April 24, 2015
(9:00 am – noon)

FINAL EXAMINATION

DEPARTMENT & COURSE NO.: PHYS 1070

TIME: 3 hours

EXAMINATION: Physics 2: Waves and Modern Physics

EXAMINERS: G. Gwinner, R. Roshko

Equal marks for all 26 questions. No marks are subtracted for wrong answers.

Record all answers on the computer score sheet provided. **USE PENCIL ONLY!** Black pen will look good but may not be read reliably by the scoring machine. **Mark only <u>one</u> answer for each question!** Select the answer which is closest to yours.

A formula sheet is provided for your use; you may **not** use your own formula sheet. Calculators of any type are allowed.

Be sure your name and student number are printed on the score sheet and the student number correctly coded in the box at the top right-hand side of the sheet.

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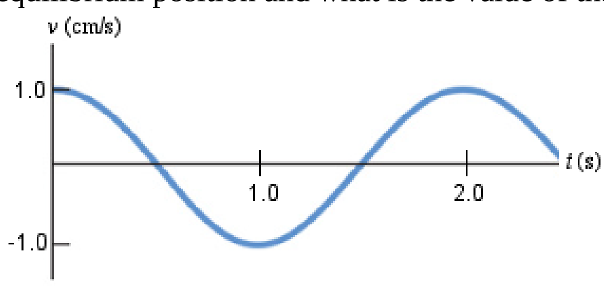
1. A block is executing simple harmonic motion at the end of a spring. A graph of velocity versus time for the block is shown below. At what time will the block be at its greatest positive displacement from the equilibrium position and what is the value of that displacement?

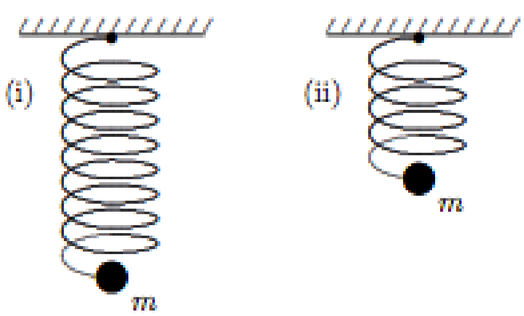


(a) 2.0 s; 1.0 cm (b) 2.0 s; 3.1 cm (c) 1.5 s; 0.32 cm (d) 0.5 s; 3.1 cm (e) 0.5 s; 0.32 cm

2. A simple pendulum consists of a small bob of mass 300 g at the end of a 1.0 m cord of negligible mass. The pendulum is displaced from its equilibrium position by an angle of 0.10 rad and released from rest. How many seconds pass before the pendulum acquires its maximum kinetic energy?

(a) 0.15 s (b) 0.50 s (c) 1.0 s (d) 2.0 s (e) n.o.t.

3. A simple harmonic oscillator consists of a particle of mass m and an ideal spring with spring constant k. The particle oscillates as shown in (i) with period T. If the spring is cut in half and used with the same particle, as shown in (ii), the period will be:



(a) $2T$ (b) $\sqrt{2T}$ (c) $T/\sqrt{2}$ (d) T (e) $T/2$

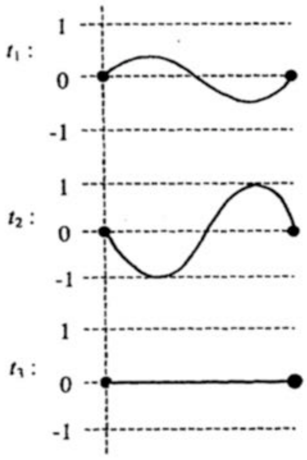
4. A sinusoidal wave on a string is described by the equation

$$y = 0.15\sin(0.80x - 50t)$$

with x and y in meters and t in seconds. The linear mass density of the string is 0.012 kg/m. What is the average power transmitted by the wave?

