The Thirtieth Annual SLAPT Physics Contest
Washington University in Saint Louis
April 25, 2015

Comprehensive Exam

$g = 9.8\ \mathrm{m\ s^{-2}}$ $\qquad$ $G = 6.67\times10^{-11}\mathrm{m^3kg^{-1}s^{-2}}$

$e = 1.6\times10^{-19}\mathrm{C}$ $\qquad$ $c = 3\times10^{8}\ \mathrm{m\ s^{-1}}$

$R = 8.314\ \mathrm{J\ mol^{-1}\ K^{-1}}$ $\qquad$ $k_B = 1.38\times10^{-23}\ \mathrm{m^2kg\ \ s^{-2}K^{-1}}$

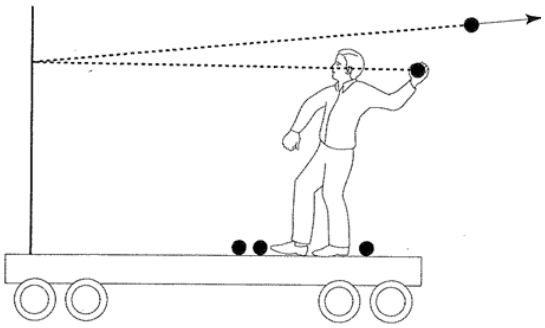
$\epsilon_0 = 8.85\times10^{-12}\ \mathrm{m^{-3}kg^{-1}s^4A^2}$ $\qquad$ $\mu_0 = 1.26\times10^{-6}\ \mathrm{m\ \ kg\ \ s^{-2}A^{-2}}$

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 sheets must have your name, your school, and COMPREHENSIVE on them.

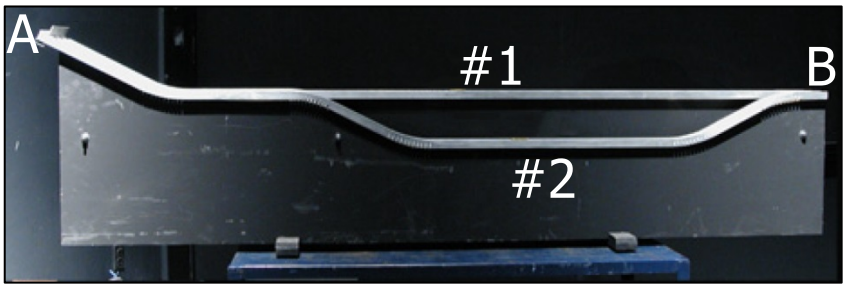
1. Suppose you are on a cart, initially at rest on a track with very little friction. You throw a ball at a partition that is rigidly mounted on the cart. If the ball flies past you after it bounces off the partition, where will the cart be after the ball passes and how will you be moving?

A. Left of where it started, moving left
B. Right of where it started, moving right
C. Just where it started, and not moving
D. Just where it started, moving left
E. Just where it started, moving right



2. Two identical balls leave point A at the same time with the same initial speed. Which ball will arrive at the point B first?

A. The ball following path #1
B. The ball following path #2
C. They arrive at the same time
D. Impossible to tell



3. Four point particles, each with mass $^1/_4\,M$, are connected by massless rods so that they form a square whose sides have length L. What is the moment of inertia I of this object if it is spun around an axis going through the center of the square perpendicular to the plane of the square?

A. $^1/_{16}\,ML^2$
B. $^1/_8\,ML^2$
C. $^1/_4\,ML^2$
D. $^1/_2\,ML^2$
E. ML^2

4. If global warming proceeds during the next century as anticipated, it is possible that the polar ice caps will melt, substantially raising sea levels around the world (and flooding coastal cities such as New York). Would this shorten, lengthen, or have strictly no effect on the duration of the day?

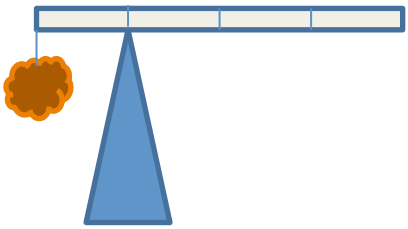
A. Lengthen the day slightly.
B. Shorten the day slightly.
C. Have strictly no effect on the length of the day.

5. If a car's x-position at time $t = 0$ is $x(0) = 0$ and it has an x-velocity of $v_x(t) = b(t - T)^2$, where b and T are constants, which function below best describes $x(t)$?

