# UNIVERSITY OF MANITOBA

April 16, 1998
9:00 a.m.-12:00 p.m.

FINAL EXAMINATION

PAPER NO.: 387



DEPARTMENT & COURSE NO.: 16:107

TIME: 3 hours

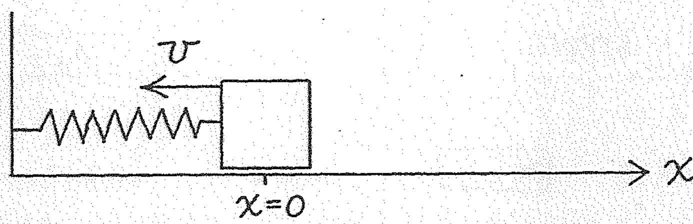
EXAMINATION: Physics II: Waves & Modern Physics

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

## PART A – Multiple Choice

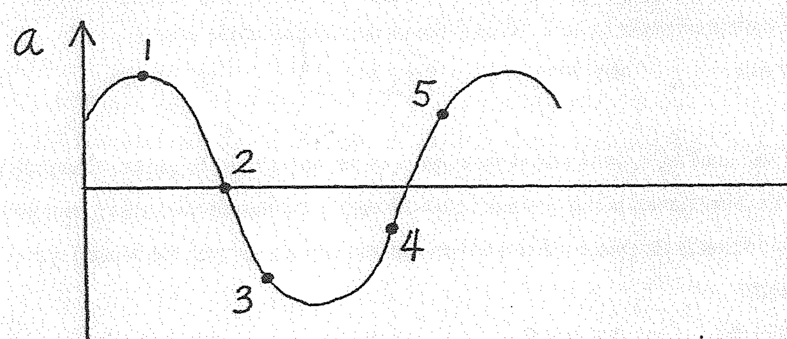
Answer **all twenty** multiple choice questions on the IBM sheet, with a pencil. For version A of the test, fill in lines 1-20; for version B of the test, fill in lines 21-40.

17 A1. A mass at the end of a horizontal spring is performing simple harmonic oscillations described by $x = x_m \cos(\omega t + \phi)$. The diagram below shows the behaviour of the oscillator at t = 0. What is the phase angle $\phi$?




$\boxed{\text{(a) } \pi/2}$ (b) 0 (c) $\pi$ (d) $3\pi/2$ (e) $\pi/4$

17 A2. The acceleration a(t) of a particle undergoing simple harmonic motion along the x-axis between $x = +x_m$ and $x = -x_m$ is shown below. At which of the labelled points is the particle between x = 0 and $x = +x_m$ and moving towards the equilibrium point?




(a) 1 (b) 2 (c) 3 $\boxed{\text{(d) } 4}$ (e) 5

17 A3. When a mass m is hung vertically from spring A and another mass m/2 is hung vertically from spring B, the springs are stretched by the same distance. The two spring-mass systems are then set into vertical simple harmonic motion with the same amplitude. What is the ratio of the total energies $E_A/E_B$ of the two oscillators?

(a) 1/2 $\boxed{\text{(b) } 2}$ (c) $\sqrt{2}$ (d) $1/\sqrt{2}$ (e) 4

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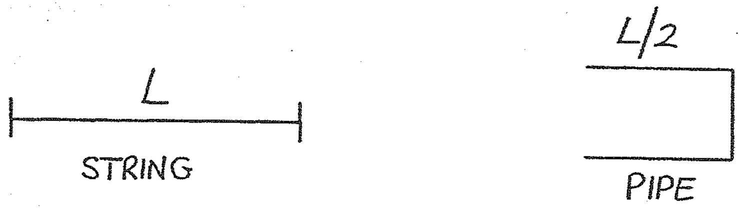
19 A4. The tension in a string of length L, fixed at both ends, is adjusted until the speed of waves on the string equals the speed of sound in air. The third harmonic mode of oscillation is set up in the string. What harmonic n does this frequency correspond to in a pipe of length L/2 with one open end and one closed end?




(a) $n = 1$  $\boxed{\text{(b) } n = 3}$  (c) $n = 5$  (d) $n = 7$  (e) $n = 4$

19 A5. A source emitting sound of frequency 200 Hz moves away from a stationary listener at 80 m/s. Find the wavelength of the sound waves between the source and the listener. Assume sound travels in still air at 340 m/s.

