# The $65^{\text {th }}$ Annual Merck State Science Day Competition May 19, 2015 

## Physics

## DIRECTIONS

The "answer panel" at the bottom of the window is pre-set to show 10 answer boxes per page.
1.The current question has a black border.
2. Enter your answer choice using the keyboard.
3. Click Confirm to record your answer.
4. Questions that have been answered will be tinted Green
5. Any answer can be edited. Confirm the correction.
6.> moves to the next set of questions (<moves back)
7. Click on any number to answer that question.
8. Confirm all entries. Each answer is recorded only when Confirm is used.
9. When finished, use FINISHED TEST in lower left.

The test has $\underline{\mathbf{6 0}}$ items that will be scored. You have $\underline{\mathbf{9 0}}$ minutes in which to answer all the questions.

Hint: The size of the lettering in the bottom answer panel can be adjusted using CTRL + to magnify the browser view.

There is subject-specific information on the next page that you may find useful in answering certain questions. Be sure to view it before you begin the test.

## General Information:

| Proton mass, $m_{P}=1.67 \times 10^{-27} \mathrm{~kg}$ | Electron charge, $e=1.60 \times 10^{-19} \mathrm{C}$ |
| :--- | :--- |
| Electron mass, $m_{e}=9.11 \times 10^{-31} \mathrm{~kg}$ | 1 electron volt, $1 \mathrm{eV}=1.60 \times 10^{-19} \mathrm{~J}$ |
| Avogadro's Number, $N_{o}=6.02 \times 10^{23} \mathrm{~mole}{ }^{-1}$ | Speed of light, $c=3 \times 10^{8} \mathrm{~m} / \mathrm{s}$ |
| Universal gas constant, <br> $R=8.31 \mathrm{~J} /(\mathrm{mol} \cdot \mathrm{K})=0.0821 \mathrm{~atm} \cdot \mathrm{liter} /(\mathrm{mole} \cdot \mathrm{K})$ | $G=6.67 \times 10^{-11} \mathrm{~m}^{3} /\left(\mathrm{kg} \cdot \mathrm{s}^{2}\right)$ |
| Boltzmann's constant, $k_{B}=1.38 \times 10^{-23} \mathrm{~J} / \mathrm{K}$ | Acceleration due to gravity at Earth surface: <br> $g=10 \mathrm{~m} / \mathrm{s}^{2}$ |
| $1 \mathrm{cal}=4.184 \mathrm{~J}$ |  |


| Unified atomic mass unit, $u=1.66 \times 10^{-19} \mathrm{~kg}=931 \mathrm{MeV} / \mathrm{c}^{2}$ |
| :--- |
| Planck's constant, $h=6.60 \times 10^{-34} \mathrm{~J} \cdot \mathrm{~s}=4.14 \times 10^{-15} \mathrm{eV} \cdot \mathrm{s}$ |
| Coulomb's Law constant, $k=9 \times 10^{9} \mathrm{~N} \cdot \mathrm{~m}^{2} / \mathrm{C}^{2}$ |
| 1 earth atmosphere pressure, $1 \mathrm{~atm}=1.0 \times 10^{5} \mathrm{~N} / \mathrm{m}^{2}$ |

## Equations:

| $v_{f}=v_{i}+a t$ | $2 a d=v_{f}^{2}+v_{i}^{2}$ |
| :--- | :--- |
| $d=v_{i} t+\frac{1}{2} a t^{2}$ | $\Sigma F=m a$ |
| $a_{c}=\frac{v^{2}}{r}$ | $K=\frac{1}{2} m v^{2}$ |
| $P_{g}=m g h$ | $W=F d$ |
| $P=\frac{W}{t}=\frac{\Delta E}{t}$ | $F_{g}=G \frac{M_{1} M_{2}}{R^{2}}$ |
| $F_{B}=D V g$ | $A_{1} v_{1}=A_{2} v_{2}$ |
| $P+D g y+\frac{1}{2} D v^{2}=$ Constant | $v=\lambda f$ |
| $n_{i} \sin i=n_{r} \sin r$ | $\frac{1}{f}=\frac{1}{d_{o}}+\frac{1}{d_{i}}$ |
| $f=\frac{R}{2}$ | $E=h f=p c$ |
| $\Delta E=\Delta m c^{2}$ | $Q=m c \Delta T$ |
| $\frac{P_{1} V_{1}}{T_{1}}=\frac{P_{2} V_{2}}{T_{2}}$ | $P V=n R T$ |
| $V=I R$ | $P=V I$ |

Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question and place your selection ON THE ANSWER PANEL then "Confirm."
Treat all questions as non-relativistic. Unless otherwise indicated ignore friction with the air. Figures are not drawn to scale.


