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. You may find the version of this Exam Booklet at the top of page 2. Mark the version circle in the TEST FORM box near the middle of your answer sheet. **DO THIS NOW!**

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. Print your UIN# in the STUDENT NUMBER designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION block.

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 11 ***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.**

This Exam Booklet is Version A. Mark the **A** circle in the TEST FORM box near the middle of your answer sheet. **DO THIS NOW!**

Exam Grading Policy—

The exam is worth a total of **123** points, composed of two types of questions.

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

1. A wave is described by the following equation:

$$y = A\sin[(3m^{-1})x + (900s^{-1})t]$$
$$+A\cos[(3m^{-1})x + (900s^{-1})t]$$

Which of these statements is correct?

a. The wave is moving to the Left at the speed of 300 ms^{-1} with an amplitude $2A^2$.

b. The wave is moving to the Right at the speed of 0.00333 ms^{-1} with an amplitude 2A .

c. The wave is moving to the Left at the speed of 300 ms^{-1} with an amplitude $\sqrt{2}$ A.

d. The wave is moving to the Right at the of speed 30 ms^{-1} with an amplitude $\sqrt{2}$ A.

e. The wave is a standing wave with amplitude 2A.

The following two problems pertain to the following situation

You want to design a telescope that is capable of resolving the spiral arms of a galaxy $1.4\times10^{22}\,km$ away. The spacing between the spiral arms is $1.7\times10^{17}\,km$. Assume the wavelength of light is 550 nm.

2. The diameter of the telescope lens should be,

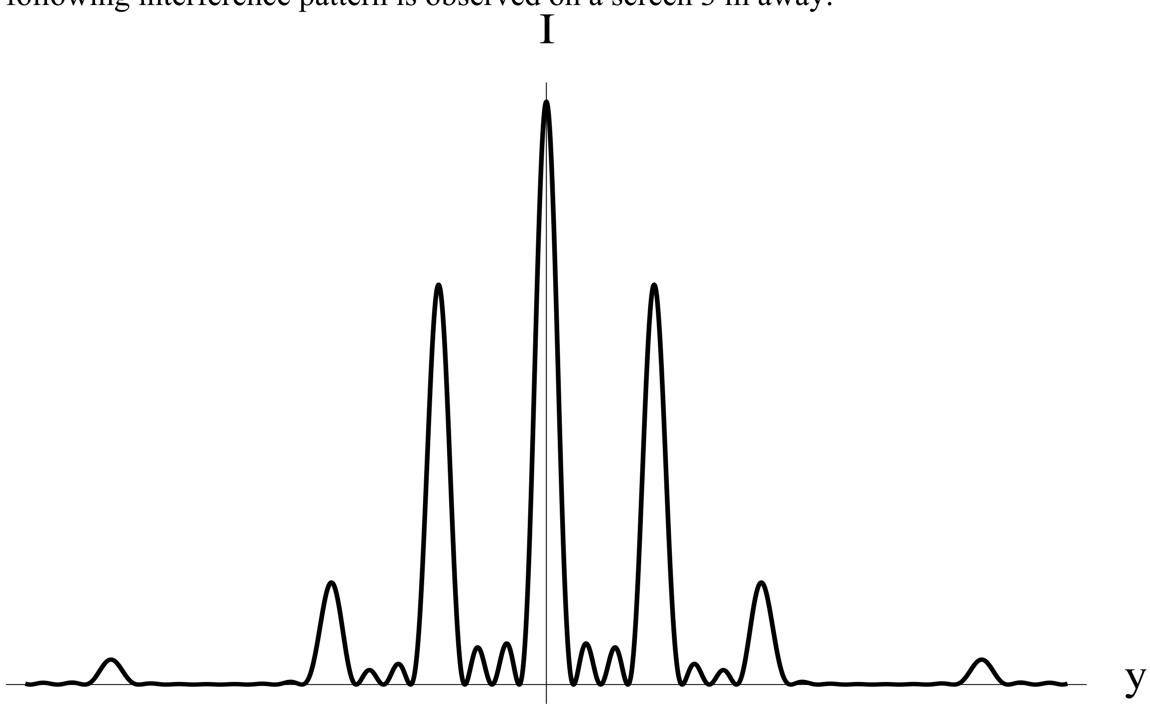
a. Bigger than 4.53 mm.
b. Smaller than 5.53 cm.
c. Smaller than 5.53 m.
d. Bigger than 5.53 cm.
e. There is not enough information given to constrain the lens size.

