The next two questions pertain to the situation described below.

b.

1) A laser light beam (the wavelength is 500 nm) hits a screen with three thin parallel slits with equal spacing of 30 microns between them. An imaging screen is 2 m away. At which angle is the second primary maximum observed?

$30 \times 10^{-6} \cdot \sin\theta = 500 \times 2 \times 10^{-9}$

$\sin\theta = \frac{1}{30} \approx \theta = 0.033$

a. 0.099 rad
✓ b. 0.033 rad
c. 0.05 rad
d. 0.016 rad
e. 0.066 rad

$d \sin\theta = k\lambda$

$\theta = \arcsin\left(\frac{2\lambda}{d}\right)$

a.

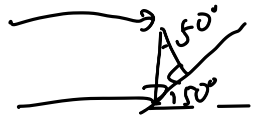
2) Leaving all other parameters of the experiment the same as above, the angle at which the second primary maximum is observed can be increased by (please choose correct answer):

a. increasing the wavelength ✓ ✓
b. increasing the distance between the slits × ×
c. decreasing he wavelength × ×

second primary maximum
second-order principle maximum

$d \sin\theta = 2\lambda$

$\theta \nearrow \quad \lambda \nearrow \quad d \searrow$



The next two questions pertain to the situation described below.

3) A spectrometer is used to analyze the light coming from a distant source. The spectrometer has 1995 slits in a diffraction grating whose total width is 6 mm. The light is normally incident on the grating and illuminates the whole grating. The third-order principle maximum is observed at an angle of 50º from normal incidence. What is the wavelength of the light coming from the source?

e.

$d = \frac{6\times10^{-3}}{1995}$ $\quad$ $\frac{6\times10^{-3}}{1995}$

$d\sin\theta = 2\lambda$

$\lambda = \frac{d}{2}\sin\theta$ $\quad$ $d = \frac{6\times10^{-3}}{1995}$

$d\sin 50^\circ = 3\lambda$

e.

a. 500 nm
b. 1150 nm
c. 384 nm
d. 2300 nm
e. 768 nm

4) Suppose the correct answer to the previous problem were λ=650 nm and the distance between the slits in the spectrometer were actually 3 microns. Now suppose a second source with a slightly longer wavelength λ+Δλ is analyzed with this spectrometer, but with only 1000 lines illuminated. What is the smallest increase in wavelength (Δλ) that could be detected ? (Hint: what is the highest order that can be used?)

$\frac{\Delta\lambda}{\lambda} = \frac{1}{1000}$ $\quad$ $\Delta\lambda = 0.65$

a. $\quad$ 4

a.

a. Δλ = 0.16 nm
b. Δλ = 0.64 nm
c. Δλ = 0.213 nm

$d\sin\theta = 1\lambda$

$\frac{\Delta\lambda}{\lambda} = \frac{1}{1000\cdot 4}$

$p = \frac{h}{\lambda} = \frac{hf}{c}$

$3\times10 = k\cdot\frac{hf}{c}$ $\quad$ $k = \frac{30c}{hf} = 1.51\times10^{28}$

The next two questions pertain to the situation described below.

Let's explore propelling a small spaceship with mass 10 kg. The ship emits photons from its thrusters, whose total momentum propels it forward.

(d) 5) How many photons of frequency 9×10^{14} Hz should be emitted (in a beam) to change the velocity by 3 m/s?

a. 1.51×10^{36}
b. 6.63×10^{-37}
c. 6.63×10^{-21}
d. d. 1.51×10^{28}
e. 1.51×10^{20}

$n = \frac{mv \cdot c}{hf}$

$p = \frac{h}{\lambda} = \frac{hf}{c}$

k ↳ f ↗

(c) 6) How would the number of photons needed change if the frequency would be increased?

a. Increase
b. Stay the same
c. Decrease

$hf = \frac{hc}{\lambda}$

$1.1214 \times 10^{-14} = \frac{hc}{\lambda}$

The next two questions pertain to the situation described below.

A photon is incident on a metal with work function 1.1214×10^{-19} J, ejecting an electron.

7) If the wavelength of the photon is 2×10^{-7} m, what is the kinetic energy of the emitted electron immediately after its emission?

