

Last Name: _____ First Name _____ NetID _____
Discussion Section: _____ Discussion TA Name: _____

Instructions—

Turn off your cell phone and put it away.

Keep your calculator on your own desk. Calculators may not be shared.

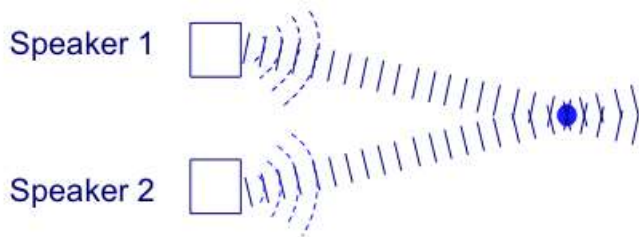
This is a closed book exam. You have ninety (90) minutes to complete it.

1. Use a #2 pencil; do **not** use a mechanical pencil or a pen. Fill in completely (until there is no white space visible) the circle for each intended input – both on the identification side of your answer sheet and on the side on which you mark your answers. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner.
2. Print your last name in the **YOUR LAST NAME** boxes on your answer sheet and print the first letter of your first name in the **FIRST NAME INI** box. Mark (as described above) the corresponding circle below each of these letters.
3. Print your NetID in the **NETWORK ID** boxes, and then mark the corresponding circle below each of the letters or numerals. Note that there are different circles for the letter “I” and the numeral “1” and for the letter “O” and the numeral “0”. **Do not** mark the hyphen circle at the bottom of any of these columns.
4. **This Exam Booklet is Version A.** Mark the **A** circle in the **TEST FORM** box at the bottom of the front side of your answer sheet.
5. Stop **now** and double-check that you have bubbled-in all the information requested in 2 through 4 above and that your marks meet the criteria in 1 above. Check that you do not have more than one circle marked in any of the columns.
6. Do **not** write in or mark any of the circles in the **STUDENT NUMBER** or **SECTION** boxes.
7. On the **SECTION line**, print your **DISCUSSION SECTION**. (You need not fill in the **COURSE** or **INSTRUCTOR** lines.)
8. Sign (**DO NOT PRINT**) your name on the **STUDENT SIGNATURE line**.

Before starting work, check to make sure that your test booklet is complete. You should have 10 numbered pages plus two Formula Sheets at the end.

Academic Integrity—Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including expulsion.

The next three problems refer to the following situation:



1. Suppose that you are listening to music playing from two sound speakers. One is emitting a harmonic wave $y_1 \propto \cos(kx - \omega t)$ and the second is emitting a harmonic wave $y_2 \propto \sin(kx - \omega t)$. Assume both waves produce an intensity I_1 when they are on individually. What is the intensity at a point equidistant from both speakers when both speakers are on?

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

2. Suppose that Speaker 1 is now pushed directly toward the listener by 1% of the wavelength of the sound. How does the intensity at the listener change?

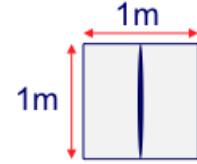
- a. Decreases
- b. Increases
- c. Stays the same

3. Now we move the listener to a location where no sound at all is heard when both speakers are on. We then reduce the intensity from Speaker 2 to $\frac{1}{4}$ that from Speaker 1: $I_2 = I_1/4$. What is the new total intensity at the listener?

- a. 0
- b. $I_1/4$
- c. $I_1/2$
- d. $3I_1/4$
- e. $9I_1/4$

The next three problems refer to the following situation:

We illuminate a two-slit diffraction grating with a laser with wavelength 600 nm. The slits are spaced by 0.01 mm. Assume the slits are very thin, i.e., you can ignore their width. The laser beam is aligned to pass through the slits and hit a square screen with area 1m by 1m. The central maximum (as shown in the adjacent figure) is aligned with the center of the screen (note that additional maxima, if there are any, are not shown).



4. How many interference maxima will we expect to see on the square screen if it is a distance 5m away from the slits?

- a. 1
- b. 3
- c. 7
- d. 8
- e. 33

5. Using the same setup as the previous problem, how can we change the slit spacing so that the principal maximum with the new spacing lies at exactly the same position as the first minimum with the original spacing?

- a. Increase the spacing.
- b. Decrease the spacing.
- c. Cannot be done for this wavelength of light.

6. Suppose the measured intensity of the central maximum is 8 W/m^2 . If we now change out the two-slit diffraction grating with a 5-slit grating with the same slit-spacing (and slit widths) what is the new maximum intensity measured on the screen?

