# 28th Annual SLAPT Physics Contest

# Washington University in St. Louis

# April 27, 2013

## Comprehensive Physics Test

$g = 9.8\ \frac{m}{s^2}$ $\quad e = 1.6 \times 10^{9} C$ $\quad 1cm^3 = $ millimeter

$R = 8.314\ \frac{J}{mol \cdot K}$ $\quad c = 3.0 \times 10^{8}\ \frac{m}{s}$ $\quad$ Coulomb constant, k=$8.99 \times 10^{9}\ \frac{Nm^2}{C^2}$

Please answer the following questions on the supplied answer sheet. You may write on this test booklet and keep it for your records. Only the answer sheets will be scored.

Your answer sheets must have your name, your school, and MECHANICS on them

The cash prizes for this exam will be:
First Prize of $100, Second Prize of $50, and Third Prize of $25.

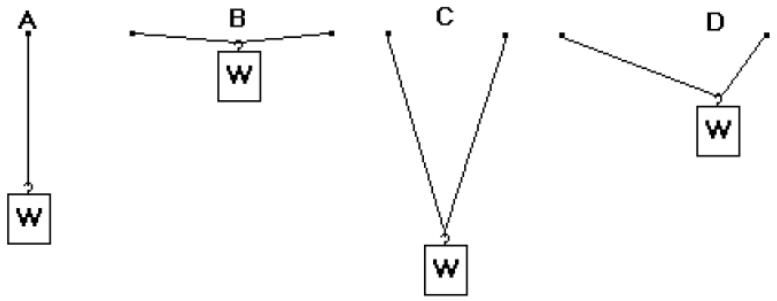
Newton Awards will be presented to the next highest scoring twenty percent of the contestants, and certificates to the top three scoring schools.

Award Ceremony at approximately 12:30 in this room

1. A tractor-trailer truck is traveling down the road. The trailer's mass is 4 times the mass of the tractor. If the tractor accelerates forward, the force that the trailer applies on the tractor is
   A. 4 times greater than the force of the tractor on the trailer.
   B. 2 times greater than the force of the tractor on the trailer.
   C. equal to the force of the tractor on the trailer.
   D. 1/4 the force of the tractor on the trailer.
   E. zero since the tractor is pulling the trailer forward.

2. An airplane with air speed 120 km/h is heading due north in a wind blowing due east at 50 km/h. What is the ground speed of the plane?
   [A] 60 km/h [B] 120 km/h [C] 130 km/h [D] 140 km/h [E] None of these

3. A weight can be hung in any of the following four ways. In which case is the string most likely to break?

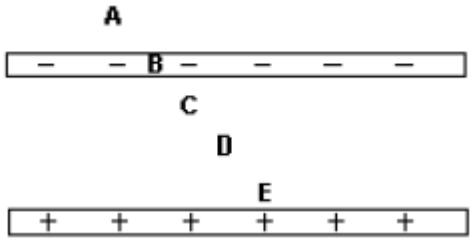



   A. A  B. B  C. C  D. D  E. all the same

4. If air resistance can be neglected, what happens to the horizontal velocity component of a basketball as it is thrown to the basket from the free-throw line?
   A. increases
   B. decreases
   C. decreases until the ball reaches the top then increases as the ball comes down
   D. increases until the ball reaches the top then decreases as the ball comes down
   E. remains constant

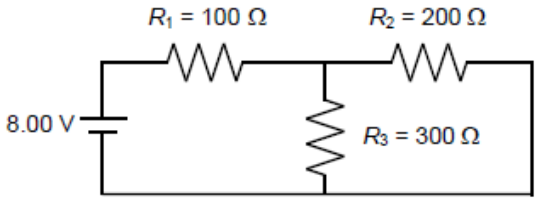
5. What is the resistance of a 60 watt light bulb designed to operate at 120 volts?
   A. 0.5 Ω  B. 2 Ω  C. 60 Ω  D. 240 Ω  E. 7200 Ω

6. Consider the two oppositely charged plates as shown in the diagram. At which of the marked points shown in the diagram would a positively charged particle have the greatest electrical potential energy?