(a)

a. 8.81×10^{-19} J
b. 1.12×10^{-19} J
c. 1.5×10^{15} J

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$\frac{hc}{\lambda} = 1.1214 \times 10^{-19}$

8) What is the largest photon wavelength that would eject an electron?

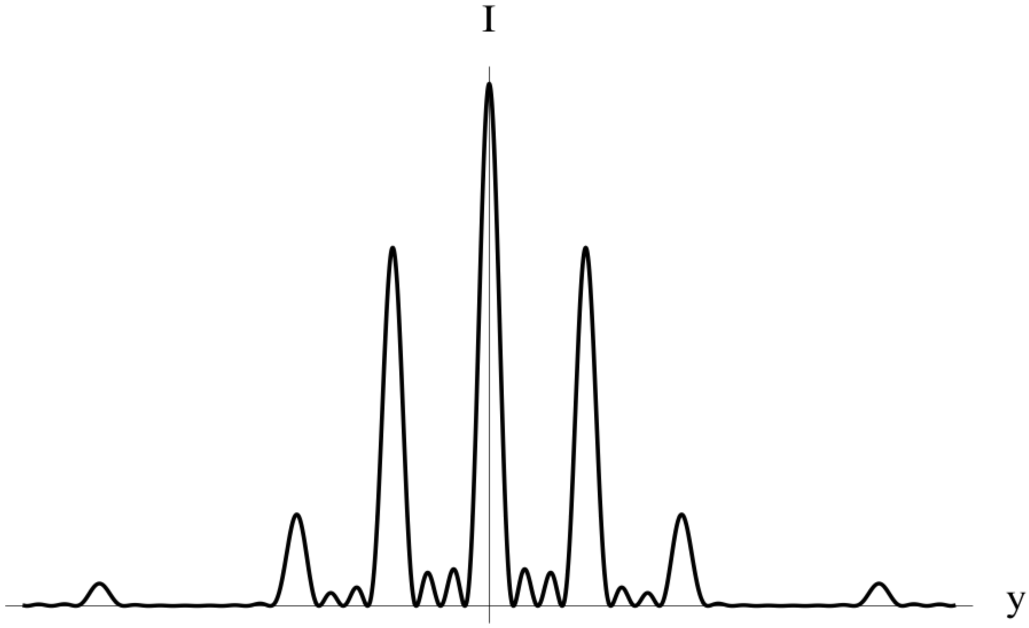
(d)

1.1

a. 2×10^{-7} m
b. 1.69×10^{14} m
c. 5.91×10^{-15} m
d. 1.77×10^{-6} m
e. Any photon would cause an electron to be ejected

The next three questions pertain to the situation described below.

A diffraction grating is illuminated by a blue laser (wavelength 235 nm) and the following interference pattern is observed on a screen 3 m away. **[Note after giving the exam; there is a bug in the coding of this problem. The wavelength is randomized but the third problem doesn't reflect that.]**



(a) 9) How many slits does this diffraction grating have? 4

a. 4
b. 3
c. 2

10) Why is the third principal maximum missing?

(a)

a. Because the phasors from all points contained within a single slit form a closed circle.
b. Because the phasors from all slits form a square.
c. Because the phasors from the three first slits form a triangle.

11) Suppose the distance between the slits is 94000 nm. What is the angle of the beam propagating to the second principal maximum of the diffraction pattern? (Assume that the zero'th order principal maximum is located at zero angle).

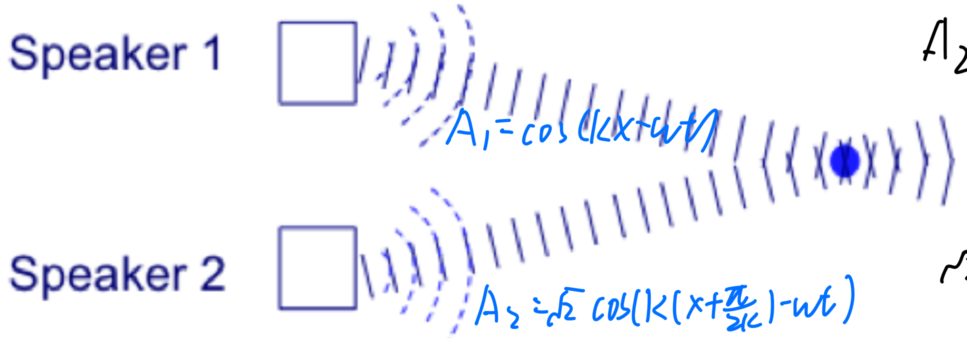
$94000 \times 10^{-9} \sin\theta = 2 \cdot 235 \times 10^{-9}$

(b)

a. 0.001 rad
b. 0.005 rad
c. 0.01 rad
d. 4 rad
e. 1 rad

The next three questions pertain to the situation described below.

