INSTRUCTIONS:

This exam contains 20 multiple-choice questions plus 1 extra credit question, each worth 3 points. Choose one answer only for each question. Choose the best answer to each question. Answer all questions.

Allowed material: Before turning over this page, put away all materials except for pens, pencils, erasers, rulers and your calculator. There is a formula sheet attached at the end of the exam. Other copies of the formula sheet are not allowed.

Calculator: In general, any calculator, including calculators that perform graphing, is permitted. Electronic devices that can store large amounts of text, data or equations (like laptops, e-book readers, smart phones) are NOT permitted. Calculators with WiFi technology are NOT permitted. If you are unsure whether or not your calculator is allowed for the exam, ask your TA.

How to fill in the bubble sheet:

Use a number 2 pencil. Do NOT use ink. If you did not bring a pencil, ask for one. You will continue to use the same bubble sheet you already used for Exam 1. Bubble answers 43-63 on the bubble sheet for this exam.

Only, if for some reason you are starting a new bubble sheet, write and fill in the bubbles corresponding to:
- Your last name, middle initial, and first name.
- ★ ★ Your ID number (the middle 9 digits on your ISU card) ★ ★
- Special codes K to L are your recitation section. Always use two digits (e.g. 01, 09, 11, 13).

Please turn over your bubble sheet when you are not writing on it.

If you need to change any entry, you must completely erase your previous entry. Also, circle your answers on this exam. Before handing in your exam, be sure that your answers on your bubble sheet are what you intend them to be. You may also copy down your answers on a piece of paper to take with you and compare with the posted answers. You may use the table at the end of the exam for this.

When you are finished with the exam, place all exam materials, including the bubble sheet, and the exam itself, in your folder and return the folder to your recitation instructor.

No cell phone calls allowed. Either turn off your cell phone or leave it at home. Anyone answering a cell phone must hand in their work; their exam is over.

Best of luck,

Dr. Soeren Prell
43. A styrofoam sphere of radius $R$ has an initial density $\rho_0$. You now carefully compress the sphere so its radius is $R/2$. What is the density of the compressed sphere?

A) $2\rho_0$
B) $4\rho_0$
C) $\rho_0\sqrt{8}$
D) $\rho_0\sqrt{2}$
E) $8\rho_0$

Solution

$$\rho = \frac{m}{V} = \frac{m}{\frac{4}{3}\pi R^3} = \frac{m}{\frac{4}{3}\pi \left(\frac{R_0}{2}\right)^3} = \frac{m}{\frac{4}{3}\pi \frac{R_0^3}{8}} = 8 \left(\frac{m}{\frac{4}{3}\pi R^3}\right) = 8\rho_0$$

44. A cubical block of stone is lowered at a steady rate into the ocean by a crane, always keeping the top and bottom faces horizontal. Which one of the following graphs best describes the gauge pressure $p$ on the bottom of this block as a function of time $t$ if the block just enters the water at time $t = 0$ s?

Solution

$$p_{\text{gauge}} = p_{\text{abs}} - p_{\text{atm}} = \rho g \gamma = \rho g (vt) = (\rho g) t$$
45. A wooden raft has a mass of 55 kg. With no load the raft floats in water (density 1000 kg/m³) with 64% of its volume submerged. What maximum mass of sand can be put on the raft without sinking it?

A) 45 kg  
B) 20 kg  
C) 35 kg  
D) 86 kg  
E) 31 kg

Solution

\[ F_{B,\text{max}} = (m_{\text{raft}} + m_{\text{sand}})g = W_{\text{displ,max}} = \rho_{\text{water}} V_{\text{raft}} \Rightarrow m_{\text{sand}} = \frac{\rho_{\text{water}} V_{\text{raft}}}{g} - m_{\text{raft}} \]

\[ F_B = m_{\text{raft}}g = W_{\text{displ}} = \rho_{\text{water}} \left(0.64V_{\text{raft}}\right) \Rightarrow V_{\text{raft}} = \frac{m_{\text{raft}}g}{0.64 \rho_{\text{water}}} \]

\[ \Rightarrow m_{\text{sand}} = \frac{m_{\text{raft}}}{0.64} - m_{\text{raft}} = m_{\text{raft}} \left(\frac{1}{0.64} - 1\right) = 31 \text{ kg} \]

46. One of the dangers of tornados and hurricanes is the rapid drop in air pressure that is associated with such storms. Assume that the air pressure inside of a sealed house is 1.02 atm when a hurricane hits. The hurricane rapidly decreases the external air pressure to 0.910 atm. What net outward force is exerted on a square window of the house that is 2.16 m on each side?