A. $x(t) = 2\,b(t - T)$
B. $x(t) = 3\,b(t - T)^3$
C. $x(t) = (1/3)\,b(t - T)^3$
D. $x(t) = (1/2)\,b(t - T)$
E. $x(t) = (1/3)\,b[\,(t - T)^3 + T^3]$

6. A 1-kg rock is suspended by a massless string from one end of a 1-m measuring stick. What is the mass of the measuring stick if it is balance by a support force at the 0.25-m mark?

A. 0.25 kg
B. 0.5 kg
C. 1kg
D. 2kg
E. 4 kg

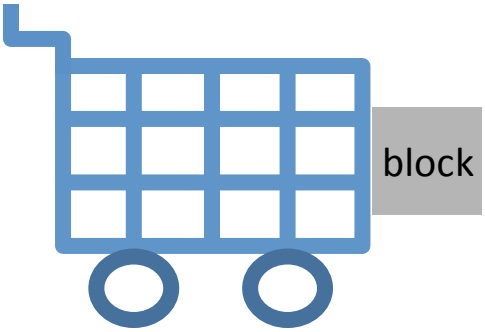


7. Two people are attempting to break a rope, which will break if the tension on the rope exceeds 360 N. If each person can exert a pull of 200 N,

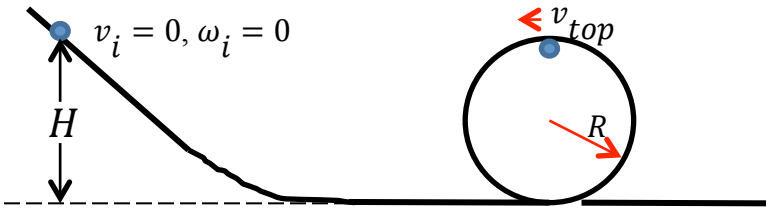
A. they can break the rope if they each take an end and pull
B. they can break the rope if they tie one end to the wall and both pull on the other.
C. they can break the rope if they use either of the strategies above.
D. they cannot break the rope.

8. A block is placed against the vertical front of a cart as shown below. What acceleration must the cart have for the block not to fall? The coefficient of static friction between the block and the cart is μ_s.

A. $a_x = 2g/\mu_s$
B. $a_x = g/2\mu_s$
C. $a_x = g/\mu_s$
D. The cart doesn't need to accelerate as long as it travels at a high enough speed.

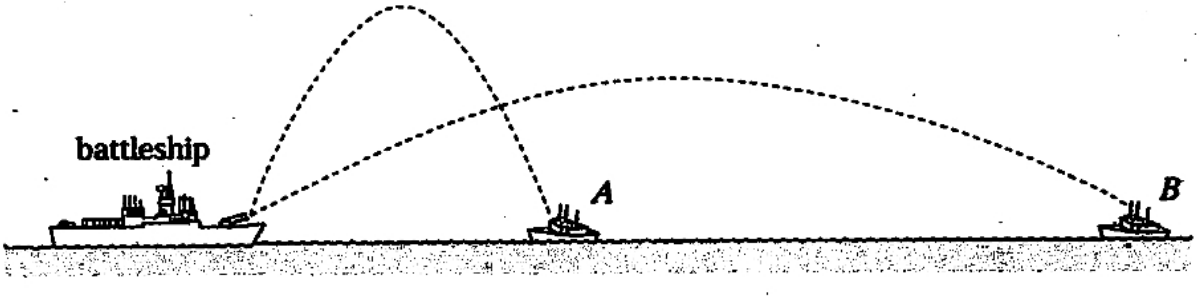


9. A ball of mass m and radius r starts at rest at the top of a hill of height H, rolls down the hill, then goes around a vertical loop of radius R. What is the minimum height H from which the ball can be released if it is to remain in contact with the track as it reaches the top of the loop?



A. $H_{min} = 2R$
B. $H_{min} = 2.3R$
C. $H_{min} = 2.5R$
D. $H_{min} = 2.7R$
E. $H_{min} = 3R$

10. A battleship simultaneously fires two shells at enemy ships. If the shells follow the parabolic trajectories shown, which ship gets hit first?