- a. 0.40 W/m^2
- b. 1.60 W/m^2
- c. 8.0 W/m^2
- d. 40 W/m^2
- e. 50 W/m^2

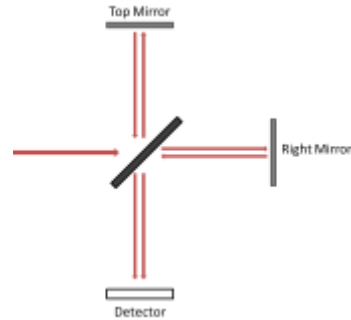
7. Light of wavelength 700 nm is incident upon a diffraction grating of width 3 mm that has 1500 lines. If we only illuminate half of the lines on the grating, what effect does this have on the principal maxima of the resulting interference pattern?

- Spacing increases and width doubles.
- Spacing increases and width is halved.
- Spacing decreases and width doubles.
- Spacing doesn't change and width is halved.
- Spacing doesn't change and width doubles.

The next two problems refer to the following situation:

8. A Michelson interferometer splits a beam of light of unknown wavelength producing a bright fringe (i.e., all of the intensity) at the detector. As one mirror is moved a distance 2.1 microns from its original position, exactly 7 new fringes are observed to appear at the detector. What is the wavelength of the unknown light?

- 300 nm
- 400 nm
- 500 nm
- 600 nm
- 700 nm



9. If the top mirror is replaced by one that leaks half of the light (i.e., reflects only 50% of the intensity), which of the following describes the intensity at the detector (in terms of the initial beam intensity) as the right mirror is moved further to the right?

- $I_{max} = \left| \sqrt{\frac{I}{4}} + \sqrt{\frac{I}{8}} \right|^2$, $I_{min} = \left| \sqrt{\frac{I}{4}} - \sqrt{\frac{I}{8}} \right|^2$
- $I_{max} = \left| \sqrt{\frac{I}{4}} + \sqrt{\frac{I}{8}} \right|^2$, $I_{min} = 0$
- $I_{max} = 3I/8$, $I_{min} = I/8$
- $I_{max} = \left| 2\sqrt{\frac{I}{4}} \right|^2$, $I_{min} = \left| 2\sqrt{\frac{I}{8}} \right|^2$
- $I_{max} = I$, $I_{min} = \left| \sqrt{\frac{I}{4}} - \sqrt{\frac{I}{8}} \right|^2$

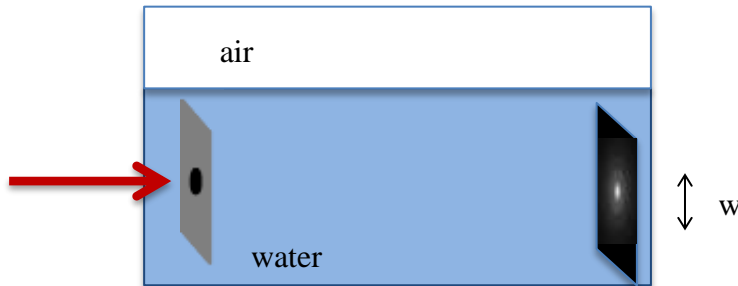
The next two problems refer to the following situation:

10. Plane wave light of wavelength 350 nm passes through a hole of diameter 5 microns and leaves a spot on a screen 2 m away. If the wavelength is doubled to 700 nm, then what is the ratio between the area of the new light's spot and that of the original spot?

- a. $A_{700\text{nm}}/A_{350\text{nm}} = 1/2$
- b. $A_{700\text{nm}}/A_{350\text{nm}} = 2$
- c. $A_{700\text{nm}}/A_{350\text{nm}} = 4$

11. The setup from the previous problem is now submerged underwater. When the original 350 nm wavelength plane wave enters the water ($n_{\text{water}}=1.34$) and passes through the hole how does the resulting spot width w' compare to the original spot width w ?

- a. $w' = 0.75w$
- b. $w' = w$
- c. $w' = 1.34w$
- d. $w' = 1.49w$
- e. $w' = 2.68w$



12. Consider two lasers and two lenses. The lasers both emit the same wavelength of 600 nm. The diameters of the lasers and lenses as well as the focal lengths of the lenses are given in the tables below. Which combination of laser and lens can produce the smallest spot size?

Item	Lens A	Lens B	Laser #1	Laser #2
Diameter	0.8 cm	0.9 cm	1.0 cm	1.1 cm
Focal Length	5 cm	7 cm		

- a. Laser #1 and lens A
- b. Laser #2 and lens B
- c. They both produce the same spot size.

The next three problems refer to the following situation:

Suppose 10^{22} photons/square meter hit the Earth every second when the Sun is overhead. Assume the wavelength of solar light reaching Earth is 570 nm.

