April 23, 1999
1:30 p.m. - 4:30 p.m.

FINAL EXAMINATION

PAPER NO.: 914

DEPARTMENT & COURSE NO.: 16:107

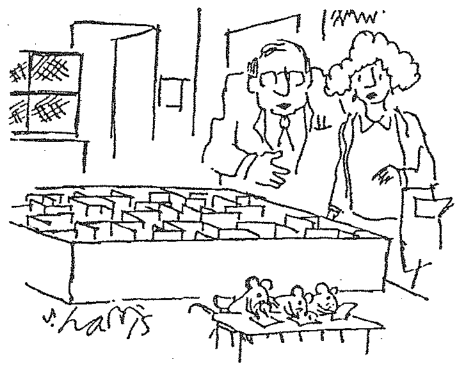
TIME: 3 hours

EXAMINATION: Physics II: Waves & Modern Physics

EXAMINERS: R. C. Barber, R. M. Roshko, B. W. Southern

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.



"THEN, AS YOU CAN SEE, WE GIVE THEM SOME MULTIPLE CHOICE TESTS."

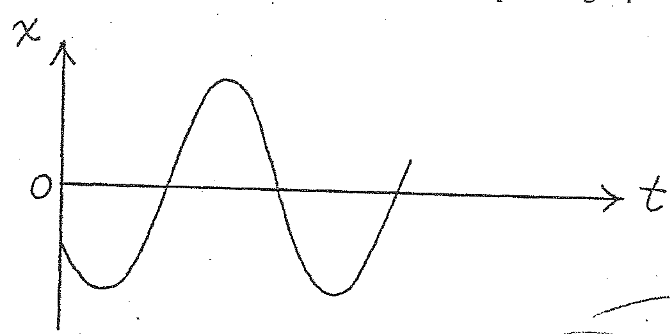
PART A – Multiple Choice

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

A1. A particle oscillates with simple harmonic motion along the x-axis. Its displacement is given by $x(t) = (0.5)\cos(3\pi t)$, where x is in metres and t is in seconds. The *total distance* travelled by the particle between t = 0 s and t = 0.5 s is

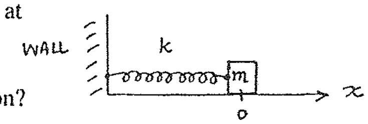
(a) 0.4 m (b) 0.8 m (c) 1.5 m (d) 2.6 m (e) 5.4 m

A2. The figure below shows the displacement of a particle executing simple harmonic motion with $x = x_m \cos(\omega t + \phi)$. In which of the following ranges does the phase angle ϕ for this motion lie?



(a) $-\pi < \phi < -\pi/2$ (b) $-\frac{\pi}{2} < \phi < 0$ (c) $0 < \phi < \frac{\pi}{2}$ (d) $\frac{\pi}{2} < \phi < \pi$ (e) $\pi < \phi < \frac{3\pi}{2}$

A3. An object of mass 2.0 kg is attached to a horizontal spring of constant $k = 400$ N/m, and rests on a horizontal, frictionless surface. Suddenly the mass is given a sharp push towards the wall with instantaneous speed $v = 0.3$ m/s at $x = 0$. If the unstretched length of the spring is 8.0 cm, what will be the *maximum* length of the spring during the resulting simple harmonic motion?



(a) 8.0 cm (b) 10 cm (c) 11 cm (d) 12 cm (e) 15 cm

$f = \frac{V}{2L} = \frac{\sqrt{T/\mu}}{2L_w}$

L_w

A4. A wire of mass 1.0 g is stretched between two fixed supports 0.50 m apart. It is placed near the open end of a tube of length 0.20 m, which is closed at the other end. The tube is designed so that, when the wire is oscillating in its fundamental mode, the tube resonates at its fundamental frequency. What is the tension in the wire when this occurs? Assume that the speed of sound in air is 340 m/s.

L_T $f = \frac{V}{4L_T}$

(a) 20 N (b) 50 N (c) 160 N (d) 240 N (e) 360 N

A5. A bat flying toward an obstacle at 12 m/s emits high-frequency sound at a frequency of 80 kHz. The sound reflects off the obstacle and returns to the bat. What is the period of the reflected sound heard by the bat? Assume that the speed of sound in still air is 340 m/s.

