1. Two significant figures suffice.

2. Exam is closed book. Calculators allowed.

3. Write your name and your instructor's name legibly on each page.

4. This examination has two sections:
   a) SECTION I CONTAINS THE LAB QUESTIONS.
      There are two questions in this section. Each question has about the same
      effect on your course grade as midterm questions with the same point value.
      The scores on section I will not be curved.

   b) SECTION II IS THE MIDTERM EXAMINATION.
      It consists of 9 multiple choice questions, 6 true-false questions, and 4
      problems. The scores on this section will be curved.

5. Check now that you have a complete exam.

6. You have a total of 48 minutes to complete both sections.

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Values of physical constants and conversion factors

Velocity of light in vacuum \( c = 3.00 \times 10^8 \) m/sec

Velocity of sound in air \( (20^\circ \text{ C}) = 343 \) m/sec

\( 1 \text{ nm} = 10^{-9} \) m
SECTION I. Lab Questions.

1. In the experiment shown above, you recorded the positions of the movable slide at which constructive interference occurs, for sound of a fixed frequency. Suppose you have recorded the data in the table above. What is (Circle the most correct answer) the wavelength of the sound? (4 points)
   a) 5.8 cm
   b) 11.5 cm
   c) 23.2 cm
   d) 44 cm
   e) 68.3 cm

   Slide Positions at Maxima
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<td>51.0</td>
<td>63.0</td>
<td>74.0</td>
<td>85.5</td>
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2. When you look at the spectrum from a mercury discharge tube through a grating, you see 3 prominent lines, which are yellow, green, and deep blue.
   TRUE or FALSE: Of these three lines, the yellow line appears at the largest angle from the central white image. (2 points)
   T F (Circle T or true, F for false)
SECTION II. Midterm Exam.

Part A. Multiple choice (5 points each). Circle the letter corresponding to the best answer for each question.

1. Which of the following actions will NOT increase the resonant frequencies of a stretched string?
   a) Wrap the string with heavy wire.
   b) Increase the tension in the string.
   c) Make the string shorter.
   d) All of the above will increase the resonant frequencies.
   e) None of the above will increase the resonant frequencies.

2. Which one of the following wave phenomena occur for light waves but not for sound waves?
   a) Refraction
   b) Diffraction
   c) Interference
   d) Reflection
   e) Polarization

3. The intensity of sunlight at the top of the earth’s atmosphere is 1340 W/m². What is the intensity of sunlight striking Mars? The earth is $1.5 \times 10^8$ km from the sun, and Mars is $2.3 \times 10^8$ km from the sun.
   a) 570 W/²
   b) 870 W/²
   c) 1080 W/²
   d) 2050 W/²
   e) None of the above is close to the correct answer.

4. In a standing wave on a string fixed at both ends, the distance between one end of the string and the nearest antinode is 0.20 m. What is the wavelength of the traveling waves which are interfering to produce this standing wave?
   a) 0.2 m
   b) 0.4 m
   c) 0.6 m
   d) 0.8 m
   e) There is not enough data provided to answer this question.
5. Sound waves from the vibrating string in the previous question travel through the air to a listener. How are these sound waves in air and the traveling waves on the string related?
   a) They must have the same frequency.
   b) They must have the same wavelength.
   c) They must have the same speed.
   d) The frequency, wavelength and speed must all be the same.
   e) The frequency, wavelength and speed may all be different.

6. Two pure tones are sounded together, and a beat frequency of 4 Hz is heard. What happens to the beat frequency if the frequency of one of the tones is increased?
   a) The beat frequency decreases.
   b) The beat frequency increases.
   c) The beat frequency may either increase or decrease.
   d) The beat frequency does not change if the distance between the sources and the listener does not change.

7. When light traveling through air reflects from a piece of glass, the light undergoes a 180° phase reversal. This is similar to what happens when
   a) a wave traveling in a string reflects from a fixed end.
   b) a wave traveling in a string reflects from a free end.
   c) light traveling through glass reflects from an air layer.
   d) light traveling through glass refracts on entering an air layer.

8. A double slit of slit separation $10^{-4}$ cm and a grating with $10^3$ slits per cm are used with the same light source, which emits light of a single wavelength. Which of the following statements is true?
   a) With this grating, the maxima occur at the same angles as for this double slit, but the grating maxima are much narrower than those from this double slit.
   b) This grating will produce maxima which are both narrower and occur at larger angles than those of this double slit.
   c) The interference **minima** produced by this double slit occur at the same angles as the maxima produced by this grating.
   d) The double slit produces bright fringes of many orders $m$, but the grating produces only the $m=1$ fringe.
9. As shown in the figure above, unpolarized light of intensity \( I_0 \), coming from the left, encounters two pieces of polaroid plastic. The transmission axis of polaroid 1 is vertical, while that of polaroid 2 is horizontal. It is desired to increase the light intensity at B by adding a third polaroid, with transmission axis at 45° to the vertical. Where should this third polaroid be placed?

a) It is impossible to increase the intensity of the light at B by adding more polaroids.
b) Put it to the left of polaroid 1.
c) Put it between polaroids 1 and 2.
d) Put it between polaroid 2 and B.
e) Any of b), c), or d) would work.