The following figure and discussion are for questions 1-5
A 500.0 N block is pushed down an incline for a distance of 15.0 m by a constant force of 200.0 N . The block starts at a point 9.0 m off a horizontal plane as shown to the left. ( $3,4,5$ triangle). The block is initially travelling at $8.0 \mathrm{~m} / \mathrm{s}$ along the plane. The force of friction between the block and the plane is 150.0 N
1.The work done by the 200.0 N force is $\qquad$ J.
А) 7500
B) 3000
C) 2400
D) 1800
E) 1500
2. The potential energy loss by the block is $\qquad$ J.
А) 7500
B) 6000
C) 4500
D) 3000
E) 1500
3. The speed of the block when it reaches the bottom of the plane is approximately $\mathrm{m} / \mathrm{s}$.
А) 24
B) 18
C) 16
D) 12
E) 10
4. The coefficient of friction between the block and the plane is $\qquad$ .
A) 0.65
B) 0.50
C) 0.41
D) 0.38
E) 0.25
5. If the weight of the block were 1000.0 N , the force of 200.0 N in moving the block the 15.0 m would do $\qquad$ it did on the 500.0 N block.
A) double the work
B) more work but less than double
C) the same amount of work
D) half the work
E) one fourth

The following discussion is for questions 6 and 7
6-7. Given a 100.0 N solid steel block and a beaker containing water, all on a balance. The balance reads 500.0 N . The block is placed in the water, and is totally submerged, at rest on the bottom of the beaker, which is still on the balance.
6. The balance now reads $\qquad$ N .
A) 500.0
B) 400.0
C) 300.0
D) 200.0
E) 100.0
7. Instead of the 100.0 N steel block, a 100.0 N wood block is on the balance with the beaker and water. The block is put into the water and it floats. The balance now reads $\qquad$ N. A) 500.0
B) 400.0
C) 300.0
D) 200.0
E) 100.0

The following graph and discussion are for question 8
8. Given a record of net force in Newtons


Distance in meters versus distance in meters for a 3.0 kg mass moving on a horizontal frictionless plane. The mass is at rest when $t=$ zero. The kinetic energy of the mass when the mass was at the 10.0 m mark was $\qquad$ J.
А) 100
B) 90
C) 75
D) 25
E) 7.1


The following figure and discussion are for question 9 9. A "massless cord" is attached loosely to a horizontal surface. A weight W is suspended from the center of the string forming an angle two theta ( 2 q ) as shown. The tension in the string is $\qquad$ .
A) $2 \mathrm{~W} \cos (\mathrm{q})$
B) $W \cos (q)$
C) W
D) $\mathrm{W} /(2 \cos (\mathrm{q}))$ E) $\mathrm{W} / 2$


## The following figure and discussion are for

 question 1010. A gas in a chamber passes through a cycle ABCA as shown by the figure to the left. During the process $\mathrm{AB}, 16$ Joules of heat is added to the gas. In the process BC , no heat is exchanged with the gas. For the complete cycle ABCA, the work done by the gas is 12 Joules. How much heat is added to or removed from the gas during process CA?
A) 28 J is removed
B) 4 J is removed
C) 4 J is added
D) 28 J is added
E) No heat is added or removed