13. Estimate how much power strikes per square meter.

- a. 60 Watts
- b. 140 Watts
- c. 3480 Watts

14. An engineer wants to capture this energy from the sun using the photoelectric effect. She uses a solar cell which extracts the maximum kinetic energy of all the ejected electrons. She calibrates the solar cell using red light (700 nm). With red light, the maximum kinetic energy per electron is 1.4 eV. Now she uses the solar cell to extract energy from solar light (570 nm). What percent of the energy from the solar light can be extracted?

- a. 0%
- b. 22%
- c. 79%
- d. 83%
- e. 100%

15. Suppose the wavelength of solar light emitted from the sun (and hence reaching the Earth) changes to 760 nm but the total energy of the Sun's output remains constant. Which of the following are true:

- (1) The total number of photons per square meter per second striking the Earth goes up.
- (2) The energy of each photon goes down.
- (3) The maximum kinetic energy per ejected electron (in the previous question) goes down
- (4) The total energy extracted by the solar cell (in the previous question) per second stays the same.
- (5) The total energy extracted by the solar cell (in the previous question) per second decreases.

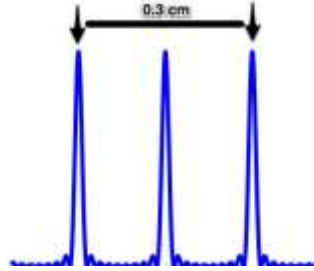
- a. only 1
- b. only 1 and 2
- c. only 2, 3, and 5
- d. only 1, 2, and 4
- e. only 1, 2, 3, and 5

The next two problems refer to the following situation:

An electron is accelerated from rest through a 10-kV potential, and then directed onto a grating.

16. If the distance between two first-order maximum measured 1 m from the source is 0.3 cm (see fig.), what is the slit separation on the grating?

- a. 0.12 nm
- b. 4.1 nm
- c. 6.2 nm
- d. 8.2 nm
- e. 10.1 nm



17. Suppose instead of using electrons, light was used and produced the same interference pattern. What is the ratio of the light's wavelength to the electron's wavelength?

- a. $\lambda_{\text{photon}}/\lambda_{\text{electron}} = 0.52$
- b. $\lambda_{\text{photon}}/\lambda_{\text{electron}} = 1.0$
- c. $\lambda_{\text{photon}}/\lambda_{\text{electron}} = 10.1$

18. An engineer wishes to propel a space-craft by firing a laser backward. The laser emits photons at a rate of 10^{22} photons per second. Calculate the recoil force on the space-craft when using a green laser of wavelength 500 nm.

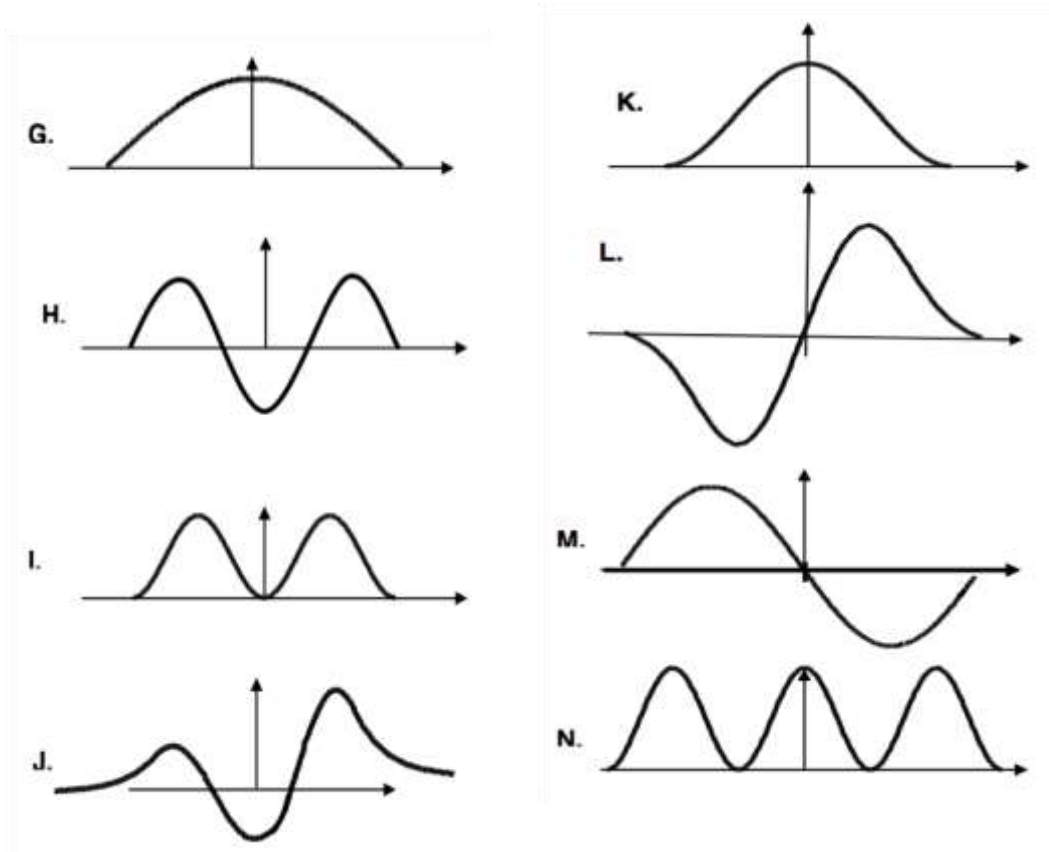
- a. 6.21 N
- b. 0.5×10^{-5} N
- c. 1.3×10^{-6} N
- d. 1.3×10^{-5} N
- e. 2.2 N

