April 18, 2000
9:00 a.m. - 12:00 p.m.

FINAL EXAMINATION

PAPER NO.: 477

DEPARTMENT & COURSE NO.: 16:107

TIME: 3 hours

EXAMINATION: Phyiscs II: Waves and Modern Physics

EXAMINERS: R. C. Barber, S. A. Page, R. M. Roshko

INSTRUCTIONS

This paper consists of two parts. Part A consists of 20 multiple choice questions each worth 2 marks. Part B consists of 2 long answer questions each worth 10 marks. Total 60 marks. Plan to spend about 2 hours on part A and 1 hour on part B of this exam.

PART A – Multiple Choice

Answer **all twenty** multiple choice questions on the IBM sheet, with a pencil.
Each question is worth 2 marks.

A1. A mass m hanging at the end of a vertical spring is executing simple harmonic motion with an angular frequency ω and an amplitude $y_m = 0.82$ cm. At $t = 0$, the mass is 0.43 cm *above* its equilibrium position and it is moving *up*. Assuming that its motion is described by $y = y_m \cos(\omega t + \phi)$, with the positive y axis pointing up, find the phase angle ϕ.

(a) 21° (b) 58° (c) 120° (d) 230° (e) 302°

A2. A block of mass m hanging at the end of a vertical spring with spring constant k is executing simple harmonic motion with amplitude y_m. When the mass is at the extreme lowest point of its motion, a piece of the block of mass $m/4$ breaks off and falls. If the remainder of the block continues to oscillate, by what factor will its maximum speed increase?

(a) $2/\sqrt{3}$ (b) 5/4 (c) 3/2 (d) 2 (e) 3

A3. Two identical strings of the same length L and the same linear mass density μ, each fixed at both ends, are placed near each other. When string A starts oscillating in its fundamental ($n = 1$) mode, the motion of the air induces the nearby string B to vibrate in its third ($n = 3$) harmonic. What is the ratio T_B/T_A of the tension of string B to the tension of string A?

(a) 1/9 (b) 1/4 (c) 1/2 (d) 3 (e) 6

A4. A skydiver falling at a constant speed carries a buzzer which emits a sound of frequency 1800 Hz. Her friend standing directly below her on the ground measures the frequency of these sound waves to be 2150 Hz. What frequency does the skydiver measure for the sound waves *reflected* from the ground? Assume the speed of sound is 343 m/s.

(a) 125 kHz (b) 450 kHz (c) 2500 Hz (d) 7400 Hz (e) 160 MHz

A5. Light of wavelength 500 nm is incident normally on a diffraction grating. If the *third order* maximum of the diffraction pattern is observed at 30° from the central maximum, determine the *total number* of diffraction *maxima* which will be observed for light of wavelength 700 nm.

(a) 3 (b) 4 (c) 6 (d) 9 (e) 12

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A6. Light with a wavelength of 442 nm passes through a screen with two slits separated by $d = 0.400$ mm. Ignoring diffraction effects, how far away must a viewing screen be placed so that a dark fringe appears directly in line with each slit with three bright fringes between them?

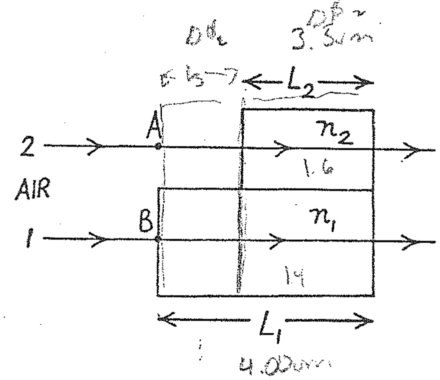
(a) 0.12 m (b) 0.30 m (c) 0.86 m (d) 1.30 m (e) 1.85 m

A7. Two slits 0.10 mm wide, separated by 0.20 mm centre-to-centre, in an opaque screen, are illuminated by light of wavelength 500 nm. How many complete interference fringes will be observed within the central diffraction envelope on a screen 2.0 m away?

(a) 11 (b) 9 (c) 7 (d) 5 (e) 3

A8. Two waves of light with wavelength 600.0 nm in air ($n = 1$), travel through two plastic layers as shown, with $L_1 = 4.00$ μm, $L_2 = 3.50$ μm, $n_1 = 1.40$, and $n_2 = 1.60$. If the waves are *in phase* at points A and B, what is the phase difference between the waves when they emerge from the two plastic layers?