The following figure and discussion are for question 11-13
Given four point charges, all equal in magnitude. One charge is placed at each of the four corners of a square. The two plus
b
-Q charges, +Q , are at the end of one diagonal and the two negative charges, -Q , are at the end of the other diagonal. Point a is the mid-point of the square. Point b is the mid-point of the line joining the upper two charges. (not drawn to scale)

$$
-\mathbf{Q} \quad+\mathbf{Q}
$$

11. The electric potential at point $\mathbf{a}$ is $\qquad$ . the electric potential at point $\mathbf{b}$.
A) Less than
B) the same as
C) more than
12. The electric field strength, $E$, at point $\mathbf{a}$ $\qquad$ .
A) does not point in the same direction as that at point $\mathbf{b}$
B) is smaller in magnitude than that at point $\mathbf{b}$
C) would be greater in magnitude if one of the positive charges were removed
D) all of the above (A,B,C)
E) none of the above
13. If one $+Q$ and one $-Q$ traded places giving a situation with two plus charges at the lower corners and two minus charges at the upper corners, the electric field strength, E, at point a would $\qquad$ .
A) increase
B) remain
C) decrease
14. An object is tossed directly up in the air. If there were friction from the air, the object would $\qquad$ .
A) take longer to fall back than to rise to the top, and arrive back traveling slower than when it started upward.
B) take longer to fall back than to rise to the top, and arrive back traveling as fast as it started upward.
C) take as long to rise as to fall back, and arrive back traveling slower than when it started upward.
D) take more time to rise to the top than to fall back, and arrive back traveling slower than when it started upward.
E) take more time to rise to the top than to fall back, and arrive back traveling faster than when it started upward.

## The following figure is for question 15


15. A 50.0 N weight is attached to a spring scale. The spring scale is attached to a "massless string". A force on the string lowers the spring scale and attached weight at a constant downward speed of $2.0 \mathrm{~m} / \mathrm{s}$. The spring scale reads $\qquad$ N.
A) 74
B) 62
C) 59
D) 50
E) 44

The following equation and discussion are for questions 16 and 17
Given: the expression for a traveling wave that gives y in meters when x is in meters and $t$ is in seconds:

$$
y_{(x, t)}=0.04 \operatorname{Cos}\left(\pi \frac{x}{3}-\pi \frac{t}{2}\right)
$$

16. The value of $y$ for $x=6.0 \mathrm{~m}$ and $t=3.0 \mathrm{~s}$ is $\qquad$ m.
A) 0.000
B) 0.028
C) 0.035
D) 0.040
E) 0.045
17. The period of the wave is $\qquad$ s.
A) $1 / 8$
B) $1 / 4$
C) $1 / 2$
D) 2
E) 4
18. If the length of a piano wire is increased by 5 percent ( 1.05 m from 1.00 m with its linear density remaining the same) the approximate change in tension required to keep its fundamental frequency the same is $\qquad$ .
A) a decrease of 20 percent
D) an increase of 5 percent
B) a decrease of 10 percent
E) an increase of 10 percent
C) a decrease of 5 percent
19. A 4.0 kilogram object oscillates in simple harmonic motion with a frequency of 1.0 Hz . The constant of proportionality (spring constant) for the motion, K , is approximately __N/m.
А) 1.4
B) 60
C) 100
D) 141
E) 160

The following discussion is used for questions 20 and 21
20-21 Given two light bulbs, a 100 W and a 75 W , connected in series with an ideal emf..
20. The current is $\qquad$ .
A) greater in the 100 W bulb
B) the same in both bulbs
C) greater in the 75 W bulb.
21. The 75 W bulb burns out. The current in the 100 W bulb $\qquad$
A) increases
B) remains the same
C) decreases

## The following discussion is used for questions 22 through 24

22-24 A 1000 N block rests on a horizontal surface. The coefficient of static friction between the block and the surface is 0.45 and the coefficient of kinetic friction is 0.20 .
22. A horizontal force of 400 N is applied to the block. After 2 seconds the speed of the block is $\qquad$ $\mathrm{m} / \mathrm{s}$.
A) 0
B) 4.0
C) 19.5
D) 28.0
E) 32.0
23. If a horizontal force of 500 N were applied to the block moving the block from rest a distance of 10 meters, the work done by the block's weight (the gravitational force of the earth on the block) would be $\qquad$ J.
A) 0
B) 4000
C) 5000
D) 1000
E) 10,000
24. For the 500 N force, the speed of the block at the end of the 10 meters would be $\qquad$ $\mathrm{m} / \mathrm{s}$.
A) 0.0
B) 3.3
C) 7.7
D) 10.6
E) 12.8