(a) 6.4 m  (b) 0.8 m  (c) 4.2 m  $\boxed{\text{(d) 2.1 m}}$  (e) 8.6 m

18 A6. A transverse wave of frequency 40 Hz propagates down a string. Two points on the string 5 cm apart are out of phase by $\pi/6$. What is the phase velocity of the wave?

(a) 2 m/s  (b) 10 m/s  $\boxed{\text{(c) 24 m/s}}$  (d) 36 m/s  (e) 52 m/s

41 A7. Two waves of light, both with wavelength $\lambda$ in air, are initially in phase. One travels in air ($n = 1$) and the other travels along a parallel path through a medium of thickness L and index of refraction $n = \frac{3}{2}$. What is the phase difference between the two waves after the second wave emerges from the medium?

(a) $2\pi L/3\lambda$  (b) $2\pi L/\lambda$  (c) $\pi L/2\lambda$  (d) $3\pi L/2\lambda$  $\boxed{\text{(e) } \pi L/\lambda}$

41 A8. Laser light falls on three evenly spaced, very narrow slits. When one of the outside slits is covered, the first-order interference <u>maximum</u> is at 60° from the normal. If the centre slit is now covered and the two outside slits are open, find the angle of the second order interference <u>minimum</u>.

(a) 22°  $\boxed{\text{(b) 40.5°}}$  (c) 60°  (d) 76°  (e) 88.7°

43 A9. What is the highest order maximum that can be observed using light of wavelength 750 nm and a diffraction grating with 4000 slits per centimetre?

(a) 1  (b) 2  $\boxed{\text{(c) 3}}$  (d) 4  (e) 5

43 A10. Monochromatic light is normally incident on a grating that is 1 cm wide and has 10,000 slits. The first order line is deviated at a 30° angle. What is the wavelength, in nm, of the incident light?

(a) 300 (b) 400 $\boxed{\text{(c) 500}}$ (d) 600 (e) 1000

41 A11. How fast must you move towards a red light ($\lambda = 650\ nm$) for it to appear green ($\lambda = 525\ nm$)?

(a) .840c (b) .106c $\boxed{\text{(c) .210c}}$ (d) .420c (e) 1.20c

X 20 A12. Two spaceships are approaching each other. If the speed of each ship is .900c relative to the earth, what is the speed of one ship relative to the other ship?

(a) zero $\boxed{\text{(b) .995c}}$ (c) .694c (d) 1.8c (e) .900c

20 A13. An electron of rest energy .511 MeV has a total energy of 0.6 MeV. The speed of the electron is

(a) .912c (b) .263 c (c) .769c $\boxed{\text{(d) .524c}}$ (e) 1.53c

46 A14. A photon has a wavelength of 550 nm. What would be the de Broglie wavelength of an electron with the same kinetic energy as the energy of the photon?

(a) 0.58 nm $\boxed{\text{(b) 0.82 nm}}$ (c) 550 nm (d) 1.64 nm (e) 1.16 nm

45 A15. A photon with an energy of 0.600 MeV hits an electron and scatters at an angle $\phi$ (as measured with respect to its original direction). If the energy of the scattered photon is 0.379 MeV, what was the angle $\phi$?

(a) 0.50° (b) 51° (c) 30° (d) 1.04° $\boxed{\text{(e) 60°}}$

46 A16. A group of $10^7$ electrons (in a transistor) each having a kinetic energy of 0.50 eV strike a potential energy barrier of height 0.70 eV and a width of 0.75 nm. How many of the electrons pass through the barrier?

(a) $1.00\times10^7$ (b) 323 $\boxed{\text{(c) } 3.23\times10^5}$ (d) $3.72\times10^3$ (e) 0

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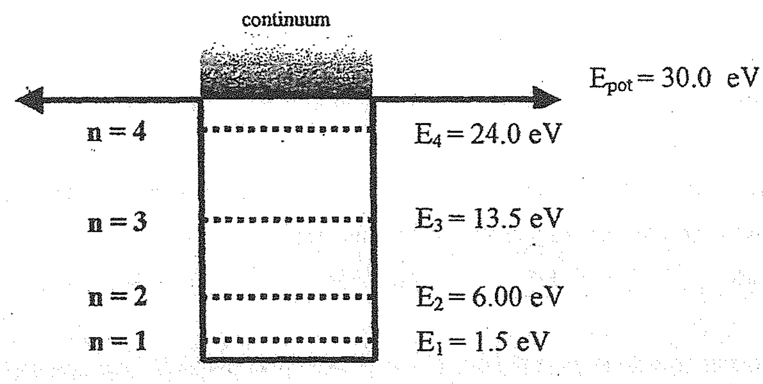
An electron is confined in a finite potential well with a depth of 30 eV and a width of 100 pm. The possible energy levels are shown in the diagram below. (Questions A17, A18, and A19 refer to the diagram.)