A) \(4.51 \times 10^5 \text{ N}\)  
B) \(5.87 \times 10^4 \text{ N}\)  
C) \(5.46 \times 10^5 \text{ N}\)  
D) \(6.14 \times 10^5 \text{ N}\)  
E) \(5.19 \times 10^4 \text{ N}\)

Solution

\[ F = A \Delta P = (2.16 \text{ m})^2 (1.02 - 0.910) \text{ atm} \left(\frac{1.01 \times 10^5 \text{ Pa}}{1 \text{ atm}}\right) = 5.19 \times 10^4 \text{ N} \]
47. Water flowing through a cylindrical pipe suddenly comes to a section of pipe where the diameter decreases to 86% of its previous value. If the speed of the water in the larger section of the pipe was 32 m/s what is its speed in this smaller section if the water behaves like an ideal incompressible fluid?

A) 43 m/s  
B) 37 m/s  
C) 28 m/s  
D) 24 m/s

Solution

\[ A_1 v_1 = A_2 v_2 \Rightarrow \]

\[
v_2 = \frac{A_1}{A_2} v_1 = \left( \frac{\pi (d_1/2)^2}{\pi (d_2/2)^2} \right) v_1 = \left( \frac{d_1^2}{d_2^2} \right) v_1 = \left( \frac{d_1}{d_2} \right)^2 v_1 = \left( \frac{1}{0.86} \right)^2 (32 \text{ m/s}) = 43 \text{ m/s} \]

48. Water flows out of a large reservoir with a diameter of 16.4 m through a narrow pipe 8.0 m below the surface, as shown in the figure. What is the speed of the water as it comes out of the pipe?

A) 8.9 m/s  
B) 9.9 m/s  
C) 13 m/s  
D) 14 m/s  
E) 16 m/s

Solution

\[
P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2
\]

\[
\left( P_1 = P_2 = P_{\text{atm}}, \ v_2 = 0, \ y_2 - y_1 = h \right)
\]

\[
\frac{1}{2} \rho v_1^2 = \rho g h \Rightarrow v_1 = \sqrt{2gh} = \sqrt{2(9.8 \text{ m/s}^2)(8.0 \text{ m})} = 13 \text{ m/s}
\]
49. Two small balls, A and B, attract each other gravitationally with a force of magnitude $F_0$. If we now double both masses and the separation of the balls, what will now be the magnitude of the attractive force on each one?

A) $16 F_0$
B) $8 F_0$
C) $4 F_0$
D) $F_0$
E) $F_0/4$

Solution

\[ F = G \frac{m_A m_B}{r^2} = G \frac{(2m_A)(2m_B)}{(2r_0)^2} = G \frac{m_A m_B}{r_0^2} = F_0 \]

50. The reason an astronaut on the International Space Station feels weightless is that

A) the astronaut is beyond the range of the earth's gravity.
B) the astronaut is falling.
C) the astronaut is at a point in space where the effects of the moon's gravity and the earth's gravity cancel.
D) this is a psychological effect associated with rapid motion.
E) the astronaut's acceleration is zero.

Solution

The astronaut feels earth’s gravity, which provides the centripetal acceleration for the astronaut to be in circular orbit around earth. The ISS is much closer to earth than the point where the effects of moon's gravity and earth's gravity cancel. The astronaut falls toward (and misses) earth because of orbital velocity at the same rate the ISS does.
51. Suppose NASA wants a satellite to revolve around Earth 5 times a day. What should be the radius of its orbit if we neglect the presence of the Moon?

A) $1.44 \times 10^7$ m  
B) $0.69 \times 10^7$ m  
C) $7.22 \times 10^7$ m  
D) $2.11 \times 10^7$ m  
E) $3.45 \times 10^7$ m

Solution

$$T^2 \frac{r^3}{G_M} \Rightarrow r^3 = \frac{GM^2}{4\pi^2} \Rightarrow$$

$$r = \sqrt[3]{\frac{GM^2}{4\pi^2}}$$

$$= \sqrt[3]{\left(6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2\right) \left(5.98 \times 10^{24} \text{ kg}\right) \left(\frac{24}{5} \text{ hr}\right) \left(3600 \text{ s/hr}\right)^2} \div 4\pi^2$$

$$= 1.44 \times 10^7 \text{ m}$$

52. When a 0.35-kg package is attached to a vertical spring and lowered slowly, the spring stretches 12 cm. The package is now displaced from its equilibrium position and undergoes simple harmonic oscillations when released. What is the period of the oscillations?