$A_1 = \cos(kx - \omega t)$
$A_2 = \sqrt{2}\cdot\cos(k(x+\frac{\pi}{2k}) - \omega t)$
$= \sqrt{2}\cdot\cos(kx - \omega t + \frac{\pi}{2})$
$+\frac{\pi}{2}$



$A_1 = \cos(kx+\omega t)$

$A_2 = \sqrt{2}\cos(k(x+\frac{\pi}{2k})-\omega t)$
$= \sqrt{2}\cos(kx-\omega t+\frac{\pi}{2})$

$c^2 = a^2+b^2-2ab\cos\varphi$

$3I_1$

Suppose a microphone (blue circle) is used to measure the intensity of the sound waves created by two speakers. Speaker 1 is emitting a harmonic wave $y_1 \propto cos(kx-\omega t)$ and speaker 2 is emitting a harmonic wave $y_2 \propto cos(kx-\omega t)$. Assume speaker 1 alone emits sound with intensity I_1, and speaker 2 alone emits sound with intensity $2I_1$. Also, assume that the **distance from speaker 2 to the microphone is longer by** $\pi/2k$ than the distance from speaker 1 to the microphone.

$\frac{\pi}{2} \cdot \frac{\pi}{2}$ $\quad \frac{\pi}{2}k \quad (1+\sqrt{2})^2 = (3+2\sqrt{2})I_1$

12) What is the intensity detected by the microphone when both speakers are on?

(C)

a. $4I_1$
b. I_1
c. $3I_1$
d. 0
e. $2I_1$

$c^2 = a^2+b^2-2ab\cos\theta$

13) Suppose that Speaker 1 is now pushed directly toward the microphone by 1% of the wavelength of the sound. How does the intensity at the microphone change? Assume that the intensity of a single wave does not change with distance.

(C)

a. Increases
b. Stays the same
c. Decreases

$(1+\sqrt{2})^2$
$(3+2\sqrt{3})I$
$\frac{\pi}{2}k$
$\Delta\phi$
$-\frac{\pi}{2k}+\frac{\pi}{2}$

14) Suppose now that the conditions are like in the original problem, but the second loud speaker has an added relative phase of $\pi/2$, resulting from the electronic circuit connected to the speaker. This means that the second speaker emits a wave of the form $y_2 \propto cos(kx-\omega t+\pi/2)$. What is the new intensity at the microphone?

(A)

a. 0.17 I_1
b. 0
c. 4.2 I_1
d. $I_1/2$
e. $2I_1$

$\sqrt{2}-1$

$4.23\times10^{-7} = 1.22\frac{\lambda}{1.1}$

381

You would like to image a binary star system using an optical telescope. The two stars have an angular separation of 4.23×10^{-7} rad. The telescope uses a lens with a diameter of 1.1 m and a filter to select a particular range of wavelengths.

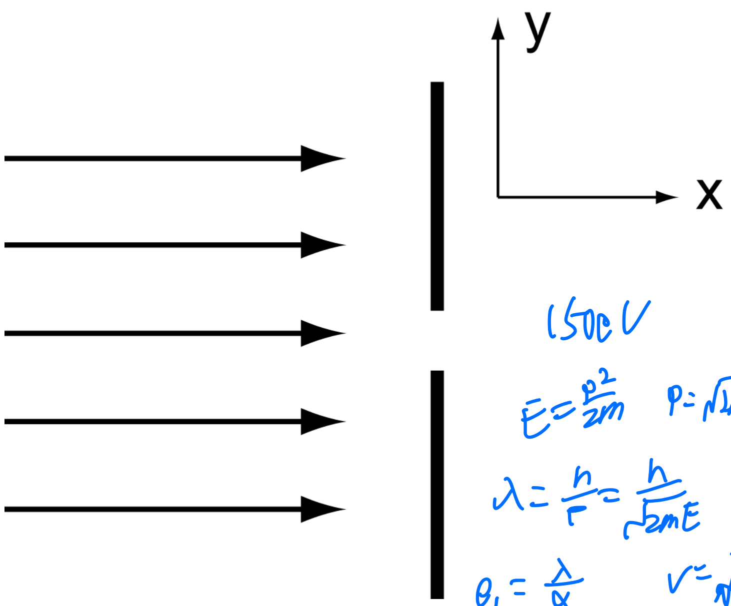
15) Which of the following wavelengths is closest to the longest wavelength light for which the two stars can be clearly resolved?