PART B. True-False (2 points each). Circle the T if the statement is true, or the F if the statement is false.

Questions 1-6 below concern the double slit experiment shown above. Light of a single wavelength \( \lambda \) from a point source passes through two very narrow slits separated by a distance \( d \) and strikes a screen at a large distance \( L \) beyond the slits. A graph of the light intensity vs. position at the screen is shown.

T   F   1. The phenomenon best illustrated here is the refraction of light.
T   F   2. At point C, light from the two slits interferes constructively because the travel times from slits 1 and 2 are equal.
T   F   3. Light arriving at point B has traveled a distance \( \lambda/2 \) farther from slit 1 than from slit 2.
T   F   4. Covering up slit 1 can increase the light intensity at B.
T   F   5. Increasing the wavelength of the light will increase the distance between the central maximum and the first minimum.
T   F   6. Halving the distance \( d \) between the slits will make the intensity maxima occur closer together.
PART C. Problems. Work the problems in the space provided. You must show all work to receive any credit for correct answers. Partial credit is available for incomplete solutions.

1. An organ pipe has successive resonant frequencies of 250 Hz and 350 Hz.
   a) Is the organ pipe open at both ends, or closed at one end? How can you tell?  
      (5 points)

   b) How long is this pipe? The speed of sound in air is 343 m/sec.  
      (6 points)

2. Two loudspeakers are connected to the same signal generator, but are connected 180° out of phase, so that one speaker cone is moving out as the other one is moving in. If the speakers are 0.20 m apart, find the smallest angle at which constructive interference occurs for sound of wavelength 0.10 meters.  
   (10 points)
3. A thin sheet of plastic with refractive index \( n = 1.50 \) is 1200 nm thick.
   a) How many cycles does a light wave go through in passing through this sheet, if the wavelength of light in air (refractive index 1.000) is 600 nm?
      (6 points)

   b) By how many cycles is the light delayed in the plastic, relative to light of the same frequency passing through an equal thickness of air?
      (6 points)

4. What is the smallest thickness of an air layer between two glass plates, if the glass is to appear bright in reflected light of wavelength 500 nm?
   (10 points)
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1. Two significant figures suffice.

2. Exam is closed book. Calculators allowed.

3. Write your name and your instructor's name legibly on each page.

4. This examination has two sections:
   a) **SECTION I CONTAINS THE LAB QUESTIONS.**
      There are four true-false questions in this section. Each question has about
      the same effect on your course grade as midterm questions with the same
      point value. The scores on section I will not be curved.
   
   b) **SECTION II IS THE MIDTERM EXAMINATION.**
      It consists of 12 multiple choice questions, 5 true-false questions, and 5
      problems. The scores on this section will be curved.

5. Check now that you have a complete exam.

6. You have a total of 48 minutes to complete both sections.

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Values of physical constants and conversion factors

Velocity of light in vacuum \( c = 3.00 \times 10^8 \text{ m/sec} \)

Planck's constant \( h = 6.63 \times 10^{-34} \text{ J-sec} \)

\( hc = 1243 \text{ eV-nm} \)

Rydberg constant for hydrogen \( R = 1.097 \times 10^7 \text{ m}^{-1} = 1/91.2 \text{ nm} \)

Electron rest mass \( m = 9.11 \times 10^{-31} \text{ kg} \)

Electron rest energy \( E_0 = 0.511 \text{ MeV} \)

Ionization energy of hydrogen = 13.6 eV

Radius of first Bohr orbit = \( 0.529 \times 10^{-10} \text{ m} \)

1 nm = \( 10^{-9} \text{ m} \)

1 eV = \( 1.6 \times 10^{-10} \text{ J} \)

1 MeV = \( 10^6 \text{ eV} \)
SECTION 1. Lab Questions.

The setup for the photoelectric effect experiment is shown below.

True-false (2 points each). Circle the T if the statement is true, or the F if the statement is false.

1. The current in the sensitive ammeter A is proportional to the number of electrons per second reaching the stopping electrode.
   
   T  F

2. The stopping voltage V determines the maximum kinetic energy of electrons reaching the stopping electrode.
   
   T  F

3. Making the light bluer by changing filters increases the value of V needed to make the current in A go to zero.
   
   T  F

4. Reducing the intensity of the light with a sheet of wax paper reduces the current in A, but does not affect the value of V needed to make the current in A go to zero.
   
   T  F
Part A. Multiple choice (3 points each). Circle the letter corresponding to the best answer for each question.

A spaceship passes the earth at high speed on the way to a distant star. Observers in the spaceship measure the ship to be 1000 m long, while observers on earth measure the spaceship to be 800 m long.