A. A
B. B
C. Both are hit at the same time
D. Need more information

11. Consider a mass connected to a spring that is hanging vertically from a post. At $x = 0$ the mass is passing through the equilibrium position and moving in the $-x$ direction. If the equation of motion for the oscillating mass can be described by $x(t) = A\cos(\omega t + \theta)$, determine the phase angle θ.

A. $+\pi$
B. $+\pi/2$
C. $-\pi/2$
D. $-\pi$

12. A person riding a merry-go-round passes very close to a person standing on the ground once (event A) and then again (event B). Which person's watch measures *proper time* between these two events? (Assume that the ground is an inertial frame and that the merry-go-round rider moves at a constant speed.)

A. The rider in the merry-go-round
B. The person standing on the ground
C. Both
D. Neither

13. In the situation described in the previous question, which person (if any) measures the *spacetime interval* between the events?

A. The rider in the merry-go-round
B. The person standing on the ground
C. Both
D. Neither

14. How does a particle's relativistic kinetic energy compare to its newtonian kinetic energy when the particle's speed is $v \neq 0$?

A. $K > \frac{1}{2}mv^2$
B. $K < \frac{1}{2}mv^2$
C. It depends on the value of v.

15. Consider two point charges q_1 and q_2 lying on the x axis. Consider a third charge q_3 located somewhere near q_1 andq_2. Assume that the net force exerted by these charges on $q_3$is zero. This implies that q_3 must lie somewhere along the x axis, True or False?

A. True
B. False

16. Imagine that we place two particles a certain distance apart. The electric field at some point on the line *between* the particles is zero. What is the most general thing we can say about the (otherwise unknown) signs and magnitudes of the particles' charges? The charges have

A. the same sign and magnitude
B. opposite signs but the same magnitude
C. the same sign, but may have different magnitudes
D. opposite signs, but may have different magnitudes

17. Consider two concentric spherical shells, one with radius R and one with radius $2R$. Both have the same charge Q. At a point just inside the outer shell, the magnitude of the electric field is

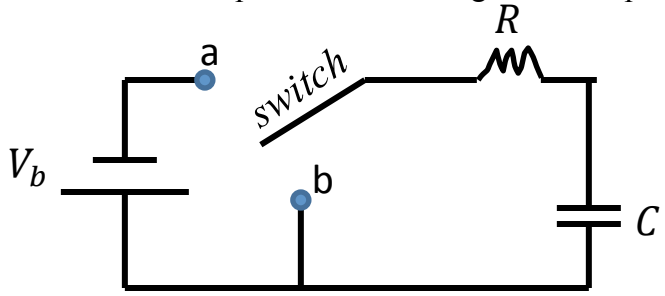
A. zero
B. $2kQ/R^2$
C. $kQ/2R^2$
D. $kQ/4R^2$

18. Imagine a plastic ball of radius R that has been given a total positive charge of Q that has somehow been uniformly distributed throughout its interior. The magnitude of the electric field at a distance of $\frac{1}{2}R$ from the ball's center is

A. zero
B. $kQ/4R^2$
C. $kQ/2R^2$
D. $4kQ/R^2$

19. Consider the circuit below. After the *switch* is thrown to position a the charge on the capacitor as a function of time is

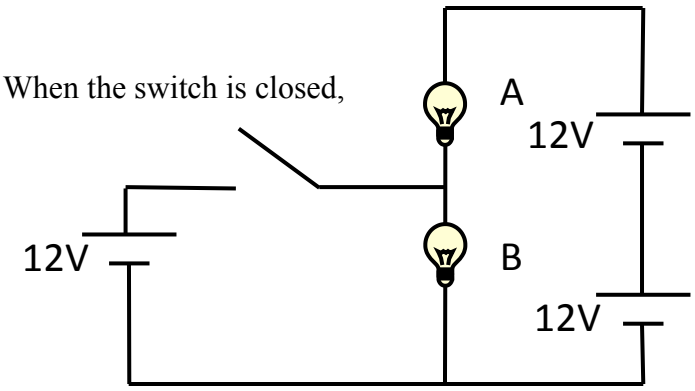
A. $Q_c = CV_b\left(1 + e^{-t/RC}\right)$
B. $Q_c = CV_b(1 - e^{-t/RC})$
C. $Q_c = CV_b\left(1 - e^{t/RC}\right)$
D. $Q_c = CV_b(1 - e^{-RC/t})$



20. Consider two wires with the same length. Wire A has a diameter half that of B but is otherwise identical. Both have the same electric field acting in them. How do the *currents* in these wires compare?