## The following discussion is used for questions 25 through 27

25-27 A long string is attached to a small vibrator. The other end of the string passes over a pulley. A mass is attached to that end producing a tension in the string of 15 N . Two meters of the string are in vibration. A driving frequency of 120 HZ produces a standing wave of two loops.
25. The speed of the transverse wave on the string is $\qquad$ $\mathrm{m} / \mathrm{s}$.
A) 360
B) 240
C) 141
D) 120
E) 80
26. The frequency required to have the string vibrate as one loop is $\qquad$ Hz
A) 360
B) 240
C) 140
D) 120
E) 60
27. If the string were heavier ( had a larger mass per unit length ), then the frequency required to produce two loops would $\qquad$ 120 Hz .
A) be less than
B) remain
C) be more than
28. The image formed on the retina of the eye is always $\qquad$ .
A) larger than the object
B) real
C) erect
D) farther from the lens than the object
E) 0.01 the size of the object
29. A beam of electrons is undeflected when it passes simultaneously through an electric field of 10 Newtons/Coulomb perpendicular to its path and a magnetic field of $2.0 \times 10^{-4} \mathrm{~T}$ perpendicular both to its path and to the electric field.
The speed of the electrons is approximately $\qquad$ $\mathrm{m} / \mathrm{s}$
A) $2 \times 10^{-4}$
B) $5 \times 10^{-4}$
C) $1 \times 10^{+4}$
D) $2 \times 10^{+4}$
E) $5 \times 10^{+4}$
30. Given an iceberg floating in the ocean. If the part of the iceberg which you can see floating above the water is cut off and therefore removed from the iceberg, the
$\qquad$ .
A) the buoyant force on the iceberg would increase
B) iceberg would sink to the bottom
C) iceberg's density would decrease
D) the pressure on the bottom of the iceberg would decrease
31. A small sphere is dropped from the top of a very tall building at time equals zero. In the time interval between $t=1.0 \mathrm{~s}$ and $\mathrm{t}=3.0 \mathrm{~s}$, the sphere fell $\qquad$ m.
А) 44.1
В) 39.2
C) 21.4
D) 19.6
E) 9.8
32. An automobile travels with rectilinear motion a distance of $100,000 \mathrm{~m}$ at a constant speed of 200,000 meters per hour. Then at rate of 20,000 meters/hour it travels an additional distance of $100,000 \mathrm{~m}$. The average speed of the automobile for the total $200,000 \mathrm{~m}$ distance was approximately $\qquad$ meters/hour .
A) 110,000
B) 102,000
C) 52,000
D) 36,000
E) 22,000
33. A skydiver leaps from an airplane and increases in speed until the skydiver reaches a terminal speed. Which diagram correctly represents the forces then?


D.

E.


The following data, graph, and discussion are for questions 34 through 36
34-36. Given a record of Position, in meters, as a function of time, in seconds, for a small mass executing rectilinear motion.

34. The average velocity of the mass for the 3 second interval from $t=1.0$ to $\mathrm{t}=4.0 \mathrm{~s}$ was $\mathrm{m} / \mathrm{s}$.
А) 13.8
В) 17.3
C) 18.5
D) 23.0
E) 51.9
35. The acceleration of the mass was $\qquad$ .
A) positive and increasing
B) positive and decreasing
C) negative and increasing
D) negative and decreasing
36. The velocity of the mass when time was 2.5 s was approximately $\qquad$ m/s
A) 2
B) 7
C) 12
D) 17
E) 22

## The following description is for questions 37 and 38

Monochromatic coherent light passes through a double slit forming on a screen an interference pattern with maximums 0.04 m apart.
37. If light with twice the frequency had been used, the maximums would have been $\qquad$ m apart.
А) 0.12
В) 0.08
C) 0.04
D) 0.02
E) 0.01
38. If the original light were used but the screen was twice as far away, the separation between interference maximums would $\qquad$ .
A) double
B) increase but less than double
C) be the same
D) be halved
E) decrease