(a) 21 W (b) 2.5 W (c) 5.4×10^{-3} W (d) 1.4×10^{-6} W (e) 2.5×10^{-7} W

5. A standing wave is excited on a string fastened to two fixed supports. The sequence of pictures shows the shape of the string at times t_1, t_2, and t_3. Rank the pictures in order of increasing kinetic energy of the string.



(a) t_3, t_2, t_1 (b) t_1, t_2, t_3 (c) t_2, t_1, t_3 (d) t_1, t_3, t_2
(e) The kinetic energy is the same in all pictures

6. A sinusoidal wave train is moving along a string. The equation giving the displacement as a function of position and time is

$$y(x,t) = 0.12 \sin[8\pi\left(t - \frac{x}{50}\right)]$$

where x, y are in meters and t is in seconds. At t = 2.4 s, the transverse velocity of an element of string at x = 5.0 m is:

(a) 0.037 m/s (b) 0.27 m/s (c) 0.93 m/s (d) 1.6 m/s (e) 3.0 m/s

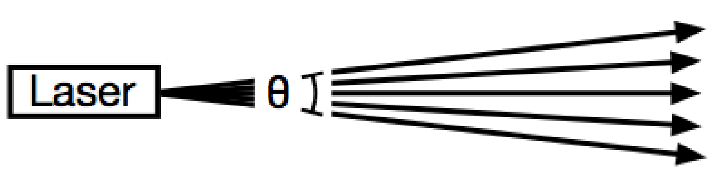
7. An organ pipe open at both ends is 1.55 m long. A second organ pipe that is closed at one end and open at the other is 0.77 m long. Which of the following sets of frequencies consists of frequencies that are resonances for both pipes?

(a) 110 Hz, 330 Hz, 550 Hz (b) 220 Hz, 440 Hz, 660 Hz (c) 110 Hz, 220 Hz, 330 Hz
(d) 330 Hz, 440 Hz, 550 Hz (e) 220 Hz, 660 Hz, 1100 Hz

8. A truck moving at 36 m/s passes a police car moving at 45 m/s in the opposite direction. If the siren on the police car operates at a frequency of 500 Hz, what is the difference between the frequencies heard by the truck driver when the police car is a large distance ahead of him, compared to when the police car is a large distance behind?

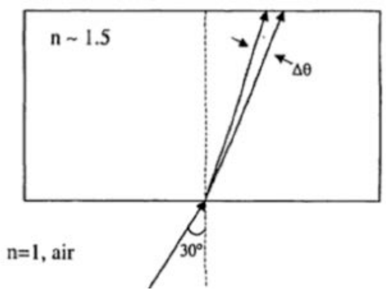
(a) 240 Hz (b) 238 Hz (c) 242 Hz (d) 236 Hz (e) 234 Hz

9. A laser, radiating at 633 nm, has a power output of 3.0 mW. The beam diverges with an angular spread of $\theta = 0.17$ mrad. Assuming the beam exits the laser from a point-like aperture, the intensity of the beam 40 m from the laser is: (Hint: the area of the beam at 40 m from the laser is very small)



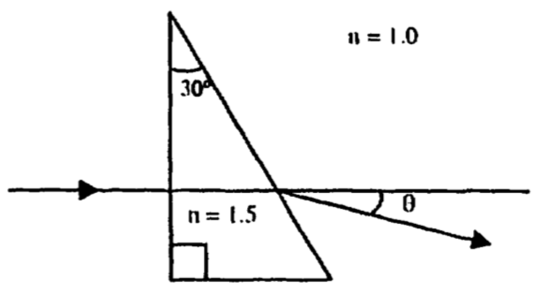
(a) 1.9×10^{-6} W/m^2 (b) 7.5×10^{-5} W/m^2 (c) 3.6×10^{-2} W/m^2
(d) 21 W/m^2 (e) 83 W/m^2

10. A beam of light enters a slab of glass at 30° to the normal, as sketched. It is observed that the angle of refraction of blue light is 0.3° smaller than that of red light in the glass. If the index of refraction for blue light is n = 1.52, what is the index of refraction for red light in the material?