A. $I_A = 2I_B$
B. $I_A = I_B$
C. $I_B = 2I_A$
D. $I_B = 4I_A$

21. The light bulbs in the circuit are identical. When the switch is closed,



A. the intensity of light bulb A increases.
B. the intensity of light bulb A decreases.
C. the intensity of light bulb B increases.
D. the intensity of light bulb B decreases.
E. nothing changes.

22. A velocity selector uses crossed electric and magnetic fields to pass only charged particles of a certain velocity. If the magnetic field has a strength of $B = 0.01$ T, what electric field strength would pass ions having a speed of $0.01c$?

A. $3\times10^4\text{N/C}$
B. $3\times10^2\text{N/C}$
C. $1\times10^4\text{N/C}$
D. $3\times10^2\text{V/m}$
E. 3 V/m

23. Given that the Earth is, to an excellent approximation, a magnetic dipole, the intensity of cosmic rays (charged particles flying through outer space) bombarding its surface is greatest

A. at the poles
B. at mid-latitudes
C. at the equator
D. in St. Louis

24. A sinusoidal standing sound wave inside a tube that is open at both ends must fit between the tube's ends

A. An integer number of wavelengths
B. An integer number of half-wavelengths
C. An odd integer number of quarter-wave-lengths

25. A wave traveling on a Slinky that is stretched to 4m takes 2.4 s to travel the length of the Slinky. A standing wave which consists of three antinodes and four nodes is created on the Slinky. At what frequency must the Slinky be oscillating?

A. 0.208 Hz
B. 0.313 Hz
C. 0.625 Hz
D. 0.833 Hz

26. Imagine that sound waves with a certain definite wavelength flow through a partially opened sliding door. If the door is closed somewhat further (but not shut entirely), the angle through which the sound waves are diffracted

A. decreases.
B. increases.
C. remains the same.
D. depends on quantities not specified.

27. Three telescopes of the same diameter operate in different portions of the electromagnetic spectrum: infrared, visible, and radio. If diffraction effects limit their resolution, which telescope has the highest resolution?

A. Infrared telescope
B. Visible telescope
C. Radio telescope
D. All three telescopes have the same resolution

28. As a particle's speed approaches that of light, the difference between its relativistic momentum p and its relativistic energy E becomes small (compared to E), true or false?

A. True
B. False

29. Imagine that in Iceland, scientists discover geothermal vents that produce abundant pressurized steam with a temperature of $300^{\circ}\mathrm{C}$. Engineers construct a heat engine that uses this steam as a hot reservoir and a nearby glacier as a cold reservoir. What is the maximum possible efficiency of this engine?

A. 100%
B. 52%
C. 45%
D. 22%

30. Imagine that we place a $100-$gram aluminum block with an initial temperature of $100°\mathrm{C}$ in a Styrofoam cup containing a $100-$gram sample of water at $0°\mathrm{C}$. (The specific heats of aluminum and water are $900\mathrm{J\ kg^{-1}K^{-1}}$ and $4186\ \mathrm{J\ kg^{-1}K^{-1}}$, respectively.) The final temperature of the system will be closest to

A. $0°\mathrm{C}$
B. $20°\mathrm{C}$
C. $50°\mathrm{C}$
D. $80°\mathrm{C}$
E. $100°\mathrm{C}$

31. Imagine you have a bulb which emits light in all directions. Which scenario below gives the largest average energy density at the distance specified and thus, at least qualitatively, the best illumination

A. a 50 W bulb at a distance R.
B. a 100 W bulb at a distance 2R.
C. a 200 Watt bulb at a distance 4R.

32. A planar electromagnetic wave is propagating through space. Its electric field vector is given by $\vec{E} = E_0 \cos(kz - \omega t)\hat{x}$. Its magnetic field vector is

A. $\vec{B} = B_0 \cos(kz - \omega t)\hat{y}$
B. $\vec{B} = B_0 \cos(kz + \omega t)\hat{y}$
C. $\vec{B} = B_0 \cos(ky - \omega t)\hat{z}$
D. $\vec{B} = B_0 \cos(ky - \omega t)\hat{x}$
E. $\vec{B} = B_0 \cos(kz - \omega t)\hat{z}$

33. Imagine that in a certain region of space (which might be inside a charge or current distribution), a field has constant x and z components and y component proportional to $y2$. Is this a possible electric or magnetic field in this case?