## Use the following information for questions 39 and 40

Given two "point masses" moving along a straight line on a horizontal frictionless surface. At time equals zero, one has a mass 3.0 kg and is moving at $5.0 \mathrm{~m} / \mathrm{s}$ to the right. Also, at time equals zero, the second has a mass 5.0 kg and is moving to the right at $3.0 \mathrm{~m} / \mathrm{s}$. It is 3.0 meters to the right of the other. The two masses have a perfectly elastic collision.
39. The total linear momentum in this system of two masses before they collide is $\mathrm{kg} \mathrm{m} / \mathrm{s}$.
A) 0
В) 8.0
C) 16.0
D) 24.0
E) 30.0
40. The velocity of the 3.0 kg particle after the collision was $\qquad$ .
A) $4.0 \mathrm{~m} / \mathrm{s}$ to the left
B) $4.0 \mathrm{~m} / \mathrm{s}$ to the right
C) $2.5 \mathrm{~m} / \mathrm{s}$ to the left
D) $2.5 \mathrm{~m} / \mathrm{s}$ to the right
E) zero (the mass is at rest)

Use the following information for questions 41 and 42
41-42 Given a 0.01 m tall object placed 0.30 m from a spherical mirror. The mirror forms a 0.03 m tall erect image of the object.
41. The magnitude of the radius of curvature of the mirror is _ m .
А) 0.90
В) 0.60
C) 0.45
D) 0.225
E) 0.15
42. If the mirror were used under water ( index of refraction of water is 1.33 ), its focal length would be $\qquad$ its focal length in air.
А) $4 / 3$
В) $16 / 9$
C) the same as
D) $3 / 4$
E) $9 / 16$

The following figure, and discussion are for questions 43 and 44
43-44 A planet $P$ is located three times as far from the sun as the earth is from the sun, as shown
43. The time it takes planet $P$ to complete one revolution around the sun is $\qquad$ earth years.
А) 2.1
B) 3.0
C) 5.2
D) 9.0
E) impossible to tell with information given
44. The gravitational force from the sun on planet $P$ is $\qquad$ times the sun's pull on the earth.

A) 0.50
В) 0.33
C) 0.25
D) 0.11
E) impossible to tell with information given

The following figure, and discussion are for question 45

45. Given two resistors connected in parallel to an ideal emf of 12.0 volts, as shown to the left. The current in resistor R is 3.0 A , as indicated by the ammeter. The electrical energy consumed by resistor $R$ is $\qquad$ Watts.
A) 48
B) 36
C) 24
D) 12
E) 6

The figure below and discussion are for question 46.
46. The apparatus shown below represent three ways to produce an image of an arrow.
The image of the arrow is larger than the arrow itself in which figure, I, II, III. ?

A) I only
B) II only
C) I and III only
D) II and III only
E) I, II, III
47. Given two electromagnetic waves, one of wavelength $6.0 \times 10^{-7} \mathrm{~m}$ and the other of wavelength $7.0 \times 10^{-7} \mathrm{~m}$, travelling in space. When the two waves meet in space, they combine (interfere) to form a wavelength $\qquad$ m.
A) $42.0 \times 10^{-7}$
B) $21.0 \times 10^{-7}$
C) $6.5 \times 10^{-7}$
D) $1.0 \times 10^{-7}$
E) none - they do not interfere