A) 0.70 s  
B) 0.48 s  
C) 0.29 s  
D) 0.077 s  
E) 1.4 s

Solution

$$k = \left| \frac{F}{\Delta x} \right| = \frac{mg}{\Delta x} \Rightarrow \omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{mg}{\Delta x}} \Rightarrow \sqrt{\frac{g}{\Delta x}} = \sqrt{\frac{9.8 \text{ m/s}^2}{0.120 \text{ m}}} = 9.0 \text{ rad/s}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{(9.0 \text{ rad/s})} = 0.70 \text{ s}$$
53. The figure shows a graph of the velocity $v$ as a function of time $t$ for a system undergoing simple harmonic motion (for example a mass connected to a spring). Which one of the following graphs represents the acceleration of this system as a function of time?

A) graph a  
B) graph b  
C) graph c  
D) graph d  
E) none of the graphs

**Solution**

The velocity as a function of time graph is a sine function

$$v = A \omega \sin(\omega t) = v_{\text{max}} \sin(\omega t).$$

For such a function the acceleration as a function time graph is given by

$$a = A \omega^2 \cos(\omega t) = a_{\text{max}} \cos(\omega t).$$

At $t = 0$, the velocity as a function of time curve has a large positive slope $a = \frac{\Delta v}{\Delta t}$. Graph b is the only graph with positive acceleration $a$ at $t = 0$. 

54. What is the length of a simple pendulum with a period of 2.0 s?

A) 20 m  
B) 0.99 m  
C) 1.2 m  
D) 1.6 m  
E) 0.87 m

Solution

\[ T = 2\pi \sqrt{\frac{L}{g}} \Rightarrow L = g \left( \frac{T}{2\pi} \right)^2 = \left( \frac{9.8 \text{ m/s}^2}{2\pi} \right)^2 = 0.99 \text{ m} \]

55. What is the frequency of a pressure wave of wavelength 2.5 m that is traveling at 1400 m/s?

A) 178 Hz  
B) 1.78 kHz  
C) 560 Hz  
D) 5.6 kHz  
E) 17.8 MHz

Solution

\[ f = \frac{v}{\lambda} = \frac{1400 \text{ m/s}}{2.5 \text{ m}} = 560 \text{ Hz} \]
56. A piano wire of linear mass density 0.0050 kg/m is under a tension of 1350 N. What is the wave speed in this wire?

A) 130 m/s  
B) 260 m/s  
C) 520 m/s  
D) 1040 m/s  
E) 2080 m/s  

**Solution**  
\[ v = \sqrt{\frac{F}{m/L}} = \sqrt{\frac{1350 \text{ N}}{0.0050 \text{ kg/m}}} = 520 \text{ m/s} \]

57. A certain glass window reduces the intensity level of the sound from 72 dB to 47 dB. By what factor is the intensity reduced by this glass window?

A) \(3.2 \times 10^{-3}\)  
B) \(2.2 \times 10^{-2}\)  
C) \(5.6 \times 10^{-2}\)  
D) \(1.0 \times 10^{-1}\)  
E) \(1.5 \times 10^{-1}\)  

**Solution**  
\[ \Delta \beta = \beta_2 - \beta_1 = 47 \text{ dB} - 72 \text{ dB} = -25 \text{ dB} \]  
\[ \Delta \beta = (10 \text{ db})\log \left( \frac{I_2}{I_0} \right) - (10 \text{ db})\log \left( \frac{I_1}{I_0} \right) = (10 \text{ db})\log \left( \frac{I_2}{I_0} \right) - (10 \text{ db})\log \left( \frac{I_1}{I_0} \right) = (10 \text{ db})\log \left( \frac{I_2}{I_1} \right) \]  
\[ -25 \text{ dB} = (10 \text{ db})\log \left( \frac{I_2}{I_1} \right) \Rightarrow \frac{I_2}{I_1} = 10^{-2.5} = 3.2 \times 10^{-3} \]
58. Two in-phase loudspeakers are 3.0 m apart. They emit sound with a frequency of 490 Hz. A microphone is placed half-way between the speakers and then moved along the line joining the two speakers until the next point of constructive interference is found. At what distance from that midpoint is that first point? The speed of sound in air is 343 m/s.