1. If observers on the spaceship measure it to be 100 m wide, what width do the earth observers measure?
   a) 80 m
   b) 100 m
   c) 125 m

2. Observers on the spaceship measure the time to go from earth to the star to be 10.0 years. How long does this journey take, according to the earth observers?
   a) 8.0 years
   b) 10.0 years
   c) 12.5 years

3. On earth, a standard candle takes 1.0 hour to burn. If the spaceship people burned a similar candle in a similar atmosphere, they would report that the candle takes ___ to burn.
   a) 0.8 hours
   b) 1.0 hour
   c) 1.25 hours

4. What is the speed of the earth, as seen by the spaceship observers?
   a) Zero
   b) 0.6c
   c) 0.8c

5. What is the speed of light from the star, as seen by the spaceship?
   a) 0.2c
   b) 0.4c
   c) 1.0c
   d) 1.6c
   e) 1.8c
Part B. True-false (2 points each). Circle the T if the statement is true, or the F if the statement is false.

T  F  1.  It is possible to decide by experiment whether one is in an accelerated reference frame or not, if one believes one can distinguish real forces from fictitious ones.

T  F  2.  The results of the Michelson-Morley experiment were consistent with the earth's being at rest with respect to the ether.

T  F  3.  The results of the Michelson-Morley experiment were consistent with the idea that there is no preferred inertial frame.

T  F  4.  An electron accelerated through \( \frac{q}{m} \) voltage of 10 volts will acquire 10 eV of kinetic energy.

T  F  5.  In order to ionize an atom, you must supply energy.

Part C. Multiple choice (5 points each). Circle the letter corresponding to the best answer for each question.

1.  What must be the energy of a photon to produce an electron-positron pair, if 1.0 MeV of kinetic energy is given to each particle?

   a)  1.0 MeV  
   b)  1.51 MeV  
   c)  2.0 MeV  
   d)  2.51 MeV  
   e)  3.02 MeV

2.  In the Compton effect, an x-ray photon is scattered by an electron, which recoils with some kinetic energy.  What happens to the wavelength of the scattered photon?

   a)  The wavelength increases. 
   b)  The wavelength decreases. 
   c)  The wavelength remains the same. 
   d)  The wavelength of the photon and electron must be the same.

3.  What is the longest wavelength of light that will eject electrons from a metal whose work function is 3.0 eV?

   a)  414 nm  
   b)  615 nm  
   c)  716 nm  
   d)  There is no longest wavelength.
4. Which of the following was the most important new idea in Bohr's model of the hydrogen atom?

a) Positive charge is concentrated in the nucleus.
b) The atom can be described as a miniature solar system.
c) Light is continuously radiated due to the centripetal acceleration of the electron.
d) Discrete energy levels in the atoms are responsible for the observed spectral lines.
e) Electron standing waves explain how energy levels arise.

5. In Bohr's picture of the hydrogen atom, when an electron is excited from the ground state \((n=1)\) to \(n=2\), the new orbit has a radius

a) \(1/4\) as large as the radius of the ground state orbit.
b) \(1/2\) as large as the radius of the ground state orbit.
c) \(2\) times as large as the radius of the ground state orbit.
d) \(4\) times as large as the radius of the ground state orbit.

6. What is the longest wavelength of light which can be absorbed by hydrogen in its ground state?

a) \(91\) nm 
b) \(122\) nm 
c) \(486\) nm 
d) \(656\) nm 
e) There is no longest wavelength.

7. If de Broglie was correct in stating that massive objects have wave properties, why can't we detect interference effect with pitched baseballs?

a) The wavelength is much too short for observable effects to be seen. 
b) The wavelength is much too long for observable effects to be seen. 
c) A pitched baseball is not nearly fast enough for observable effects to be seen. 
d) De Broglie's statement applies only to electrons.
Part C. Problems. Work the problems in the space provided. You must show all work to receive any credit for correct answers. Partial credit is available for incorrect solutions.

1. A muon is a subatomic particle with a mass of 106 MeV/c² (that is, a rest energy of 106 MeV). If you observe a moving muon with a kinetic energy of 800 MeV to live for $20 \times 10^{-6}$ sec before decaying, what lifetime would be observed by an observer moving with the muon? (7 points)

2. When a sample of metal is illuminated by 0.7 watts/cm² of ultraviolet light of wavelength 300 nm, 1000 electrons with kinetic energies from zero to 2.50 eV are emitted each second.
   
   a) What is the work function of the metal, in eV? (6 points)

   b) How many photons are striking 1 cm² of the metal each second? (6 points)
3. A hydrogen atom absorbs a photon and jumps to the state \( n = 3 \). What wavelengths of light could be emitted by the atom as it returns to its ground state? (7 points)

4. A hydrogen atom in its ground state is ionized by absorbing an ultraviolet photon. The electron is knocked out of the atom, and has \( 2.0 \text{ eV} \) of kinetic energy left after it is free. What was the wavelength of the photon? (7 points)

5. What is the kinetic energy, in eV, of an electron which has a wavelength equal to the radius of a hydrogen atom \( (0.53 \times 10^{-10} \text{ m}) \)? (7 points)