The following figure, and discussion are for questions $\mathbf{4 8}$ through 50


Given two thin lenses, L1 and L2, with their optical axis coinciding, and a small object positioned on the optic axis. The two lenses are 0.40 m apart. The focal length of L 1 , the lens on the left, is 0.20 m . The focal length of L 2 , the lens on the right, is 0.40 m . The object is 0.60 m to the left of L 1 , and is 0.02 m tall.
48. The final image formed by this combination of lenses compared with the small object is $\qquad$ .
A) real and reduced
B) virtual and reduced
C) real and enlarged
D) virtual and enlarged
E) no image is formed
49. The final image formed by this combination of lenses would be located $\qquad$ of L2.
A) 0.60 m to the right
B) 0.13 m to the right
C) 0.10 m to the right
D) 0.13 m to the left
E) 0.10 m to the left
50. If the two lenses are put side by side forming a rough compound lens, its focal length would be approximately $\qquad$ m.
А) 0.60
B) 0.30
C) 0.13
D) -0.10
E) -0.13
51. Given a column of air in a tube. The tube is closed at one end, and open at the other. A series of tuning forks are held near the open end. The column resonates for the following frequencies: $240 \mathrm{~Hz}, 400 \mathrm{~Hz}$, and 720 Hz . If these frequencies are integral multiples of the tube's fundamental frequency, the fundamental frequency might be $\qquad$ Hz.
A) 360
В) 180
C) 120
D) 80
E) 60
52. Given a 10.0 m tall cylindrical water tank. It is filled with water to a depth of 9.0 m . The upper end of the tank is open to the atmosphere. The tank is 10.0 m in diameter. There is a small round hole about 0.02 m in diameter in the side of the tank 1.0 m above the bottom. The speed of the water as it exits through the hole is
$\qquad$ $\mathrm{m} / \mathrm{s}$.
А) 3.6
B) 4.2
C) 10.8
D) 12.5
E) 13.3

## The following description is for questions 53,54 , and 55.

Given a uniform ladder 5.0 m long with a weight of 500.0 N . A 100.0 N bucket hangs from the ladder at a point 4.0 m up the ladder, i.e. 3.2 m above the horizontal floor. The ladder is inclined against a frictionless vertical wall, touching a point on the wall 4.0 m above the floor (The sine of the angle of inclination of the ladder with the horizontal floor is $4.0 / 5.0$ or 0.80 ). The coefficient of static friction between the base of the ladder and the floor is 0.50
53. The normal component of the force from the floor on the ladder is $\qquad$ N
A) 0
B) 360
C) 480
D) 540
E) 600
54. The angle that the force from the floor on the ladder makes with the floor is approximately $\qquad$ degrees.
А) 72
В) 68
C) 53
D) 37
E) 29
55. If the weight of the ladder were $1,000.0 \mathrm{~N}$ and that of the bucket were 200.0 N , double their original values, the floor's frictional force component would $\qquad$ .
A) not change from the original
B) double and not be maximum
C) increase, not double, and not be a maximum
D) be the maximum possible, the ladder would be on the verge of slipping.
E) not be enough, the ladder would slip
56. Given a closed container of "ideal" gas. It has a volume of 2.0 liters and its temperature is 100.0 degrees Celsius. The gas is under an absolute pressure of 30.0 psi. Then the volume of the gas is increased to 3.0 liters. Its pressure is not changed. The "ideal" gas' new temperature is __ degrees Celsius.
А) 819
B) 663
C) 560
D) $420.0 \quad$ E) 287
57. Given a glass of water with ice cubes in it. If the ice melts, the water level in the glass $\qquad$
A) rises
B) does not change
C) lowers
58. Given a horizontal pipe. It "necks down" (reduces in diameter) from a 0.10 m diameter to 0.05 m diameter, but still remains horizontal. It is filled with an ideal incompressible liquid. In the larger area section of the pipe the speed of the fluid is $0.02 \mathrm{~m} / \mathrm{s}$. In the smaller area section the speed of the liquid is $\qquad$ $\mathrm{m} / \mathrm{s}$
А) 0.08
В) 0.10
C) 0.12
D) 0.16
E) 0.19

The following description is for questions 59 and 60
59-60 The specific heats, expressed in $\mathrm{J} / \mathrm{kg} \mathrm{C}^{0}$, for some materials are Copper 387 Iron 448 Aluminum 900 Ice 2090 Water 4186

Given 1.0 kg of each of these materials, all of which are at 10 degrees Celsius. No heat is gained from, nor lost to the environment.
59. If the aluminum were heated to 100.0 degrees Celsius and then added to the water, assuming one can neglect the container, the water's final temperature will be ___ degrees Celsius .
A) 3.2
В) 15.9
C) 25.9
D) 31.5
E) 36.8
60. Adding 20 Joules of energy slowly and evenly to each of the five will result in the temperature of the $\qquad$ rising the least. Starting temperature is 10 degrees Celsius
A) Copper
B) Iron
C) Aluminum
D) Ice
E) Water

## End of Test