A. A B. B C. C D. D E. E

7. What is the magnitude of the current that flows from the 8.00 V voltage source in the circuit shown in the diagram?




A. 13.3 mA
B. 16.0 mA
C. 36.4 mA
D. 26.7 mA
E. 80.0 mA

8. A 5.00 Ω resistor and a 30.0 mH inductor are connected in series to a sinusoidal voltage source with an amplitude 26.0 V and an angular frequency 400 $s^{-1}$. What is the amplitude of the current in the circuit?
A. 2.00 A
B. 3.33 A
C. 3.67 A
D. 5.20 A
E. 130 A

9. Unpolarized light with intensity $I_0$ traveling toward the east is normally incident on an ideal polarizing film with its axis of polarization tilted 40.0° to the north of vertical. What is the intensity of the light transmitted by the polarizing film?
A. $I_0 \cos 40^\circ$
B. $I_0 \cos 50^\circ$
C. $I_0 \cos^2 40^\circ$
D. $I_0 \cos^2 50^\circ$
E. $I_0/2$

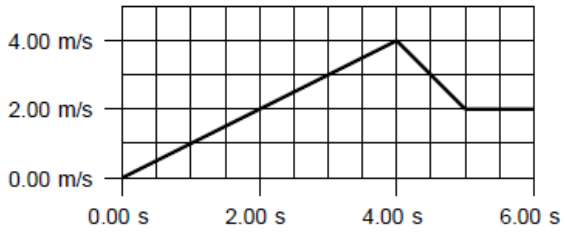
10. An observer on the earth watches a spaceship pass by traveling toward the east at a speed of 0.800*c*, where *c* is the speed of light in vacuum. The spaceship launches a missile toward the west at a speed of 0.600*c* (relative to the spaceship). What is the speed of the missile as measured by the observer on the earth?
    A. 0.122 *c*
    B. 0.200 *c*
    C. 0.385 *c*
    D. 0.921 *c*
    E. 1.400 *c*

11. Light with wavelength λ causes electrons to be ejected from a metal surface with a maximum kinetic energy 2.00 eV. Light with wavelength 1.50λ causes electrons to be ejected from the same metal surface with a maximum kinetic energy 1.00 eV. What is the wavelength of the light?
    A. 632 nm
    B. 589 nm
    C. 532 nm
    D. 489 nm
    E. 413 nm

12. During a beta decay process in which the nucleus emits an electron and an antineutrino, the nucleus
    A. decreases in atomic mass number by one.
    B. increases in atomic mass number by one.
    C. decreases in atomic number by one.
    D. increases in atomic number by one.
    E. decreases in atomic number by two.

13. Which is a dimensionally correct set of units for power?
    A. kg·s
    B. kg·m/s
    C. $kg \cdot m^2/s$
    D. $kg \cdot m^2/s^2$
    E. $kg \cdot m^2/s^3$

14. A graph of velocity as a function of time is shown for the rectilinear motion of an object. What is the magnitude of the displacement of the object during the 6.0 s interval shown in the graph?

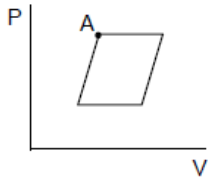



A. 9.0 m
B. 12.0 m
C. 13.0 m
D. 17.0 m
E. 20.0 m

15. In the situation described in problem 14, what is the magnitude of the average acceleration during the 6.0 s time interval shown in the graph?

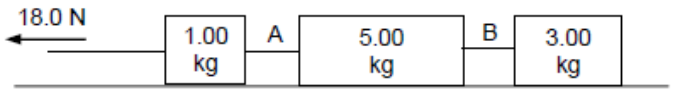
A. 0.33 $m/s^2$
B. 0.67 $m/s^2$
C. 1.00 $m/s^2$
D. 2.00 $m/s^2$
E. 3.00 $m/s^2$

16. A cyclic thermodynamic process for an ideal gas is shown on the P-V diagram. For one complete irreversible cycle of the process, starting at point A and proceeding clockwise,




A. no total heat is added to the system.
B. no total work is done on the system.
C. the total change in the entropy of the universe is zero.
D. the total change in the energy of the gas is zero.
E. the temperature of the system remains constant throughout the cycle.

17. Three masses are on a level, frictionless surface. They are attached as shown by unstretchable strings A and B of negligible mass. A horizontal 18.0 N force pulls on the 1.00 kg mass. What is the magnitude of the acceleration of the 5.00 kg mass?