(a) 1.20 rad (b) 5.24 rad (c) 0.31 rad (d) 0.89 rad (e) 3.65 rad



Relativity

A9. A meson moving through a laboratory at a speed v travels a distance L during its lifetime (the time from the moment the meson is created until the moment it decays) according to observers at rest in the laboratory. If the meson were at rest in the laboratory its lifetime would be:

(a) $\frac{L}{v}(1 - v/c)$

(b) $\frac{L}{v}(1 - v/c)^{-1}$

(c) $\frac{L}{v}(1 - v^2/c^2)^{-1/2}$

(d) $\frac{L}{v}(1 - v^2/c^2)^{1/2}$

(e) $(L/v - vx/c^2)(1 - v^2/c^2)^{-1/2}$

A10. The coordinates of two events A and B, both of which take place on the x-axis of a given reference frame S, are $x_A = 100$ m, $t_A = 0$ s and $x_B = 0$ m, $t_B = 9\times10^{-8}$ s. What is the distance between these two events as measured by observers in another reference frame S' which is moving at a speed of 0.95c in the positive x direction relative to the first frame?

(a) 31 m (b) 78 m (c) 100 m (d) 240 m (e) 402 m

A11. Quasar Q1 is moving away from us at a speed of $0.8c$. Quasar Q2 is moving away from us in the opposite direction at a speed of $0.5c$. The speed of Q1 as measured by an observer on Q2 is:

(a) $0.21c$ (b) $0.5c$ (c) $0.93c$ (d) $1.3c$ (e) $2.17c$

Relativity

A12. A source at rest emits light of wavelength 500 nm. When it is moving at $0.90c$ directly away from an observer, the observer detects light of wavelength:

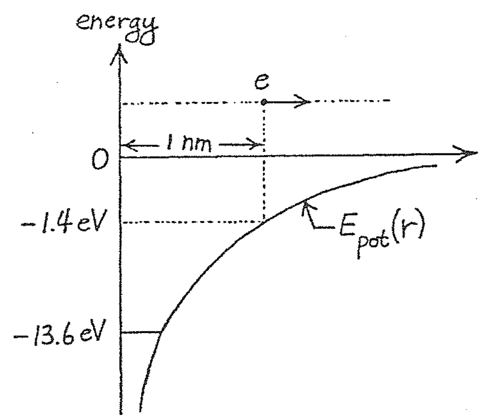
(a) 26 nm (b) 115 nm (c) 500 nm (d) 2.2×10^3 nm (e) 9.5×10^3 nm

A13. According to relativity theory a particle of mass m with a momentum of $2mc$ has a speed of:

(a) $2c$ (b) $4c$ (c) c (d) $c/2$ (e) $0.89c$

A14. A hydrogen atom in its ground state absorbs a photon to become ionized. What is the energy of this photon if the escaping electron has a kinetic energy of 25.0 eV when it is 1.00 nm away from the nucleus, where its potential energy is $E_{pot} = -1.4$ eV, as shown.

(a) 13.6 eV (d) 38.6 eV
(b) 25.0 eV (e) 40.0 eV
(c) 37.2 eV



A15. A diffraction grating with 600 lines per mm is used to study the spectrum of hydrogen in a discharge tube. At what angle θ should the second order red line of the Balmer series be observed? (This line corresponds to the $n = 3 \rightarrow n = 2$ transition.)

(a) 23° (b) 26° (c) 45° (d) 52° (e) 80°

A16. A radioactive source emits γ-rays (high energy photons) with an energy of 1.00 MeV. The γ-rays scatter from electrons in the surrounding air via the Compton effect. What is the *minimum energy* of Compton-scattered γ-rays that undergo a single Compton scattering process?

(a) 0.20 MeV (b) 0.26 MeV (c) 0.34 MeV (d) 1.00 MeV (e) 1.20 MeV

The wave function $\psi(x) = \psi_0 e^{i(kx-\omega t)}$ describes a free particle of mass m travelling in one dimension along the x axis.

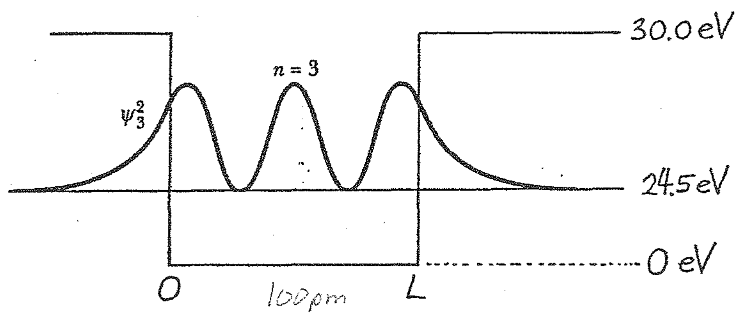
A17. What are the SI units of the constant ψ_0?

