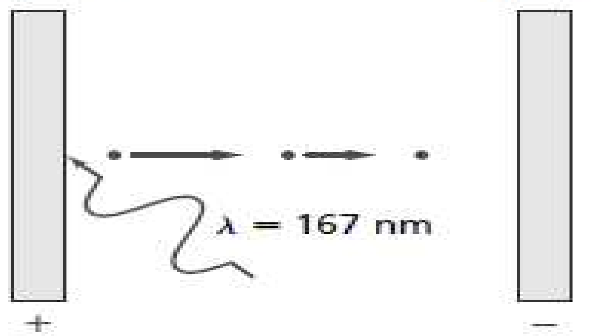
5. The stopping potential required to prevent current through a photocell is 3.2 V. Calculate the maximum kinetic energy in joules of the photoelectrons as they are emitted.

$$KE = -qV_0$$

$$= -(-1.60\times10^{-19}\ \text{C})(3.2\ \text{J/C})$$

$$= 5.1\times10^{-19}\ \text{J}$$

Incident radiation falls on tin, as shown in **Figure 27-13.** The threshold frequency of tin is 1.2×10^{15} Hz.



■ **Figure 27-13**

a. What is the threshold wavelength of tin?

$c = \lambda f$

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\ \text{m/s}}{1.2\times10^{15}\ \text{Hz}} = 2.5\times10^{-7}\ \text{m}$$

b. What is the work function of tin?

$$W = hf_0$$
$$= (6.63\times10^{-34}\ \text{J/Hz})(1.2\times10^{15}\ \text{Hz})$$
$$= 8.0\times10^{-19}\ \text{J}$$

c. The incident electromagnetic radiation has a wavelength of 167 nm. What is the kinetic energy of the ejected electrons in eV?

$$KE_{max} = \frac{hc}{\lambda} - hf_0$$
$$= \frac{(6.63\times10^{-34}\ \text{J/Hz})(3.00\times10^{8}\ \text{m/s})}{167\times10^{-9}\ \text{m}} - 8.0\times10^{-19}\ \text{J}$$
$$= 3.9\times10^{-19}\ \text{J}$$
$$(3.9\times10^{-19}\ \text{J})\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = 2.4\ \text{eV}$$

20-Define a photon, and calculate its energy . Calcuate the momentum of a photon .

Define a photon
a discrete bundle of electromagnetic energy.

. What is the momentum of a photon of violet light that has a wavelength of 4.0×10^{2} nm?

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{J·s}}{4.0\times10^{-7}\ \text{m}}$$

$$= 1.7\times10^{-27}\ \text{kg·m/s}$$