47 A17. How much energy must be given to an electron in the lowest state to just free it?

(a) 1.50 eV (b) 22.5 eV $\boxed{\text{(c) 28.5 eV}}$ (d) 30.0 eV (e) 21.5 eV

A18. What is the longest wavelength photon that can be absorbed by an electron in one of these states?

$\boxed{\text{(a) 0.28 μm}}$ (b) 0.83 μm (c) 0.21 μm (d) 0.17 μm (e) 0.12 μm

A19. An electron in the n = 4 state decays back down to the n = 1 state. How many possible spectral lines could be observed in the light during this decay?

(a) 3 (b) 4 $\boxed{\text{(c) 6}}$ (d) 7 (e) 5

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A20. The wavefunctions for a particle in an infinitely deep potential well are given by:

$$\psi_n(x) = \sqrt{\frac{2}{L}}\,\sin\left[\left(\frac{n\pi}{L}\right)x\right] \quad \text{for } n = 1,2,3\ldots$$

What is the probability of finding the particle within the region $\frac{L}{4} \le x \le \frac{3L}{4}$ when it is in the $n = 2$ state? Assume that the well extends from $x = 0$ to $x = L$.

(a) 0.82 $\boxed{\text{(b) 0.50}}$ (c) 0.60 (d) 0.10 (e) 1.00

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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. Each question is worth 10 marks.

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10 (10) B1. The special theory of relativity is based on two postulates.

(2) (a) Briefly state the two postulates.

The Lorentz transformation on the equation sheet relates the spacetime coordinates of a *single* event $(x, y, z, t)$ as seen by two observers in two inertial frames $S$ and $S'$ where $S'$ moves with velocity $v$ relative to $S$ along the positive $x$, $x'$ direction.

Consider *two* events $(x_1, y_1, z_1, t_1)$ and $(x_2, y_2, z_2, t_2)$ in frame $S$ with space separation $\Delta x = x_2 - x_1$, $\Delta y = 0$, $\Delta z = 0$ and time separation $\Delta t = t_2 - t_1$.

(2) (b) What are their space and time separations in $S'$?

(2) (c) Show that the two events can be simultaneous in frame $S'$ only if $\Delta x$ is greater than $c\Delta t$ in frame $S$.

(2) (d) If the two events occur at the same place in $S$ but at different times, what is the time separation in frame $S'$? Which of these is the proper time?

(2) (e) If the two events are simultaneous in $S$, show that their space separation $\Delta x'$ in $S'$ is larger than their space separation $\Delta x$ in S. Which of these is the proper distance?

10 (10) B2. Light from a He-Ne laser ($\lambda = 632.8$ nm) illuminates a double slit (slit widths of a = 8 μm, and centre-to-centre slit separation d = 50 μm). The resulting pattern falls on a screen located 3.00 m from the slits.

41-42

(a) On the screen, what is the distance from the centre of the pattern to the second minimum in the diffraction envelope?

(b) What is the distance on the screen between adjacent interference fringes located near the centre of the pattern?

(c) How many interference fringes are there within the central diffraction envelope?

In the above experimental arrangement, the laser is now used to illuminate a diffraction grating of 600 lines/mm.

(d) On the screen, what is the distance from the centre of the pattern to the first and the second order diffraction maxima?

(e) Consider the n = 0 central maximum fringe for this grating. The first diffraction minimum, at the side of this line, occurs at an angle $\theta_{hw}$ (which defines the half width of the line). Find an expression for the angle $\theta_{hw}$ in terms of N (the number of lines), d (the grating spacing) and $\lambda$.

(Hint: Recall the way that we got the expression for the first minimum for the single slit.)

**THE END**