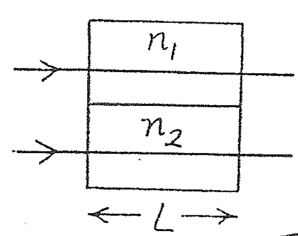
(a) 0.012 ms (b) 0.060 ms (c) 0.240 ms (d) 0.466 ms (e) 0.842 ms

A6. A harmonic wave moves down a string with speed 12.4 m/s. A particle in the string has a maximum displacement of 4.5 cm and a maximum transverse speed of 9.4 m/s. The wavelength of the travelling wave is:

$\lambda = \frac{2\pi V_p y_m}{u_m}$

(a) 16 cm (b) 37 cm (c) 56 cm (d) 86 cm (e) 122 cm

A7. Two light waves of wavelength 620 nm in air travel through two media of thickness L, with indices of refraction $n_1 = 1.45$ and $n_2 = 1.65$, as shown. The two waves are initially out of phase by π radians before they enter the media. What is the *least* thickness L for which the two waves will emerge from the two media exactly in phase?



$\Delta\phi = \frac{2\pi}{\lambda_n}\Delta L$

$= \frac{2\pi}{\lambda}(n_2 - n_1)L = \pi$

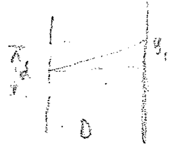
$L = \frac{\lambda}{2(n_2 - n_1)}$

(a) 0.26 μm (b) 0.45 μm (c) 0.86 μm (d) 1.05 μm (e) 1.55 μm

A8. Light of wavelength 600 nm passes through a single slit of width 0.1 mm and produces a diffraction pattern on a screen. What is the *path difference* between Huygens' wavelets which leave the top and the midpoint of the slit and meet at the *third diffraction minimum*?

$\frac{a}{2}\Delta\theta = \frac{3\lambda}{2}$

(a) 300 nm (b) 600 nm (c) 900 nm (d) 1200 nm (e) 1500 nm



A9. Light of wavelength 633 nm from a helium-neon laser falls normally on a plane containing two very narrow slits. The first interference maximum is 82 cm from the central maximum on a screen 12 m away. Find the separation of the slits.

(a) 9.3 μm (b) 3.2 μm (c) 25 μm (d) 0.22 μm (e) 64 μm

$d = \frac{(1)(633\times10^{-9})12}{82\times10^{-2}} = 9.26\times10^{-6}\,m$

$d\sin\theta = m\lambda$

$d\tan\theta = m\lambda$

$d\left(\frac{y_m}{D}\right) = m\lambda$

$\boxed{d = \frac{m\lambda D}{y_m}}$

A10. What is the longest wavelength that can be observed in the fifth-order spectrum using a diffraction grating with 4000 slits per centimetre?

(a) 96 nm (b) 125 nm (c) 266 nm (d) 380 nm (e) 500 nm

$d = \frac{1\,cm}{4000} = .25\times10^{-5} = 2.5\times10^{-6}\,m$

$d\sin\theta = m\lambda$

$\lambda = \frac{d\sin\theta}{m} = 500\,nm$

Relativity

A11. A radioactive atom has a speed 0.80 c in the positive x direction relative to the laboratory. The atom decays and ejects an electron with speed 0.50 c *relative to the atom*, in the *backward* (negative x) direction. What is the speed of the ejected electron as measured in the laboratory?

(a) 0.21 c (b) 0.30 c (c) 0.50 c (d) 0.80 c (e) 0.95 c

A12. The total relativistic energy of a particle with rest mass m is twice its rest energy. What is the momentum of the particle?

(a) $\frac{1}{4}$ mc (b) mc (c) $\sqrt{2}$ mc (d) $\sqrt{3}$ mc (e) 4 mc

A13. A spaceship is traveling at a speed 0.95 c relative to the Earth and has a contracted length of 62 m relative to the Earth. Suppose that the tail of the spaceship emits a flash of light. How long does it take the light to reach the nose of the spaceship, as measured in the frame of the spaceship?

(a) 0.66 μs (b) 1.1 μs (c) 2.2 μs (d) 3.5 μs (e) 4.2 μs

A14. Observers in reference frame S record two flashes of light separated spatially by $\Delta x = 2400$ m and temporally by $\Delta t = 5.0$ μs. Observers in frame S′, which is moving at speed v, in the positive x direction relative to S, see these flashes occur simultaneously. What is the speed v of frame S′?