3. You end up making the telescope so that it is only just capable of resolving the previously mentioned spiral arms. Suppose you now use this telescope to observe the moon (at a distance $3.8\times10^{8}\,m$ away) what is the smallest object can you resolve on the moon?

a. 4.61 km
b. 4.61 m
c. 5.61 m

The following three problems pertain to the following situation

A diffraction grating is illuminated by a blue laser (wavelength 470 nm) and the following interference pattern is observed on a screen 3 m away:



4. How many slits on the grating are illuminated?

a. 4
b. 3
c. 6

5. Which of the following is the best estimate for the relationship between the slit width (a) and the slit spacing (d)?

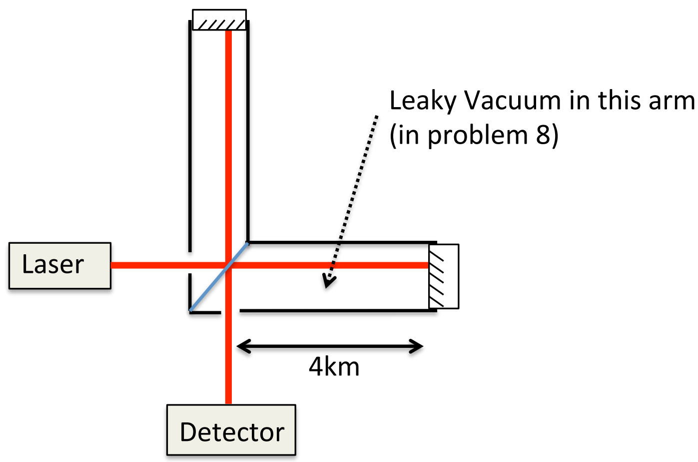
a. a is much less than d
b. $d \approx 3a$
c. $d \approx 6a$

6. The width of the laser incident on the grating is now adjusted so that the width of central maximum is 0.1 mm. Assuming the slit spacing is 0.05 mm how many slits are now illuminated?

a. 141
b. 12
c. 2450
d. 873
e. 564

The following two problems pertain to the following situation

The LIGO experiment consists of a Michelson interferometer where the two arms of the interferometer are in an ultra high vacuum. To a very good approximation the refractive index, n, equals 1 in the arms to begin with. The length of each arm is 4 km and the laser used has a wavelength of 1064 nm. The LIGO scientists work hard to adjust the mirror positions so that the intensity at the detector is maximal. They measure the intensity of the laser signal at the detector to be 20 Watts/m^2.



7. The mirror at the end of one of the arms oscillates about its equilibrium position with an amplitude of 0.1 μm. The observed intensity oscillates between:

a. 20 W/m^2 and 13.8 W/m^2
b. 20 W/m^2 and 0 W/m^2
c. 18.2 W/m^2 and 11.4 W/m^2
d. 28.4 W/m^2 and 11.4 W/m^2
e. 15.2 W/m^2 and 0 W/m^2

Unfortunately for the scientists one of the arms develops a leak which changes the refractive index in that arm over time.

8. The scientists observe the intensity at the detector and notice that the signal oscillates from maximum intensity to zero 1100 times before stabilizing. What is the new refractive index of the leaky arm?

a. $n-1 = 2.82 \times 10^{-6}$
b. $n-1 = .140$
c. $n-1 = 1.46 \times 10^{-7}$

The next TWO questions concern the situation described in the paragraph below.

A laser produces photons having an energy E = 3.5 eV.