(a) m^{-1} (c) m^{-2} (e) none, ψ_0 is dimensionless
(b) $m^{-1/2}$ (d) m^2

A18. What is the kinetic energy of this particle? ($\hbar = h/2\pi$ in the following answers.)

(a) $\hbar\omega$ (b) $\hbar k$ (c) $\frac{\hbar^2k^2}{2m} + \hbar\omega$ (d) $\frac{\hbar^2k^2}{2m} - \hbar\omega$ (e) $\frac{\hbar^2k^2}{2m}$

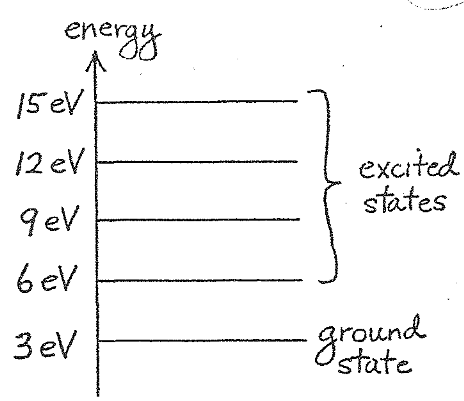
A19. An electron is trapped in a finite potential well of width $L = 100$ pm and depth 30.0 eV. The $n = 3$ probability density $|\psi_3(x)|^2$ is plotted in the figure, with energy $E_3 = 24.5$ eV. Outside the well, the wave function decays exponentially as $\psi = Ae^{-kx}$. Over what distance, measured from the edge of the well ($x = L$) does the *probability density* decay by a factor $\frac{1}{e}$?



(a) 12 pm (b) 18 pm (c) 20 pm (d) 30 pm (e) 42 pm

A20. An energy level diagram showing the ground state plus the first 4 excited states of a certain quantum-mechanical system is shown. Based on this information, the system could be:

(a) a hydrogen atom
(b) an electron in an infinite potential well
(c) an electron in a finite potential well
(d) a free electron
(e) none of these



PART B - continued on page 5

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PART B – Long Answer Questions

Answer **both** long answer questions in the exam booklet. Only the **lined pages** will be marked.
You must **show your work** in order to receive full marks.

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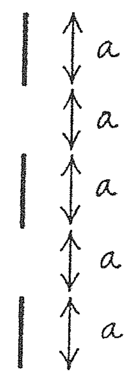
(10) B1. *Interference and Diffraction*

(3) (a) A beam of green light is diffracted by a *single slit* with a width of 0.550 mm. The diffraction pattern forms on a wall 2.06 m beyond the slit. The distance between the positions of zero intensity on both sides of the central maximum is 4.10 mm. Calculate the wavelength of the laser light.

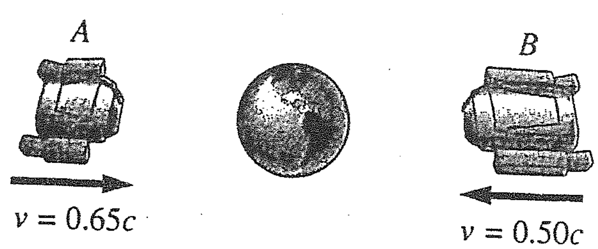
(3) (b) Given a *diffraction grating* with 400 lines/mm, how many *orders* of the *entire* visible spectrum (400-700 nm) can it produce in addition to the $m = 0$ order?

(4) (c) Considering the effects of both single-slit diffraction and multiple-slit interference for a *diffraction grating*, show that a grating made up of alternating transparent and opaque strips of *equal widths*, as shown, eliminates all of the even orders of the interference maxima, except the central one.



(10) B2. *Relativity*

Two spaceships are each 25 m long, as measured in their rest frames. Ship A is approaching Earth at $0.65c$ and Ship B is approaching Earth from the opposite direction at $0.50c$, as shown below.



(3) (a) Find the length of Ship B as measured in the Earth's frame of reference.

(3) (b) Find the speed of Ship B as measured by observers in Ship A's frame of reference.

(4) (c) Two minor explosions occur at the *same place* on Ship B, separated by a time interval of 5.0 s as measured by a clock in Ship B. What is the time interval between the same two events according to observers in Ship A's frame of reference?

THE END