2019 PhysicsBowl Answers and Solutions

1. A
   After converting all to decimal form, choice A) is the smallest
   A) 0.015    B) 0.15    C) 0.15    D) 0.15    E) 0.15

2. C
   Their lifespans are:
   Galileo (1564-1642)  Newton (1643-1727)  Cavendish (1731-1810)

3. C
   Electric potential (V) is uniform throughout

4. D
   An acceleration that is always perpendicular to the velocity is a centripetal acceleration
   and always causes a change in the object’s direction.

5. B
   Weight (W)=Force due to gravity (Fg)=mg; g_{moon}<g_{earth} so W_{moon}<W_{earth}

6. B or C
   After converting all to miles, choices B) & C) are not correct. The intended answer was C),
   however the conversion “1.00 yd=3.00 ft=12.0 in” that is given in the problem is incorrect.
   Thus, B) is also a valid answer.
   A) 2.50 miles    B) 2.50 miles    C) 2497 miles    D) 2.50 miles    E) 2.50 miles

7. C
   By increasing the distance from the center of the Earth, the force of gravity decreases
   according to: $F_g = \frac{(G)(m_{\text{person}})(m_{\text{Earth}})}{(r_{\text{Earth}}+5000m)^2}$.

8. B
   \[
   \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}; \text{ Let } d_o = d_i = 2f \implies f = \left(\frac{d_o}{2}\right); d_i = (72 \text{ cm} - d_o); \frac{1}{(\frac{d_o}{2})} = \frac{1}{d_o} + \frac{1}{(72 \text{ cm} - d_o)}
   \]
   Solving for $d_o$ gives 36 cm and solving for $f$ we get 18 cm.

9. C
   \[
   (1.0 \text{ W})(365 \text{ days}) \left(24 \frac{\text{ hours}}{\text{ day}} \right) \left(\frac{1.0 \text{ kilowatt}}{1000 \text{ watts}} \right) = 8.76 \text{ kilowatt hours}
   \]
   \[
   (8.76 \text{ kilowatt hours}) \left(\frac{\$0.10}{\text{ kilowatt hours}} \right) = \$0.876
   \]

10. E
    For mechanical waves, the speed of the wave depends upon the medium.

11. D
    The range equation: $R = \frac{(v_0^2) \sin 2\theta}{g}$ shows that doubling the launch speed ($v_o$)
    increases the range by a factor of 4. This equation results from combining the horizontal
    velocity component of a projectile launched at an angle: $v_o \cos \theta$ and using it to solve for
    the horizontal distance $x_H = v_o \cos \theta(t)$ with the vertical component of a projectile
    launched at an angle: $v_o \sin \theta$ and using it to solve for time in flight: $t = \frac{2v_o \sin \theta}{g}$.

12. B
    When the system reaches equilibrium, the net (centripetal) force will be provided by the
    spring. $kd = m\omega^2; \frac{k}{2m} = \omega^2; \omega = \sqrt{\frac{k}{2m}}$

13. D
    Based on the units in the constant ($k$) provided: $\Delta T = \frac{\text{Heat energy}(\text{glass thickness})}{(k)(\text{Area})(\text{time})}$.

14. E
    After being excited and moving to a higher energy level, the electrons return to their
    original energy level and release the excess energy as light.

15. B
    The 2018 Nobel Prize in Physics was awarded to Arthur Ashkin, Gerard Mourou, and
    Donna Strickland “for groundbreaking inventions in the field of laser physics”.
16. D

\[ F = ma = \frac{kg}{m \cdot s^2}; \quad v^2 = v_0^2 + 2a\Delta y; \quad v = 8.00 \, \frac{m}{s}; \quad 120 \, \frac{kg}{m \cdot s^2} = 2.00 \, \frac{kg}{s}; \]

\[ F = (8.00 \, \frac{m}{s})(2.00 \, \frac{kg}{s}) = 16.0 \, \frac{kg}{m \cdot s^2} = 16.0 \, N \]

17. D

For a number raised to a power, the uncertainty rule is to multiply the relative uncertainty by the power.

\[ 1.96 \pm 0.01 \, m = 1.96 \, m \pm 0.51\%; \quad v = \frac{4}{3} \pi r^3 = 31.5 \, m^3; \]

\[ (3)(0.51\%) = 1.53\%; \quad 31.5 \, m^3 \pm 1.53\% = 31.5 \pm 0.5 \, m^3 \]

18. B

**Going up:**

\[ \sum F = (F_{gravity} + F_{friction}) = ma; \]

**Going down:**

\[ \sum F = (F_{gravity} - F_{friction}) = ma \]

A larger force acting on the block will result in a larger acceleration which will cause a larger change in velocity resulting in a steeper slope on the v-t graph.