9. What is the wavelength of the photons produced, assuming that the index of refraction is 1.6?

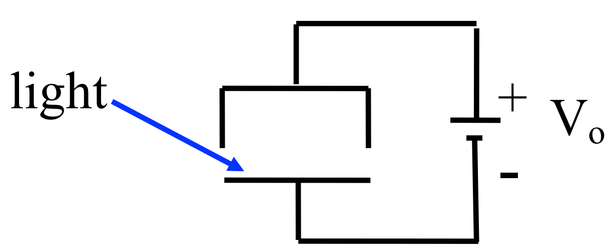
a. 110 nm
b. 221 nm
c. 333 nm
d. 414 nm
e. 514 nm

10. If this laser beam is focused on the clean surface of a metal having a work function of Φ = 1.5 eV in vacuum, what is the minimum *wavelength* λ_{min} of the electrons that will be ejected from the metal? In this problem assume that the experiment is done in vacuum.

a. λ_{min} = 0.333 nm
b. λ_{min} = 5.40 nm
c. λ_{min} = 14.2 nm
d. λ_{min} = 123 nm
e. λ_{min} = 0.867 nm

11. A photoelectric experiment is initially set up with a voltage V_o = 2 Volts and with incident blue light coming from a laser. The current flowing in the circuit is 1 nA. Now a second, identical laser is placed in parallel with the first one, so that twice the amount of light hits the cathode. What is the new value of the electric current in the circuit?

a. 1 nA
b. 2 nA
c. 4 nA



12. Use Heisenberg uncertainty to estimate the kinetic energy of the electron in the Hydrogen atom. Assume that its diameter r=0.05 nm. The result has to be expressed in eV.

a. 0 eV
b. 130 eV
c. -1.28 eV
d. 4.06 eV
e. 15.2 eV

13. A photon collides with a dust particle, which is initially at rest, in vacuum. Assume that the photon is absorbed by the particle. Which of the following is true concerning the wavelength of the photon before the collision and the de Broglie wavelength of the dust particle after the collision?

a. The wavelength of the dust particle is larger than that of the photon.
b. The wavelength of the dust particle equals that of the photon.
c. The wavelength of the dust particle is smaller than that of the photon.

14. The power emitted by a TV broadcast antenna is 1 W. If the frequency of the signal is 8 GHz, how many photons are emitted every second?

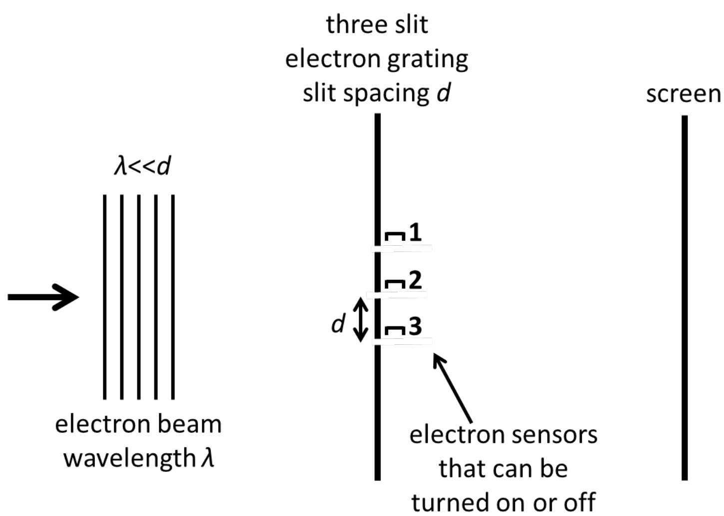
a. 2.5×10^{5}
b. 1.5×10^{20}
c. 1.9×10^{23}

15. In a hydrogen atom, an electron drops from an energy level E1= -3.4eV to the energy level E0 = -13.6eV and emits a single photon as a result of this transition. Find the wavelength of the emitted photon.

a. 15 nm
b. 43 nm
c. 105 nm
d. 121 nm
e. 1002 nm

The next three problems refer to the following situation:

Three charge sensors are placed behind each of the slits in a three slit electron grating. The electron sensors can be turned on and off, and if an electron passes through a slit next to an operating sensor, it is detected. The electron wavelength is much shorter than the slit spacing, *d*. The screen detects each charge that arrives. The total current detected on the screen is I_0.