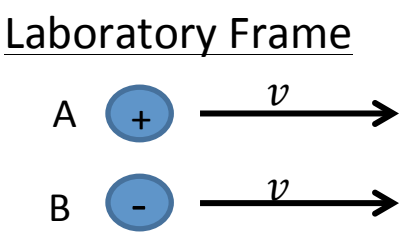
A. Possible elec. field; impossible mag. field
B. Possible mag. field; impossible elec. field
C. Possible elec. or mag. field
D. Impossible elec. or mag. field
E. We cannot answer the question with the information given.

34. Imagine that an atom has exactly two energy levels separated by some energy difference ΔE. When such atoms are in contact with a reservoir at a temperature T_1, the ratio of the number of atoms in the higher level to the number in the lower level is $1/4$. If we increase the temperature to T_2, the numerical value of this ratio

A. Increases
B. Decreases
C. Remains the same

35. Consider a beam of free particles that each have a certain (nonrelativistic) kinetic energy K. If we double this kinetic energy, what happens to the beam's de Broglie wavelength?

A. In increases by a factor of 2.
B. It increases by a factor of $\sqrt{2}$.
C. It decreases by a factor of $\sqrt{2}$.
D. It decreases by a factor of 2.



Use this figure for questions 36 and 37.

36. Two charged particles move with the same velocities in the laboratory frame, as shown above. In the laboratory frame, does particle A exert a magnetic force on particle B? If so, in what direction?

A. Yes, downward on B
B. Yes, upward on B
C. Yes, in the direction of B's motion
D. Yes, in the direction against B's motion
E. Particle B experiences no magnetic force in this frame.

37. Two charged particles move with the same velocities in the laboratory frame, as shown above. In the frame of the particles, does particle A exert a magnetic force on particle B? If so, in what direction?

A. Particle B experiences magnetic force toward Particle A.
B. Particle B experiences magnetic force away from Particle A.
C. Particle B experiences a magnetic force in the direction of its motion
D. Particle B experiences a magnetic force opposite the direction of its motion
E. Particle B experiences no magnetic force in this frame.

38. A famous detector for solar neutrinos utilized a huge vat of perchloroethylene ($Cl_2C = CCl_2$) to absorb neutrinos. If an atom of $^{37}_{17}Cl$ absorbs a neutrino, what will it become?

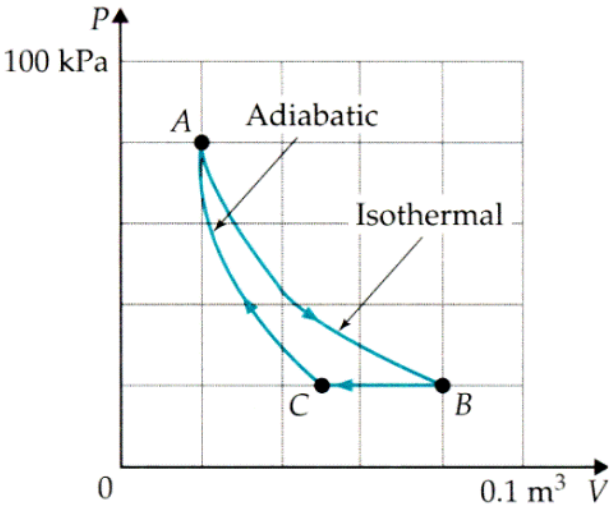
A. $^{38}_{17}Cl$
B. $^{37}_{16}S$
C. $^{37}_{18}Ar$
D. $^{36}_{18}Ar$

39. A certain radioactive substance emits quantized particles that, when placed in a magnetic field directed toward the observer, bend to the left side of their direction of travel. These radioactive nuclei are decaying via which kind of process?

A. An alpha decay process
B. A beta decay process
C. A gamma decay process
D. This is not a possible decay process

40. A jet flies in a region of the earth where the magnetic field points nearly straight upward. Which part of the airplane becomes negatively charged?

A. Its nose
B. Its tail
C. Its left wing
D. Its right wing



Use this figure for questions 41 and 42.