(c)

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

a. 930 nm
b. 190 nm
✓ c. 381 nm
d. There is no "longest wavelength"—the larger the wavelength, the better the resolution.
e. 465 nm

16) Electrons initially move in the x-direction with a velocity that corresponds to a kinetic energy of 150 eV. They then pass through an aperture with a 10-nm diameter. Estimate the minimum range of transverse (y-component) velocities that the electrons possess after passing through the aperture.



$E = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$

$\lambda = \sqrt{\frac{h^2}{2mE}}$

$\theta = 1.22\frac{\lambda}{d}$

150 eV

$E = \frac{p^2}{2m}$ $p = \sqrt{2mE}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$

$E = \frac{1}{2}mv^2$ $\sqrt{\frac{2E}{m}}$

$\theta_1 = \frac{\lambda}{a}$ $v = \sqrt{\frac{2E}{m}}$

7.4×10^4 7.9×10^4

19459

(d)

a. 10^3 m/s
b. 10^6 m/s
c. 10^5 m/s
✓ d. 10^4 m/s
e. 0 (any electrons that actually pass through the opening do not acquire any transverse momentum.)

Suppose an electron is freely moving at velocity 7 m/s.

$p = \frac{h}{\lambda} = mv$

$\lambda = \frac{h}{mv} = \frac{h}{2m} \cdot \frac{2}{v} = 1.505 \cdot \frac{2}{v}$

17) What is its wavelength?

(c)

0.0001039

a. 9.47×10^{-35} m
b. 1.96×10^{-4} m
✓ c. 1.04×10^{-4} m

$p = mv = \frac{h}{\lambda}$

$\lambda = \frac{h}{mv}$

$\Delta\theta \cdot L = \Delta y$

$d\Delta\theta = \lambda \Rightarrow \lambda = d\Delta y$

$v = \frac{h}{m\lambda} \Rightarrow v = \frac{h\,L}{m\,d\,\Delta y}$

The next two questions pertain to the situation described below.

Suppose that send an electron through two slits separated by 2×10^{-7} m. Their position is recorded on a screen 1.33 m away.

18) We observe peaks in the probability density of detecting electrons on the screen. If the peaks are separated by 0.001 m, what is the velocity of the electron? Assume you can use the small angle approximation.

(d)

$\frac{0.001}{1.33} \cdot 2\times10^{-7} = \lambda = \frac{h}{mv}$

4.84×10^{5}

a. 9.67×10^{-4} m/s
b. 4.84 m/s
c. 2.07×10^{-7} m/s
d. 4.84×10^{6} m/s
e. 1830 m/s

$v = \frac{h \times 1.33}{m \cdot 2\times10^{-10}}$

$E = \frac{p^2}{2m}$

$\Delta y = L \cdot \frac{\lambda}{d} = \frac{L}{d} \cdot \frac{h}{mv}$

$= \frac{L}{d} \cdot \frac{h}{p}$

19) What action would **decrease** the separation between the peaks observed on the screen?

C.

(c)

a. Decrease the kinetic energy of the electrons. X no
b. Increase the distance from the slits to the screen. X no
c. Increase the velocity of the electrons. ✓ ✓

C ✓

$\frac{p^2}{2m} = E$

$K = \frac{Lh}{mvd} = \sqrt{2mE}$

3.766×10^{-37}

Heisenberg, who weighs 70 kg, is pulled over by a police officer. The officer notes that Heisenberg's wave function is localized within his car, which is about 4 m long. The officer asks Heisenberg how fast he was going.