A. 2.00 $m/s^2$
B. 3.60 $m/s^2$
C. 6.00 $m/s^2$
D. 18.0 $m/s^2$
E. 36.0 $m/s^2$

18. In the situation described in problem 17, what is the tension in string B?
A. 3.00 N
B. 6.00 N
C. 12.0 N
D. 18.0 N
E. 54.0 N

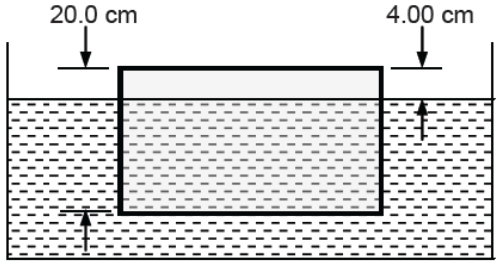
19. A binary star system consists of star A with a mass $4.00 \times 10^{30}$ kg and star B with a mass $8.00 \times 10^{30}$ kg orbiting each other in elliptical orbits. When the two stars are $5.00 \times 10^{9}$ m apart, their total kinetic energy is $2.00 \times 10^{41}$ J. How far apart are the two stars when their total kinetic energy is $3.00 \times 10^{41}$ J?
A. $2.22 \times 10^{9}$ m
B. $3.33 \times 10^{9}$ m
C. $4.05 \times 10^{9}$ m
D. $7.50 \times 10^{9}$ m
E. $1.13 \times 10^{10}$ m

20. A tire rolls without slipping along a straight line on a flat surface. The center of the wheel moves 200 m as the tire rotates 50.0 revolutions. What is the diameter of the tire?
A. 0.250 m
B. 0.637 m
C. 0.785 m
D. 1.27 m
E. 4.00 m

21. A diver leaves the diving board rotating at 1.20 rad/s with her body configured in such a manner that the moment of inertia about the axis of rotation is 30.0 $kg \cdot m^2$. As the dive progresses, the diver reconfigures her body so her rate of rotation increases to 2.00 rad/s. What is the diver's moment of inertia about the axis of rotation in the new configuration?
    A. 10.8 $kg \cdot m^2$
    B. 18.0 $kg \cdot m^2$
    C. 30.0 $kg \cdot m^2$
    D. 72.0 $kg \cdot m^2$
    E. 83.3 $kg \cdot m^2$

22. In the situation described in problem 21, what is the rotational kinetic energy of the diver in the initial configuration?
    A. 10.4 J
    B. 21.6 J
    C. 25.0 J
    D. 36.0 J
    E. 540 J

23. A 12.0 kg rectangular block of material is 20.0 cm by 30.0 cm by 40.0 cm. The block floats in a liquid so that the 20.0 cm edge is vertical and 4.00 cm of that edge is above the surface of the liquid. What is the density of the liquid?

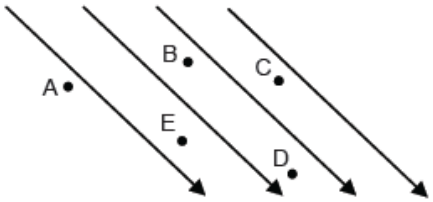



    A. 300 $kg/m^3$
    B. 375 $kg/m^3$
    C. 500 $kg/m^3$
    D. 625 $kg/m^3$
    E. 2500 $kg/m^3$

24. A source of light is located 40.0 cm from a thin lens. The virtual image of the source is located 60.0 cm from the lens. What is the focal length of the lens?
    A. 24.0 cm
    B. 120 cm
    C. 20.0 cm
    D. −20.0 cm
    E. 50.0 cm

25. An electron is traveling directly north in a magnetic field pointing directly east. What is the direction of the magnetic force on the electron?
    A. east
    B. west
    C. south
    D. up
    E. down

26. A uniform electric field is in the direction of the arrows. Which of the labeled positions is at the greatest electric potential?
    A. A
    B. B
    C. C
    D. D
    E. E




27. A two-slit interference experiment is used to measure the wavelength of a source of monochromatic light. The two slits are separated by 0.200 mm and the interference pattern appears on a screen 3.00 m from the slits. The third order bright fringe is separated from the seventh order bright fringe in the interference pattern by 2.50 cm. What is the wavelength of the monochromatic light source?
    A. 667 nm
    B. 586 nm
    C. 520 nm
    D. 467 nm
    E. 417 nm

28. The electron has a rest mass 0.511 MeV/$c^2$. What is the kinetic energy of an electron with a speed 98% of the speed of light?
    A. 0.245 MeV
    B. 0.491 MeV
    C. 2.06 MeV
    D. 2.58 MeV
    E. 12.4 MeV

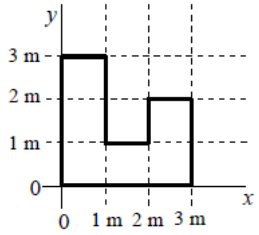
29. A small portion of the periodic table of elements is shown. A Neptunium (Np) nucleus undergoes an alpha decay and then a beta decay. What is the element of the resulting nucleus?