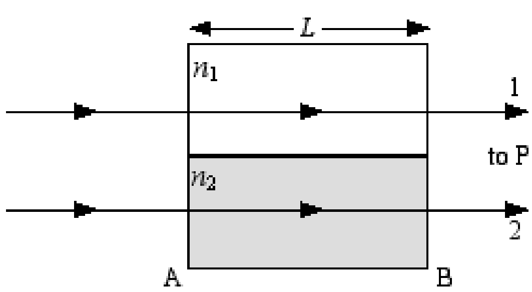
(a) 1.50 (b) 1.54 (c) 1.53 (d) 1.51 (e) 1.55

11. A light beam enters a glass prism (n = 1.50) at normal incidence as shown. The light emerges into air (n = 1.00) on the far side of the prism, deflected by an angle θ with respect to the direction of the incident light, as marked in the diagram. The value of θ is:



(a) 0° (b) 18.6° (c) 30° (d) 48.6° (e) 60°

12. Light travelling paths 1 and 2 through air are in phase at A. They then travel through plastic layers of length L with different refractive indices n_1 and n_2. Emerging from the plastic layers at B, the waves superpose at some distant observation point P. Given n_1 = 1.65, n_2 = 1.50 and L = 20.0 μm, constructive interference will occur at P when the wavelength λ is equal to:

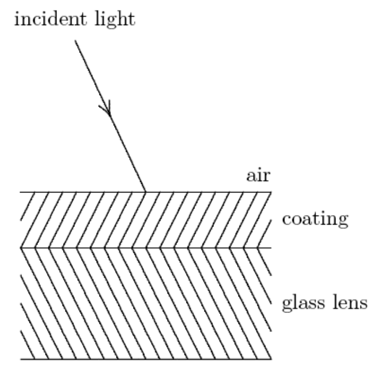


(a) 400.0 nm (b) 428.6 nm (c) 545.5 nm (d) 461.5 nm (e) n.o.t.

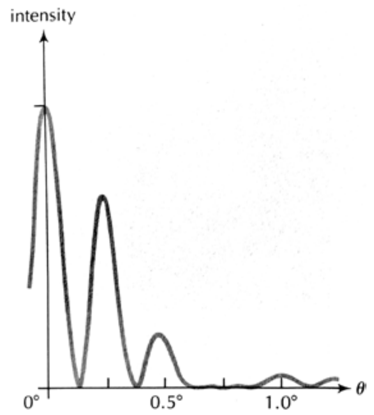
13. In a Young's double-slit experiment, a thin sheet of mica is placed over one of the two slits. As a result, the center of the fringe pattern (on the screen) shifts by 30 bright fringes. The wavelength of the light in this experiment is 480 nm and the index of the mica is 1.60. The mica thickness is:

(a) 0.090 mm (b) 0.012 mm (c) 0.014 mm (d) 0.024 mm (e) 0.062 mm

14. A lens with a refractive index of 1.5 is coated with a material of refractive index 1.2 in order to minimize reflection. If λ denotes the wavelength of the incident light in air, what is the thinnest possible such coating for light at normal incidence?
(a) 0.5 λ
(b) 0.416 λ
(c) 0.3 λ
(d) 0.208 λ
(e) 0.25 λ



15. The figure below shows a plot of the intensity of the interference pattern produced when light passes through a screen with two parallel narrow slits. The distance between the slits is 0.12 mm. The width of each of the slits is



(a) 0.500 μm (b) 0.040 mm (c) 0.080 mm (d) 0.200 mm (e) 0.500 mm

16. The emission spectrum of hydrogen is studied with a diffraction grating that contains 2500 lines per cm. At what angle with the first order red line corresponding to the n = 3 to n = 2 transition be observed?

(a) 0.09° (b) 0.16° (c) 5.2° (d) 7.8° (e) 9.4°

17. The headlights of an oncoming car are 1.8 m apart. What is the maximum distance at which the they can be distinguished from each other by an observer whose eye pupil diameter is 4.2 mm? Assume the wavelength of the lights is 510 nm.

