Two conducting spheres (1 and 2) have equal charge (Q) and exert a force $F$ on one another. A third sphere, which is identical to the first two but is Uncharged, is touched to sphere 1 then to sphere 2.

Which of the following is true about the new force $F'$ the two spheres exert on one another (compared to the old force $F$) ?

1) It is larger
2) It is the same
3) It is the smaller
Explanation:

The answer is 3. Sphere 3 is uncharged; when it is touched to sphere 1, it takes some of the charge from sphere 1. As the two spheres are identical in size and shape, the charge splits evenly between the two. So now sphere 1 has $Q/2$ and sphere 3 has $Q/2$. Now sphere 3 is touched to sphere 2; once again the charged is evenly split between the two as they are identical spheres. The total charge between sphere 2 and sphere 3 is $3Q/2$ (thanks to the $Q/2$ on sphere 3), resulting in $3Q/4$ on both spheres 2 and 3 after they have touched. After sphere 3 is removed, sphere 2 is left with $3Q/4$ while sphere 1 is left with $Q/2$. So both sphere 1 and sphere 2 now have less charge on them than before, and the force is therefore less than before.
A positively charged rod is held close to an uncharged conducting object. The conducting object is then “grounded”, the ground connection the removed, and then the rod is taken away. What is the final state of the conducting object?

[1.] Uncharged

[2.] Charged positively

[3.] Charged negatively

[4.] Uncharged, but polarized
Explanation:

The answer is 3. The conducting object is first polarized, but by grounding it we have allowed the positive charges on the far side of the object to escape (they are repelled by the rod and get as far away from it as possible). Therefore the object is left with a net negative charge. Note that this only works if you unground the object before removing the rod (do you understand why?).
A positively charged rod is held close to a freely hanging uncharged pithball.

Which of the following is true:

[1.] The rod exerts no force on the pithball
[2.] The rod repels the pithball
[3.] The rod attracts the pithball
Explanation:

The answer is 3. The pithball polarizes due to the presence of the rod (minus charges move to the left face and plus charges to the right face), because the force drops off with distance, the attractive interaction between the plus charges on the rod and the minus charges on the left side of the pithball is stronger than the repulsive force between the plus charges on the right side of the pithball and the positive charge on the rod.
A charge with value \( +q' \) is placed at the center of a square which has six charges arranged on its perimeter as shown.

In which direction is the force on the charge \( +q' \)?

[1.] along OA
[2.] along OC
[3.] along OB
[4.] along OD
Explanation:

The answer is 1. The arrangement of charge is symmetric about the line AC; therefore the force has to be along this axis. All of the charges repel $q'$; but there is more positive charge behind $q'$ than in front of it (along AC). So, the force is along OA.
Two charges, \( A \) and \( B \), have the following Electric field line pattern associated with them.

Which of the following is true?

1. \( A = +, B = -, |A| < |B| \)
2. \( A = -, B = +, |A| < |B| \)
3. \( A = -, B = +, |A| > |B| \)
4. \( A = +, B = -, |A| > |B| \)
Explanation:

The answer is 2. Field lines start on positive charges and end on negative charges. When drawing field lines, the number of field lines coming from a particular charge is proportional to the charge.
A particle with charge $-Q$ is traveling with velocity $v$ towards a region of uniform, downward directed electric field, as shown below.

Which of the following trajectories best represents the path the particle will take?
Explanation:

The answer is 1. The trajectory should be parabolic (like the particle was falling due to the influence of gravity). The particle has negative charge; thus it will experience a force in the direction opposite to the direction in which the electric field points. So the charge will go upward, with a parabolic orbit.
The figures below represent a dipole placed in an electric field at a certain orientation.

In which of the above figures is the net force on the dipole equal to zero?

[1.] a, b, c, and d
[2.] a and c only
[3.] b and d only
[4.] a and b only
[5.] c and d only
[6.] c only
Explanation:

The answer is 5. The net force on a dipole is zero when the field is uniform.
A cow stands near a tree struck by lightning as shown. Will the cow be killed?

1) YES  2) NO  3) Can’t tell
Correct answer: 1

After reaching the ground, the lightning current spreads out and runs partially horizontal. If a cow stands as shown in the figure an appreciable amount of the ground current enters the front legs and exits from the rear legs, electrocuting the cow.

If you are caught outside during a thunderstorm, you should not lie down. If a strike hits nearby, the resulting electrical potential between your head and your feet may draw enough of the ground currents to kill you. Since you also should not stand up, the best position is to squat. That way you keep your head low while minimizing the contact area with the ground.
What is the total flux leaving a shown Gaussian surface around the electric dipole?