19. D

\[ F\Delta t = m\Delta v; \quad \text{Impulse is } F\Delta t; \quad \Delta v = v_2 - v_1; \]

\[ F\Delta t = m(v_2 - v_1) = (0.500 \, kg)[3.60 \, \frac{m}{s} - (-4.80 \, \frac{m}{s})] = 4.20 \, kg \, \frac{m}{s} = 4.20 \, Ns \]

20. B

For a standing transverse mechanical wave: 3 antinodes = 1.5\( \lambda \) and 4 antinodes = 2\( \lambda \).

\[ v = \frac{\lambda}{f} \text{ and } v \text{ is constant for waves traveling in the same medium. So, the longer the wavelength, the smaller the frequency.} \]

\[ \frac{1.5}{2} = \frac{12Hz}{x}; \quad x = 16 \, Hz \]

21. D

Magnification (M) is the ratio of the image size (h_i) to the object size (h_o) or the ratio of the image distance (d_i) to the object distance (d_o) according to:

\[ M = \frac{d_i}{d_o} = -\frac{h_i}{h_o}. \]

Choice (A) would form a virtual, enlarged, positive magnification image; choice (B) would form a virtual, smaller, positive magnification image; choice (C) would form a positive magnification image, and choice (E) will form a positive image of the same size.

22. C

Because the two masses are connected by the string, they move as one mass and accelerate due to the net force:

\[ \sum F_y = F_{m_1} - F_{m_2} = (m_1 + m_2)a = (6.0 \, N - 4.0 \, N) = (0.60 \, kg + 0.40 \, kg)a; \quad a = 2.0 \, m/s^2 \]

23. A

\[ v^2 = v_0^2 + 2a\Delta x; \quad a = \frac{v^2 - v_0^2}{2\Delta x} = 2.45 \, \frac{m}{s^2} \]

\[ \sum F_y = F_g - F_{AR} = ma; \quad F_{AR} = F_g - ma = 30.0 \, N - (3.0 \, kg)(2.45 \, \frac{m}{s^2}) = 22.65 \, N \]

24. B

Because there is no charge across the capacitor, there is no potential difference across the capacitor. Therefore, the potential at the junction between the 100 \( \Omega \) resistor and the 300 \( \Omega \) resistor is the same as the potential at the junction between the 400 \( \Omega \) resistor and the 200 \( \Omega \) resistor. As a result, the 100 ohm and 400 ohm resistors can be treated as a parallel combination connected in series to the parallel combination of the 300 \( \Omega \) and 200 \( \Omega \) resistors. This gives an equivalent resistance of 200 \( \Omega \) and a total current of 60 mA. The potential difference across the top two resistors must be equal and their total current must add to 60 mA, resulting in a currents of 48 mA and 12 mA in the 100 \( \Omega \) and 400 \( \Omega \) resistors, respectively. Using the same reasoning, the currents in the 300 \( \Omega \) and 200 \( \Omega \) resistors are 24 mA and 36 mA, respectively. Using the junction to the left of the capacitor: \( \sum I_{100} = I_x + I_{300}, 48 \, mA = 24 \, mA + I_x \). \( I_x = 24 \, mA \)
25. C At steady-state, no charge flows to or from the capacitor, so any current through the 
100 Ω resistor continues to the 300 Ω resistor. The same is true for the 400 Ω resistor
and the 200 Ω resistor. The potential drops across the 100 Ω and 300 Ω resistor must
total 12 V. Because the current is the same in these resistors, the voltage drops are
proportional to the resistances: 3 V for the 100 Ω and 9 V for the 300 Ω. By the same
reasoning, the voltage drops across the 400 ohm and 200 ohm are 8 V and 4 V
respectively. The resulting potential difference between the junction to the left of the
capacitor and the junction to the right of the capacitor is 5 V. Using Q =
CΔV = (15 μF)(5 V), gives 75 μC.