| 90<br>Th | 91<br>Pa | 92<br>U | 93<br>Np | 94<br>Pu | 95<br>Am |
|---|---|---|---|---|---|

A. Th (thorium)
B. Pa (protactinium)
C. U (uranium)
D. Pu (plutonium)
E. Am (americium)

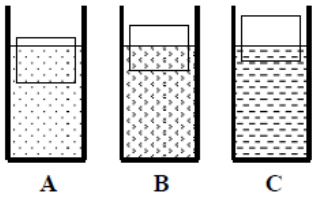
30. A uniform sheet of material is outlined by the bold lines in the diagram below. What is the *x*-component of the center of mass of the sheet of material? For significant figure purposes, all of the boundaries of the material are within 0.01 m of an integer coordinate.

A. 1.17 m
B. 1.33 m
C. 1.50 m
D. 1.67 m
E. 1.83 m



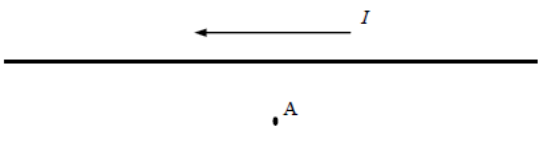

31. Three identical objects are floating in equilibrium in containers of fluid as shown. Container A holds a fluid with a density 1000 kg/m$^3$. Container B holds a fluid with a density 2000 kg/m$^3$. Container C holds a fluid with a density 3000 kg/m$^3$. What is the ratio of the buoyant force acting on the object in container A, $F_A$, to the buoyant force acting on the object in container B, $F_B$, to the buoyant force acting on the object in container C, $F_C$ ($F_A$: $F_B$ : $F_C$)?

A. 1:2:3
B. 3:2:1
C. 1:4:9
D. 9:4:1
E. 1:1:1




32. A current *I* flows toward the left along a long straight wire as indicated in the diagram. What is the direction of the magnetic field at point A?

A. toward the left
B. into the page
C. out of the page
D. toward the bottom of the page
E. toward the top of the page



33. In the situation in problem 32, if an electron were at point A moving anti-parallel to the current, which way would it feel a force?
    A. no force
    B. into the page
    C. out of the page
    D. toward the bottom of the page
    E. toward the top of the page

34. Some high school students have developed their own temperature scale. Under constant volume conditions a fixed amount of gas has an absolute pressure 400. $kN/m^2$ at temperature 800 on their scale. The pressure changes to 500 $kN/m^2$ when their temperature changes to 900. What is absolute zero temperature on their scale?
    A. 0
    B. -200
    C. 200
    D. 400
    E. 600

35. In a particular gas, a stationary source emits sound waves with a frequency 400.0 Hz that travel at a speed 200 m/s. A detector moving along a line on which the source is located measures the waves to have a frequency 380.0 Hz. What is the velocity of the detector?
    A. 1.95 m/s away from source
    B. 40.0 m/s away from source
    C. 20.0 m/s toward source
    D. 20.0 m/s away from source
    E. 10.0 m/s away from source

36. What is the critical angle for total internal reflection when a light ray travelling within a material with refractive index 1.500 reaches a surface at which the material on the opposite side of the surface has a refractive index 1.200?
    A. $53.1^o$
    B. $51.3^o$
    C. $38.6^o$
    D. $36.9^o$
    E. There is no critical angle in this case because the index of refraction on the incident side of the surface is greater than the refractive index on the other side of the surface.

37. A 2.00 μF capacitor is charged to 10.0 V and then disconnected from the charging source. The capacitor is then connected in parallel to an initially uncharged 6.00 μF capacitor. What is the ratio of the electrical potential energy stored in the capacitors after they are connected to each other to the electrical potential energy stored in the capacitors before they are connected to each other?
    A. 0.125
    B. 0.167
    C. 0.250
    D. 0.333
    E. 1.00

38. An object isolated in space is cooling down with the only significant heat transfer mechanism being radiative heat transfer. The surface of the object is a perfect absorber of electromagnetic radiation. At temperature 2000 K, the object is losing heat at the rate of $3.20\times 10^{8}$ J/s. What is the rate of heat loss from the object when it is at a temperature 1000K?
    A. $1.00 \times 10^{7}$ J/s
    B. $2.00 \times 10^{7}$ J/s
    C. $4.00 \times 10^{7}$ J/s
    D. $8.00 \times 10^{7}$ J/s
    E. $1.60 \times 10^{8}$ J/s