A) 0.18 m  
B) 0.35 m  
C) 0.50 m  
D) 0.65 m  
E) There is no point in that line where constructive interference occurs.

**Solution**

\[ \lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{490 \text{ Hz}} = 0.7 \text{ m} \]

\[ d_2 - d_1 = \lambda = \left( d_{2,0} + \Delta x \right) - \left( d_{1,0} - \Delta x \right) \Rightarrow \Delta x = \frac{\lambda}{2} = 0.35 \text{ m} \]

59. Two strings both vibrate at exactly 819 Hz. The tension in one of them is then increased slightly. As a result, six beats per second are heard when both strings vibrate. What is the new frequency of the string that was tightened?

A) 825 Hz  
B) 813 Hz  
C) 822 Hz  
D) 816 Hz  
E) 798 Hz

**Solution**

If the tension increases, so do the wave speed and the frequency.\[ f_{\text{beat}} = f_2 - f_1 \Rightarrow f_2 = f_1 + f_{\text{beat}} = 819 \text{ Hz} + 6 \text{ Hz} = 825 \text{ Hz} \]
60. In a vertical resonating pipe that is open at both ends, there

A) are displacement nodes at each end.
B) are displacement antinodes at each end.
C) is a displacement node at the top end and a displacement antinode at the bottom end.
D) is a displacement antinode at the top end and a displacement node at the bottom end.
E) No nodes or antinodes can form in vertical pipes.

**Solution**
There’s always a displacement antinode at an open end.

61. A disk, a hoop, and a solid sphere are released at the same time at the top of an inclined plane. They all have equal masses and radii and roll without slipping. In what order do they reach the bottom?

A) disk, hoop, sphere
B) hoop, sphere, disk
C) sphere, disk, hoop
D) sphere, hoop, disk
E) hoop, disk, sphere

**Solution**
An object with smaller moment of inertia will reach the bottom earlier.

\[ I_{sphere} : I_{disk} : I_{hoop} \Rightarrow \frac{2}{5} MR^2 : \frac{1}{2} MR^2 : MR^2 \Rightarrow \frac{2}{5} : \frac{1}{2} : 1 \Rightarrow 0.4 < 0.5 < 1 \]
62. A merry-go-round spins freely when Diego moves quickly to the center along a radius of the merry-go-round. As he does this,

A) the moment of inertia of the system decreases and the angular speed increases.
B) the moment of inertia of the system decreases and the angular speed decreases.
C) the moment of inertia of the system decreases and the angular speed remains the same.
D) the moment of inertia of the system increases and the angular speed increases.
E) the moment of inertia of the system increases and the angular speed decreases.

Solution
Diego’s contribution to the total moment of inertia of the system Diego/merry-go-round decreases since his radius from the rotation axis decreases. While Diego walks towards the center of the merry-go-round, no external torque acts on the system and its angular momentum is conserved. Since \( L = I \omega \), when \( I \) decreases \( \omega \) has to increase.

63. A puck moves on a horizontal air table. It is attached to a string that passes through a hole in the center of the table. As the puck rotates about the hole, the string is pulled downward very slowly and shortens the radius of rotation, so the puck gradually spirals in towards the center. By what factor will the puck's tangential speed have changed when the string's length has decreased to one-half of its original length?

A) 2
B) 4
C) \( \sqrt{2} \)
D) 1
E) \( \frac{1}{2} \)

Solution
\( v_{\text{tan}} = r \omega; \)

\[ I_1 \omega_1 = I_2 \omega_2 \Rightarrow mr_1^2 \omega_1 = mr_2^2 \omega_2 \Rightarrow \omega_2 = \omega_1 \frac{r_1^2}{r_2^2} \]

\[ v_{\text{tan},2} = r_2 \omega_2 = \omega_1 \frac{r_1^2}{r_2^2} = v_{\text{tan},1} \frac{r_1}{r_2} = v_{\text{tan},1} \left( \frac{r_1}{0.5r_1} \right) = 2v_{\text{tan},1} \]
Physics 111 Exam 3 - KEY

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