26. D The PDF version of this problem contained a typo in choice D). It should have been listed
as 4.77 x 10³ W/m². Therefore, all students that took the PDF version will receive credit
for this problem, regardless of the answer given. This type was corrected for the
WebAssign version of the exam and there will be no change to the scoring for those
students.  Power = (Intensity)(Area); I = \( \frac{P}{A} = \frac{15 \times 10^{-3} \text{W}}{(\pi)(1.0 \times 10^{-3} \text{m})^2} \)

27. D Coulomb (C) measures electric charge, the Farad (F) measures capacitance, the Tesla (T)
measures magnetic field, and the Henry (H) measures mutual inductance.

28. D On a banked curve the normal force on the car is no longer vertical and has a horizontal
component. This component then acts as the centripetal force on the car while on the
bank. \( F \_{\text{NET}} = F \_\text{Centripetal}; mg \tan \theta = \frac{mv^2}{r}; v^2 = rgtan \theta; v = \sqrt{rgtan \theta} \)

29. A \( M = \frac{d_i}{d_o} = -\frac{h_i}{h_o}; \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}; d_i = 3d_o \)

30. C The torque is applied at the gear. \( \tau = Fr = 1a \) and \( l = mr^2 \) for a ring. As a result, \( a \)
is 5.93 rad/s². Applying this acceleration to the wheel for 4.0s gives it an angular speed
of 23.7 rad/s according to \( \omega = \omega_o + a\Delta t \). When the angular speed is multiplied by the
radius, the resulting linear speed is 7.1 m/s.

31. E Using the sound intensity equation, \( dB = 10 \log \frac{I}{I_0}; I_0 = 1.0 \times 10^{-12} \frac{\text{W}}{\text{m}^2} \) and 60 dB, the
intensity (I) of the speaker is calculated to be \( 1.0 \times 10^{-6} \text{ W/m}^2 \) at 15 m.
Using \( I = \frac{P}{A} \) and \( A = 4\pi r^2 \), it is found that the power of the speaker is \( 2.8 \times 10^{-3} \text{ W} \). At
2.0 m from the speaker, the intensity is \( 5.57 \times 10^{-5} \text{ W} \).

32. C The blocks are floating so the buoyant force is equal to the weight of the blocks.
\( \sum F = 0 \) so \( F_B = mg \). Because the mass remains the same in either arrangement of the
blocks, the water level remains unchanged.

33. B When Car 2 catches and passes Car 1, they will both have the same displacement from
the starting point. \( \Delta x_1 = \Delta x_2 \). Use \( \Delta x = v_o \Delta t + \frac{1}{2} a \Delta t^2 \) for both cars, set the
two equations equal to each other, then solve for \( \Delta t \) using the quadratic formula.
34. B Using $\bar{v} = \frac{\Delta x}{\Delta t}$, Michael Phelps had an average speed of $197.71 \text{ cm/s}$. Because only 0.01 s separated him from the second-place finisher and using these numbers gives 1.98 cm.

35. A The average kinetic energy of the molecules is directly related to both their mass and the temperature. $\overline{KE} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$.

36. A Solve for $V$, $I$, & $P$ for each resistor. $R_1=2.0\text{V}, 0.04\text{A}, 0.08\text{W}$; $R_2=1.0\text{V}, 0.02\text{A}, 0.02\text{W}$; $R_3=0.4\text{V}, 0.0067\text{A}, 0.0027\text{W}$; $R_4=0.4\text{V}, 0.0133\text{A}, 0.0053\text{W}$; $R_5=0.6\text{V}, 0.02\text{A}, 0.012\text{W}$

37. A See resistor values for #36.

38. B The largest acceleration value from the graph is $-10.4 \text{ m/s}^2$. The difference between this value and the constant velocity acceleration reading of $-9.8 \text{ m/s}^2$ is 0.6 $\text{m/s}^2$ and this occurs for approximately 13.0 s. Then use $v = v_0 + a\Delta t$.