39. In Arthur Compton's scattering experiment (conducted right here at WashU!) what happened to the x-rays?
    A. Their wavelength increased
    B. Their wavelength decreased
    C. Nothing
    D. They were absorbed by the nucleus of the atom they interacted with

40. What is the efficiency (expressed as a percentage) of a Carnot engine operating between temperatures $T_H$=1000K and $T_C$=250K?
    A. 100%
    B. 75%
    C. 50%
    D. 25%
    E. 0%

41. What is the order of magnitude deBroglie wavelength of an electron that has just been accelerated through a 1V potential difference?
    A. 1fm
    B. 1pm
    C. 1nm
    D. 1μm
    E. 1mm

42. A positively charged conductor attracts a second object. Which of the following statements *could* be true?
    I. The second object is a conductor with negative net charge.
    II. The second object is a conductor with zero net charge.
    III. The second object is an insulator with zero net charge.
    A. I only
    B. II only
    C. III only
    D. I & II only
    E. I, II & III

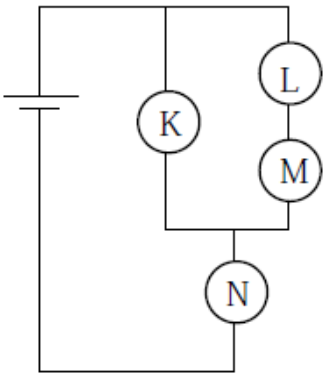
43. Which of the following could *NOT* be used to indicate a temperature change? A change in:
    A. color of a metal rod.
    B. length of a liquid column.
    C. pressure of a gas at constant volume.
    D. electrical resistance.
    E. mass of one mole of gas at constant pressure.

44. In 1998 astrophysicist used observations of Type Ia Supernova to determine that the universe had
    A. a yet unknown form of energy which they called "Dark Energy"
    B. a yet unknown form of matter which they called "Dark Matter"
    C. a yet undiscovered $5^{th}$ fundamental force
    D. expanded from a single point which they called the "Big Bang"

45. A magnet is dropped through a vertical copper pipe slightly larger than the magnet. Relative to the speed it would fall in air, the magnet in the pipe falls:
    A. more slowly because it is attracted by the innate magnetic field of the pipe.
    B. more slowly because the currents induced in the pipe produce an opposing magnetic field.
    C. at the same rate.
    D. more quickly because it is attracted by the innate magnetic field of the pipe.
    E. more quickly because the currents induced in the pipe produce a opposing magnetic field.

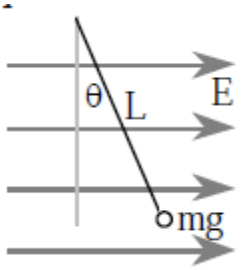
46. Albert Einstein won the Nobel Prize in Physics for his work on:
    A. general relativity.
    B. high temperature super conductors.
    C. the photoelectric effect.
    D. special relativity.
    E. transistors.

47. Four identical light bulbs K, L, M, and N are connected in the electrical circuit shown in the accompanying figure. In order of decreasing brightness (starting with the brightest), the bulbs are:
    A. K = L > M > N
    B. K = L = M > N
    C. K > L = M > N
    D. N > K > L = M
    E. N > K = L = M




48. A hypothetical planet orbits a star with mass one-half the mass of our sun. The planet's orbital radius is the same as the Earth's. Approximately how many Earth years does it take for the planet to complete one orbit?
    A. 1/2
    B. $1/\sqrt{2}$
    C. 1
    D. $\sqrt{2}$
    E. 2

49. A small object with charge *q* and weight *mg* is attached to one end of a string of length *L*. The other end is attached to a stationary support. The system is placed in a uniform horizontal electric field *E*, as shown in the accompanying figure. In the presence of the field, the string makes a constant angle θ with the vertical. What is the sign and magnitude of *q*?
    A. positive with magnitude *mg/E*
    B. positive with magnitude (*mg/E*) tanθ
    C. negative with magnitude *mg/E*
    D. negative with magnitude (*mg/E*) tanθ
    E. negative with magnitude (*E/mg*) tanθ




50. In Young's double slit experiment, second and higher order bright bands can overlap. Which third order band would occur at the same location as a second order band of wavelength 660 nm?
    A. 1320 nm
    B. 990 nm
    C. 495 nm
    D. 440 nm
    E. 330 nm