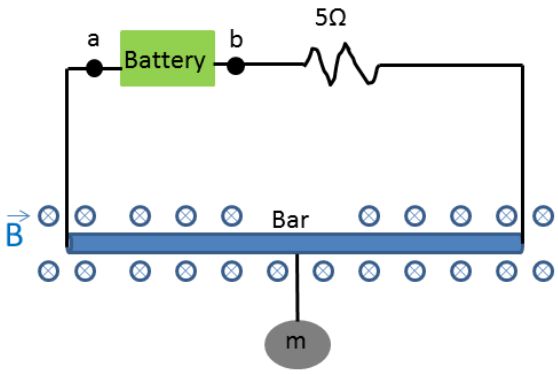
41. Is the work energy flowing into or out of the gas in process $B \rightarrow C$?

A. Into the gas
B. Out of the gas
C. There is no work energy going into or out of the gas during this process.

42. Which value is closest to the amount of work energy flowing into or out of the gas in process $B \rightarrow C$?

A. 0 J
B. 0.6 J
C. 300 J
D. 600 J
E. 1500 J

43. The picture to the right depicts a magnetic balance. The Bar (length $l = 0.6\text{m}$), suspended in a uniform magnetic field of 1.50T, is connected in series with a battery (variable voltage) and resistor (5Ω). The thin wires supporting the Bar can hold no appreciable tension, thus any weight on the Bar must be supported by the magnetic force on the Bar. What is the greatest mass this balance can measure if $V_{max} = 175\text{V}$?



A. 1.43 kg
B. 3.21 kg
C. 87.4 kg
D. 16.1 kg

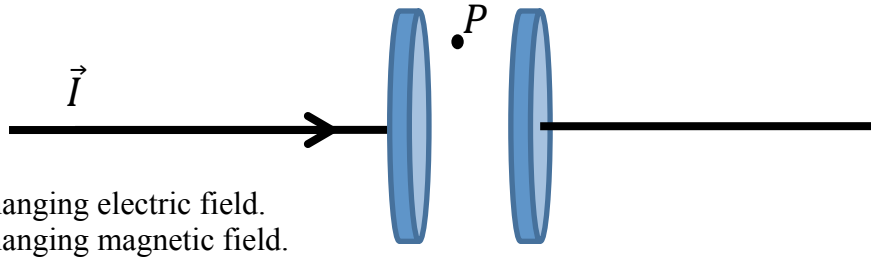
44. $^{235}_{92}$U (uranium) could decay to $^{206}_{82}$Pb (lead) by appropriate combination of alpha and beta decay processes, True or False?

A. True
B. False

45. Imagine that within a certain region of space, a magnetic field points entirely in the $+y$ direction but has a magnitude that increases as x increases. The curl of this field

A. must be zero.
B. must have a positive x component.
C. must have a positive y component.
D. must have a positive z component.
E. must have a negative component in some direction.

46. As the capacitor shown below is charged with a constant current I, at point P there is a



A. changing electric field.
B. changing magnetic field.
C. changing electric field and a magnetic field.
D. changing magnetic field and an electric field.
E. I don't know.

47. Two electrons are placed into separate (very thin) one-dimensional boxes A and B. When the electrons are excited to higher energy levels and then decay to lower levels, they emit photons. The longest-wavelength spectral line from the electron in box A is observed to have the same wavelength as the third-longest spectral line from the electron in box B. If the lengths of the boxes are L_A and L_B, respectively, then this observation implies that L_A/L_B is equal to

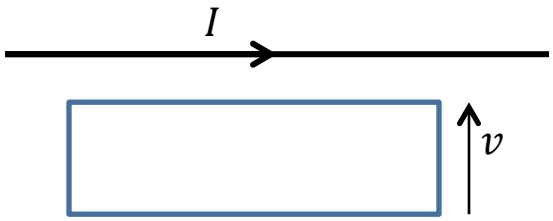
A. $3/7$
B. $7/3$
C. $\sqrt{3/7}$
D. $\sqrt{7/3}$

48. Imagine that we have a beam of quantum particles that have spin $s = 5/2$. If we evaluate the component of the particles' spin along a certain axis, how many results might we get?

A. 11
B. 8
C. 6
D. 5
E. 1

49. A conducting rectangular loop is moving relative to a long, straight current-carrying wire. What is the direction of the induced current in the rectangular loop?

A. Counterclockwise
B. Clockwise
C. There is no induced current



50. A conducting rectangular loop is moving relative to a long, straight current-carrying wire. What is the direction of the induced current in the rectangular loop?

A. Counterclockwise
B. Clockwise
C. There is no induced current