16. To begin with, the sensors are all off and electrons are sent one at a time to the grating with kinetic energy E_1 and the diffraction pattern is measured on the screen. Then the electron energy is changed to $2E_1$, and the electron current remains the same. Which statement is correct:

a. The ratio of the angles at which the first principal maximum is observed, relative to the straight through beam, $\theta(2E_1)/\theta(E_1)=4$.
b. The ratio of the angles at which the first principal maximum is observed, relative to the straight through beam, $\theta(2E_1)/\theta(E_1)=1/2$.
c. The ratio of the angles at which the first principal maximum is observed, relative to the straight through beam, $\theta(2E_1)/\theta(E_1)=\sqrt{2}$.
d. The ratio of the angles at which the first principal maximum is observed, relative to the straight through beam, $\theta(2E_1)/\theta(E_1)=1/\sqrt{2}$.
e. The ratio of the angles at which the first principal maximum is observed, relative to the straight through beam, $\theta(2E_1)/\theta(E_1)=2$.

17. Now sensor 2 is turned on, sensor 1 and 3 remain turned off. Which of the following statements is true?

a. The principal diffraction angles double, and the total current detected on the screen is I_0.
b. The principal diffraction angles remain the same, but the current detected on the screen is reduced to 2/3 I_0.
c. The principal diffraction angles are cut in half, and the current detected on the screen remains I_0.

The next three problems are closely related:

18. A one dimensional quantum particle having the same mass as the electron is placed in an infinite potential well 0.6 nm wide. Initially it is in its ground state (n=1), but a laser is used to excite it to its first excited state (n=2). Which of the following wavelengths is the closest to the wavelength of the laser that does this?

a. 396 nm
b. 446 nm
c. 505 nm
d. 581 nm
e. 698 nm

19. Compare the probability of finding the particle at the center of the well in the n=2 state versus the n=1 state.

a. $P_{middle}(n=2) > P_{middle}(n=1)$
b. $P_{middle}(n=2) = P_{middle}(n=1)$
c. $P_{middle}(n=2) < P_{middle}(n=1)$

20. Instead of a particle having the same mass as an electron, we put a particle having the same mass as a neutron in the infinite potential well. Compare the energy difference between the n=2 state and the n=1 state, ΔE_{12}, for these two cases.

a. ΔE_{12}(neutron) > ΔE_{12}(electron)
b. ΔE_{12}(neutron) = ΔE_{12}(electron)
c. ΔE_{12}(neutron) < ΔE_{12}(electron)

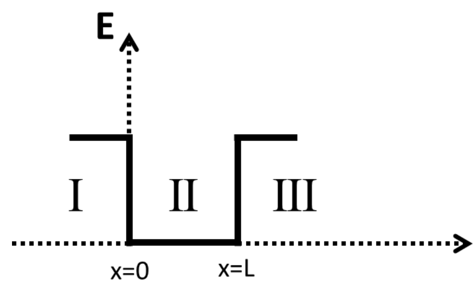
The next two problems are closely related:

21. A beam of electrons is prepared having a deBroglie wavelength of 0.05 nm. What is the kinetic energy of the beam?

a. 37.5 eV
b. 601.7 eV
c. 223.6 eV
d. 454.9 eV
e. 524.5 eV

22. If a beam of neutrons is to have the same wavelength as the electrons in the previous problem, it should have:

a. larger kinetic energy.
b. the same kinetic energy.
c. smaller kinetic energy.



23. A finite potential well extends from x=0 to x=L as shown in the figure. The well is divided into 3 regions. Region I is to the left of the well, region II is in the well and region III is to the right of the well. We consider a bound state of this well. Which of the following statements is true? Here ρ and σ are distances related to the kinetic energy and potential.

a. In region I the wave function is proportional to $e^{x/\rho}$, and in region II the wave function is proportional to $e^{-x/\rho}$.

b. In region II the wave function is proportional to $B_1\cos(x/\sigma)+B_2\sin(x/\sigma)$, and in region III the wave function is proportional to $e^{(L-x)/\rho}$.

c. In region I the wave function is proportional to $e^{-x/\rho}$, and in region III the wave function is proportional to $e^{x/\rho}$.

d. In region II the wave function is proportional to $B_2\sin(x/\sigma)$, and in region III the wave function is proportional to $e^{(L-x)/\rho}$.

e. In region I the wave function is proportional to $e^{x/\rho}$, and in region III the wave function is proportional to $e^{-(L-x)/\rho}$.