1) $Q$
2) $2Q$
3) 0
Correct answer is 3)

The electric flux leaving the closed surface corresponds to
The total charge enclosed, which is \(+Q - Q = 0\)
Using Gauss’s law, what can you say about the electric field produced by the dipole at point P?

1) Is is 0
2) It points radially outwards
3) It points upwards
4) It points downwards
Correct answer is 4:

There is no spherical symmetry and thus the electric field lines do not point radially outwards. While the total flux through the spherical Gaussian surface is still 0 we can not apply Gauss’s Law to conclude that E must be zero 0.

The electric field of a dipole depends both on $\theta$ and r and points in the $-\theta$ direction at point P (downwards).
A particle (mass m, charge -q) is projected with speed $v_0$ into the region between two parallel plates as shown. The potential difference between the two plates is $V$ and their separation is $d$. The change in kinetic energy of the particle before and after it has traversed this region is:

1. $qV/d$
2. $mv_0^2/2$
3. $qVd$
4. $qV$
5. $qVd$
The correct answer is 4:

Potential is defined as $V = \frac{W}{q}$ (work per charge). Since all work is converted into kinetic energy the change of kinetic energy is $W = qV$
Points A and B lie in between two large plates, one charged positively and the other charged negatively.

If I insert a slab of conducting material as shown below, what happens to the absolute value of the potential difference between points A and B?

[1.] Increases
[2.] Decreases
[3.] Stays the same
[4.] No way to tell
Explanation:

**The answer is 2.** By inserting the conductor, the electric field becomes zero in the region where the conductor is but does not change elsewhere. So, when I integrate the electric field between points A and B, I get a smaller absolute value (you can think of this as $d$ changing in $-Ed$ – you don’t include the length inside the conductor because the field there is zero).
Which of the following charge distributions would require the least amount of work to assemble (assuming all charges start at infinity)?

1

2

3

4
Explanation:

The answer is 2. The work required to bring opposite charges together is negative (you don’t have to do any work, the particles attract one another anyway). The work required to bring like charges together is positive (you have to work to overcome their mutual repulsion. The value of the work released or required in these two cases depends on how close you bring the charges. So, the closer together you bring like charges, the more work required. The closer together you bring unlike charges, the more energy is released. So, to minimize the work required to assemble a set of charges, you want to minimize the distance between opposite charges and maximize the distance between like charges. The only situation where the distance between opposite charges is anywhere close to the distance between like charges is in case 2. The other cases have large number of like charges close to each other, with unlike charges much further away. Therefore 2 is the lowest energy to assemble.
Two large conducting plates are given equal but opposite charge \((Q)\), and are separated by a distance \(d\).

If I pull the plates apart so that they are now separated by a distance \(2d\), what happens to the potential difference between the two plates?

[1.] stays the same

[2.] increases

[3.] decreases
Explanation:

The answer is 2. When you pull the plates apart, the electric field does not change. The potential difference is $E \Delta x$, where $\Delta x$ is the distance between the two plates. Since $E$ is constant, the potential difference increases when we increase $\Delta x$. 
Two large conducting plates are separated by a distance $d$ and are held at a constant potential difference $\Delta V$ using a battery.

If I pull the plates apart so that they are now separated by a distance $2d$, what happens to the value of the charge on the plates?

[1.] stays the same

[2.] increases

[3.] decreases
Explanation:

The answer is 3. Here the potential difference on the plates is held fixed (you can think of this in the following way: you are pushing charge onto the plates with a constant force). As I separate the plates, in order for the potential difference to be the same \((-Ed\)) , the electric field must decrease, which means that \(\sigma\) must decrease, or the charge must decrease.
Two large conducting plates are separated by a distance $d$ and have equal but opposite charge $Q$.

I now imagine a different set of conducting plates, each with area twice as large as the area of the first set of conducting plates, but with the same charge $Q$. How will the potential difference between the larger parallel plates compare with the potential difference of the first (smaller) set?

[1.] the same
[2.] larger
[3.] smaller
Explanation:

The answer is 3. Given the same amount of charge, the charge will spread itself out on the larger plates, resulting in a smaller charge density and a smaller electric field. The distance between the plates does not change, so since $E$ goes down, the potential difference decreases also.
Three capacitors with equal capacitance $C$ are arranged in the four configurations shown below. Which configuration would result in the most charge on the plates of the capacitors, if a voltage $V$ is applied?
Explanation:

The answer is 2. All three in parallel will result in the largest equivalent capacitance; this will result in the most charge on the plates \((Q = C_{eq}V)\).
Consider two capacitors, each having plate separation $d$. In each case, a metal slab of thickness $d/3$ is inserted between the plates. In case (a) the metal slab is not connected to either plate. In case (b) it is connected to the upper plate.