(a) 5.1 km (b) 6.1 km (c) 7.5 km (d) 12 km (e) 15 km

18. In a photon-detecting device based on the photoelectric effect, electrons emitted from a metal surface with work function ϕ = 2.0 eV are accelerated toward a positively charged collector plate through a potential difference V_a = 25 V. When light of wavelength λ = 413 nm is incident on the photoemission surface, what is the maximum kinetic energy of the electrons striking the collector plate?

(a) 3 eV (b) 5 eV (c) 25 eV (d) 26 eV (e) 28 eV

19. In a high energy physics experiment, a photon with energy E scatters from an unknown particle of mass m via the Compton effect. The scattered photon emerges at 90° to its initial direction with energy E/2. The mass mc^2 of the unknown particle is

(a) E/5000 (b) E/1000 (c) E/4 (d) E/2 (e) E

20. An x-ray photon of energy 20 keV scatters at 180° from an electron at rest. The kinetic energy of the recoiling electron is:

(a) 0.8 keV (b) 1.5 keV (c) 18.5 keV (d) 19.2 keV (e) 20 keV

21. An electron is trapped in a one-dimensional infinite potential well. Consider transitions between the following pairs of states:

(1) $n = 3 \rightarrow n = 1$
(2) $n = 3 \rightarrow n = 2$
(3) $n = 4 \rightarrow n = 3$

Order these transitions by the amount of energy released, from smallest to largest.

(a) 1, 2, 3 (b) 3, 2, 1 (c) 2, 3, 1 (d) 1, 3, 2 (e) 3, 1, 2

22. A free electron with kinetic energy K hits a potential barrier of height U_b = 10 eV and thickness L = 100 pm. The tunneling probability T is observed to be 0.1. What is the kinetic energy K of the incoming electron?

(a) 5 eV (b) 0.5 eV (c) 9 eV (d) 0.1 eV (e) 3 eV

23. In the hydrogen atom, the Paschen series of emission lines includes all decays for which the final state quantum number is $n = 3$. What is the shortest and longest possible photon wavelength in the Paschen series?

(a) 365 nm and 657 nm (b) 820 nm and 1880 nm (c) 275 nm and 1100 nm
(d) 4.43 nm and 10.1 nm (e) 91 nm and 121 nm

24. A hydrogen atom is initially at rest and in the $n = 2$ state. Subsequently, it decays to the ground state by emitting a photon. What is the speed of the recoiling atom afterwards? The mass of the hydrogen atom is 1.67×10^{-27} kg, or $m_H c^2$ = 940 MeV.

(a) 6040 m/s (b) 3.4 m/s (c) 6.04×10^5 m/s (d) 34 m/s (e) 604 m/s

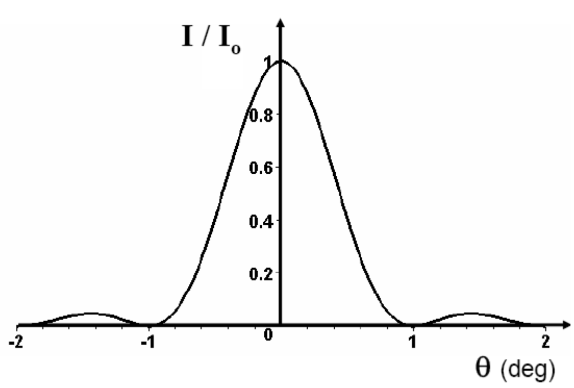
25. The wave function of a particle in the ground state of an infinite one dimensional potential well of width L is

$$\psi_1(x) = \sqrt{\frac{2}{L}}\ sin\left(\frac{\pi x}{L}\right)$$

The probability to find the particle in a small interval of width $\Delta x = L/100$ centred at $x = L/4$ is approximately

(a) 0.3 (b) 0.2 (c) 0.1 (d) 0.01 (e) 0.005

26. The figure below shows the distribution of impacts on a screen when a beam of electrons of energy 2.5×10^{-3} eV passes through a single slit. The width of the slit is



(a) 50 nm (b) 1.4 μm (c) 50 μm (d) 650 μm (e) 0.8 mm