(a) 0.50 c (b) 0.63 c (c) 0.76 c (d) 0.85 c (e) 0.98 c

A15. A particle has a wave function

$$\psi(x) = \sqrt{\frac{2}{a}}\, e^{-x/a} \quad \text{for } x > 0$$
$$= 0 \quad \text{for } x < 0$$

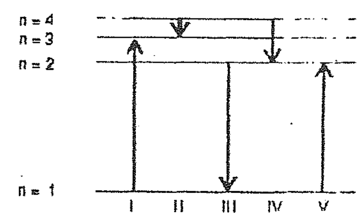
The probability that the particle is found between x = 0 and x = a is

(a) 1 (b) .71 (c) .86 (d) .32 (e) .66

A16. The ground state energy of an electron in a one-dimensional trap with zero potential energy in the interior and infinite potential energy at the walls is 2.0 eV. If the width of the well is doubled, the ground state energy will be:

(a) 0.5 eV (b) 1.0 eV (c) 2.0 eV (d) 4.0 eV (e) 8.0 eV

A17. The diagram shows the energy levels for an electron in a certain atom. Which transition shown represents the *emission* of a photon with the *shortest* wavelength λ?



(a) I. (c) III. (e) V.

(b) II. (d) IV.

A18. An electron with energy E is incident on a potential energy barrier of height E_{pot} and thickness L. The probability of tunneling increases if:

(a) E and E_{pot} decrease by the same amount.

(b) L decreases without any other changes.

(c) E decreases without any other changes.

(d) E and E_{pot} increase by the same amount.

(e) ~~E_{pot} increases without any other changes.~~

A19. Photons with a wavelength of 5.70×10^{-12} m are incident on stationary electrons. The photons scattered through 50.0° have a wavelength of:

(a) 0.87×10^{-12} m (b) 4.83×10^{-12} m (c) 5.13×10^{-12} m (d) 6.27×10^{-12} m (e) 6.57×10^{-12} m

A20. Monoenergetic electrons are incident on a single slit. If the energy of each incident electron is increased the central maximum of the diffraction pattern:

(a) widens

(b) narrows

(c) stays the same width

(d) widens for slow electrons and narrows for fast electrons

(e) narrows for slow electrons and widens for fast electrons

PART B – Long Answer Questions

Answer **both** long answer questions in the exam booklet. Only the **lined pages** will be marked.

(10) B1. A He-Ne laser ($\lambda = 632.8$ nm) is used to illuminate a double slit. The slit widths are $a = 9.0\ \mu m$ and their center-to-center separation is $d = 50\ \mu m$. The transmitted intensity pattern is observed on a flat screen located 2.00 m behind the slits.

(3) (a) Draw a sketch of the intensity pattern that would be observed on the screen.
Mark a feature on your diagram that arises from constructive interference of light from the two slits, and specify the condition with an appropriate equation relating λ and θ, where θ is the angle measured from the center of the two slits to the screen.
Mark a feature on your diagram that arises from the diffraction of light through a single slit and specify the condition with an appropriate equation relating λ and θ.

(2) (b) Show that for small angles θ, the interference fringes are approximately equally spaced on the screen, and evaluate their spacing in cm.

(4) (c) As the angle θ increases, the intensity of the pattern on the screen drops dramatically. Suppose that the lowest intensity of light that can be visually detected by an observer is 1% of the central maximum intensity. Approximately how many oscillations of the main *diffraction* envelope can be observed?

(1) (d) What could the experimentalist of part (c) do to extend the angular range of the measurements?

(10) B2. Albert Einstein was awarded the Nobel Prize in Physics in 1921 for his work on the photoelectric effect.

(2) (a) Briefly describe the photoelectric effect.

(2) (b) What assumptions did Einstein make in order to explain this effect?

(2) (c) The figure shows Millikan's measurements of the stopping potential of sodium as a function of frequency. Use this data and the value of the electron charge $e = 1.6\times10^{-19}$ C to estimate the value of Planck's constant.

(2) (d) Use the data to estimate the work function of sodium in electron volts.

(2) (e) What is the maximum speed of the photoelectrons ejected at 2.0×10^{15} Hz?