The next five problems refer to the following situation:

Consider an electron in a small carbon nanotube with length $1.2 \mu\text{m}$. We shine light onto the nanotube, and the electron is excited from its initial energy state to a higher one.

19. Which of the following could describe the electron's wavefunction after the photon absorption? Assume you can approximate the nanotube as an infinite square-well potential.

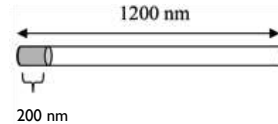
- a. G or K
- b. H or L
- c. H or M
- d. I or N
- e. All except I, N and K



Continued from the previous page.

20. For this problem, assume the electron had been excited to the 2nd excited state ($n = 3$). What is the approximate probability that we might find the electron in the left-most 200nm of the CNT (see figure)? Hint: It may help to make a careful sketch, and to note where the probability maxima are.

- a. 0.00 (i.e., less than 0.005)
- b. 0.03
- c. 0.08
- d. 0.17
- e. 0.33



21. Let's say we happen to actually find the electron in the first 10-nm part of the tube (NOT 200-nm as shown in the picture). What can you say about the subsequent likely maximum velocity of the electron (the component along the axis of the nanotube)? The answer, to an order of magnitude is,

- a. ~ 0
- b. ~ 1000 m/s
- c. $\sim 10,000$ m/s

22. Returning to the electron initially in the 2nd excited state –after some time it decays back to the ground state, emitting a photon. What is the change in momentum of the electron-carbon nanotube system in this process?

- a. 0
- b. 1.39×10^{-34} kg-m/s
- c. 1.25×10^{-33} kg-m/s
- d. 1.11×10^{-33} kg-m/s
- e. 2.76×10^{-28} kg-m/s

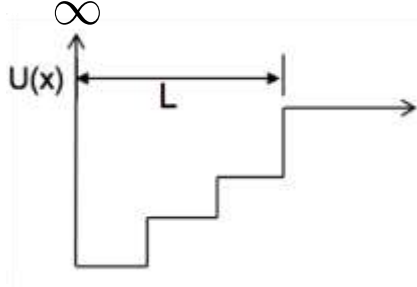
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23. In reality the CNT does not form an infinite potential well for the electron, but a finite one. What affect does this have on the wavelength of the photon emitted in the previous problem, i.e., compare $\lambda_{\text{photon, infinite well}}$ and $\lambda_{\text{photon, finite well}}$ for the 2nd excited state to ground state decay.

- $\lambda_{\text{photon, infinite well}} > \lambda_{\text{photon, finite well}}$
- $\lambda_{\text{photon, infinite well}} < \lambda_{\text{photon, finite well}}$
- $\lambda_{\text{photon, infinite well}} = \lambda_{\text{photon, finite well}}$

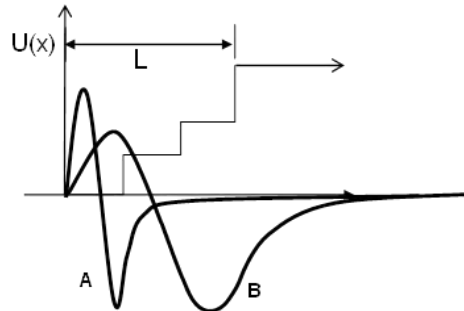
The next 2 problems refer to the following situation:

Consider a particle trapped in an energy eigenstate of the following potential, which is infinite only on the left side.



24. Which of the following is the wavefunction of the first excited state:

- A
- B
- It cannot be determined



25. Which of the following statements is true about a particle in the ground state of this potential?

- $\Psi(x)$ is symmetric about $x = L/2$.
- $\Psi(x)$ is discontinuous in at least one place.
- $d\Psi(x)/dx$ is discontinuous in at least one place.
- The particle has a definite kinetic energy.
- $\int_0^L |\Psi(x)|^2 dx = 1$