$4 \cdot 70 \cdot V \geq \frac{h}{2\pi}$

20) Assuming that quantum mechanics actually works at this scale, what is the quantum mechanical limit on how precisely he could answer? (order of magnitude)

(d)

a. +/- 10^{-43} m/s
b. +/- 10^{-10} m/s
c. +/- 10^{-24} m/s
d. +/- 10^{-37} m/s
e. +/- 0.1 m/s

$\Delta P \cdot \Delta X \geq \frac{h}{2\pi}$

$m_0 V$

$1 \left(\frac{\sin\left(\frac{\pi a \sin\theta}{\lambda}\right)}{\frac{\pi a \sin\theta}{\lambda}} \right)^2 \cdot \left(\frac{\sin\left(\frac{\pi d \sin\theta}{\lambda} N\right)}{\frac{\pi d \sin\theta}{\lambda}} \right)^2$

The next two questions pertain to the situation described below.

21) Consider a diffraction grating with fifty slits. Each slit is 100 micrometers wide and the distance between the centers of the slits is 1800 micrometers. Monochromatic light with wavelength of one micrometer is incident normally onto the screen with the slits. What is the intensity of light propagating at an angle of 0.01 radians? Assume that the intensity of the light propagating at zero angle (i.e. towards the central maximum) is equal to one. *[Hint: you may need to consider both the distance between the slits and their finite width.]*

1×10^{-6} m

(d)

$\rightarrow 1$

a. 1
b. 9
c. Not enough info to answer.
d. 0
e. 0.143

$\theta_1 = \frac{\lambda}{a}$

$\frac{10^{-6}}{10^{-4}} = 0.01$

22) If the grating only had three slits, then what shape would best describe the phasor diagram corresponding to the first zero?

(a)

a. Triangle
b. Straight line
c. Circle

$A \sin[2x - 800t] - A \cos[2x - 800t]$

$A\sqrt{2}\sin[2x-800t-\frac{\pi}{4}]$

The following equation describes a wave propagationg along x-axis:
y = A sin[(2m^{-1})x-(800s^{-1}t)] - A cos[(2m^{-1})x-(800s^{-1}t)].

$v = \frac{800}{2}$

23) Which of these statements is correct? $\frac{800}{2} = 400$

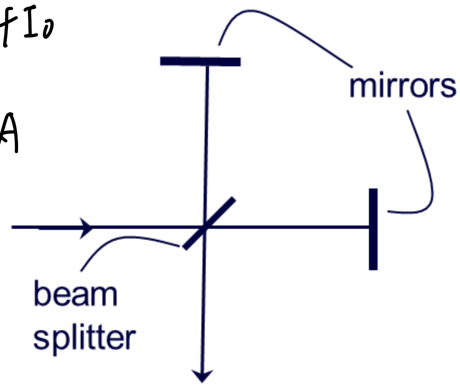
(b)

a. The wave is moving in the negative direction at the speed of 400 ms^{-1}.
b. The wave is moving in the positive direction at the speed of 400 ms^{-1}. ✓ ✓
c. The wave is moving in the negative direction at the speed of 800 ms^{-1}.
d. The wave is moving in the positive direction at the speed of 0.0025 ms^{-1}.
e. The wave is a standing wave.

$90°$ $\frac{\lambda}{4}$ $\frac{\pi}{2}$ $\frac{\pi}{4} = \frac{\Delta x}{2\pi} \cdot \lambda$

Consider a Michelson interferometer as shown at right. $4I_0$

$\frac{I}{2}$ $\sqrt{2}A$ $\Delta x = \frac{\lambda}{8}$



$\frac{\lambda}{8}$ $\frac{\lambda}{4}$ $\frac{\pi}{2}$ $\frac{\frac{\pi}{2}}{2\pi} = \frac{1}{8}\lambda$

24) After tuning the interferometer, such that there is maximal constructive interference, your lab partner bumps one of the outer mirrors, reducing the path length of that arm of the interferometer. You notice that your photometer (a tool for measuring the intensity of light) reading has reduced by a factor of 2. What is the minimum distance that the mirror could have been bumped?

(d)

$I = \frac{I}{2}$

a. λ/4
b. λ/16
c. λ/2
d. λ/8 ✓ ✓
e. λ