39. A Find the wavelength using $v = \lambda f$; $\lambda = 0.5 \text{ m}$. Because it is initially a minimum sound intensity at point $P$, this means that the signals being received are $0.5\lambda$ out of phase. $AP=2\lambda$ and $BP=2.5\lambda$. To receive a maximum sound intensity at point $P$, $B$ needs to be moved far enough from $A$ so that $BP=3\lambda=1.5 \text{ m}$. Use $c^2 = a^2 + b^2$ to find the new distance between $A$ and $B$.

40. D The mercury expands as the temperature increases. This new volume of mercury is the product of the original volume, the temperature increase, and the thermal expansion coefficient: $5.4 \times 10^{-4} \text{ cm}^3$. Using $\text{height} = \frac{\text{Volume}}{\text{cross-sectional area}}$, it is found that the mercury rises 4.5 cm or 45 mm.

41. D The induced emf results from the changing area of the coil and accompanying changing flux that results from each breath and is calculated by: $\varepsilon = -N\left(\frac{\Delta A}{\Delta t}\right)\cos\theta$

42. B In an adiabatic process, no heat is allowed to flow into or out of the system, so $Q=0$. In an isochoric process, $V$ is constant so $Q=\Delta U$, and in an isobaric process, pressure is held constant so $Q=\Delta U+W$.

43. A Treat the two blocks as one to find $F = (m_1 + m_2)a$; Using Newton’s 2nd Law in the horizontal direction for Block 1: $F_{21} = m_1\ddot{a}$; $F_{21} = \mu m_1 g$; $m_1 a = \mu m_1 g$; $\mu = \frac{a}{g}$.

Substitute for $a$: $\mu = \frac{F}{g(m_1 + m_2)}$. Use $m_2 = 3m_1$; $\mu = \frac{F}{g(m_1 + 3m_1)} = \frac{F}{g(4m)}$.

44. A The speed of a wave on a stretched string or cord depends upon on the tension of the cord ($T$), and the cord’s linear mass density ($M/L$). Examples include piano and guitar strings.

45. B The Carnot (ideal) efficiency for this engine is: $\varepsilon_{\text{ideal}} = 1 - \frac{T_L}{T_H} = 0.52$.

60% of $\varepsilon_{\text{ideal}}$ is 0.31. ($60 \text{ kW}$)($0.31) = 18.72 \text{ kW}$ is used by the engine and the remaining 41 kW are exhausted.

46. D The two most common types of cosmic rays that reach the experimental apparatus are muons and neutrinos.
47. E In both arrangements V is the same. \( V = IR \) so \( I_{\text{series}}R_{\text{series}} = I_{\text{parallel}}R_{\text{parallel}} \)

\[
R_{\text{series}} = (R_1 + R_2); \quad \frac{1}{R_{\text{parallel}}} = \left( \frac{1}{R_1} + \frac{1}{R_2} \right)
\]

48. D Choice (A) is accurate but incomplete, choice (B) is accurate but incomplete, choice (C) is inaccurate, choice (D) is accurate and complete, and choice (E) is inaccurate.

49. D The rest mass for each mass is 4.0 kg and they collide head-on with identical speeds pointing in opposite directions. This implies that the composite mass is at rest. So, recalling that the total energy is given by \( E = \gamma mc^2 \) and that the rest mass is given by \( E = mc^2 \), then \( 2\gamma mc^2 = Mc^2 \) where \( M \) is the composite mass. The particle travels at \( v = \frac{3}{5}c \) which yields \( \gamma = \frac{5}{4} \). Plug this in to get \( M = \frac{10}{4} \times 4 = 10 \text{ kg} \).

50. E An isothermal expansion of a gas occurs with no temperature change. Considering the 1st Law of Thermodynamics: \( \Delta U = Q - W \), this means that with \( T \) constant, \( Q=W \). The work done by a gas is \( W = \int PdV \) and the Ideal Gas Law \( PV = nRT \Rightarrow P = \frac{nRT}{V} \). Solving now for \( W \) we get: \( W = \int \frac{nRT}{V}dV = nRT\ln\left(\frac{V}{V_2}\right) \) and it is one mole of gas.