The capacitance is larger in:

[1.] Case (a)
[2.] Case (b)
[3.] Both are the same
Explanation:

The correct answer is 2. Case (a) is like two capacitors (each with separation $d/3$) in series. If each has capacitance $C$, then the equivalent capacitance of case (a) is $C/2$. In case (b), we effectively short out the first capacitor, and we are left with only one capacitor (the bottom one). In this case, the capacitance is $C$, and is larger than in case (a).
A cylindrical wire with resistivity $\eta$ has length $L$ and cross-sectional area $A$. I apply a voltage across the wire and current $I$ flows. I then cut the wire in half crosswise (changing $L$), and apply the same voltage. How does the current which flows in this case compare with before I made the cut?

[1.] Larger

[2.] Smaller

[3.] the same
Explanation:

The correct answer is 1. When we shorten the length of the resistor, the resistance decreases. Given that we apply the same voltage, the current must increase.
A battery of voltage $V$ is attached across a cylindrical wire resistor of length $L$ and cross-sectional area $A$, a current $I$ flows. If I double the area of the resistor (but attach it to the same battery), what happens to the drift velocity of electrons ($v_d$) in the new resistor?

[1.] $v_d$ decreases

[2.] $v_d$ stays the same

[3.] $v_d$ increases

[4.] not enough information to answer
Explanation:

The correct answer is 2. When I increase the area of the resistor, the total resistance decreases and the current increases. However, the electric field in the resistor does not change (same potential applied over the same length). Therefore the drift velocity of the electrons does not change. The current increases because the area increases (i.e. $j$ stays the same).
Cosmic rays (atomic nuclei stripped bare of their electrons) would continuously bombard Earth’s surface if most of them were not deflected by Earth’s magnetic field. Given that Earth is, to an excellent approximation, a magnetic dipole, the intensity of cosmic rays bombarding its surface is greatest at the

1) Poles  
2) mid-latitudes  
3) equator
Correct answer: 1

Assuming that the cosmic ray particles have velocities directed radially toward Earth, the particles suffering the least deflection approach Earth via its poles because it is here that the magnetic field lines most nearly point in the radial direction.
When the switch is closed, the potential difference across R is?

1) \( \frac{V N_2}{N_1} \)
2) \( \frac{V N_1}{N_2} \)
3) \( V \)
4) Zero
5) No way to tell
Correct answer: 4

Because the input is connected to a constant voltage source no potential difference is induced in the secondary coil.
A cylindrical conductor with radius $R_1$ is surrounded by a second conductor of inner radius $R_1$ and outer radius $R_2$. A current $I$ flows through the inner conductor into the board and out of the board in the outer conductor.

Which graph best represents $B(r)$?
The correct answer is 3:

According to Ampere’s law, integrating H along a closed loop just outside R2 will be zero, since the total enclosed current is \(+I - I = 0\).

Inside the inner conductor the enclosed current increases as \(r^2\) and thus the magnetic field as \(r\).
A current I flows through this hollow cylindrical conductor into the board. Which graph best represents the Magnetic field B(r)?
The correct answer is 2:

Imagine a closed circular loop just inside the inner surface of the conductor. According to Ampere’s law the enclosed current is 0 and thus $\mathbf{H}$ must be zero. Outside the outer surface of the cylinder $\mathbf{H}$ decreases as $1/r$. 
Which graph best represents the magnetic field $B(r)$ in the coaxial shown here?
The correct answer is 2:
The drawing below shows magnetic field surrounding a loop of wire (wire is black, field is drawn gray).

The arrow in this drawing indicates the direction of:

[1.] positive current flow
[2.] electron flow in the wire
[3.] neither
Explanation:

The answer is 1. Using the right hand rule, if I point my thumb in the direction of the arrow in the drawing, then my fingers correctly give the sense of rotation of the field around the wire. Therefore the arrow must point in the direction of positive current flow (which is OPPOSITE the direction of electron flow).
An unknown charged particle is moving with velocity \( \vec{v} \) as shown. It enters a region of constant magnetic field, pointing out of the page, and is deflected as shown.

What is the sign of the charge of this particle?

[1.] positive
[2.] negative
[3.] cannot be determined
Explanation:

The answer is 2. The force on this particle is:

\[ F = qv \times B \]

The velocity is to the right and the field is out of the page. The cross product of these two points downward. The particle is seen to move upwards, this means that the charge must be negative.
The orbits of two particles, $A$ and $B$, in a uniform magnetic field are sketched below.

If they have equal mass and velocity but differing charge (both positive), which particle has the larger charge?

[1.] $A$

[2.] $B$

[3.] cannot be determined
Explanation:

The answer is 1. The gyroradius of a particle (the radius of its circular orbit in a uniform magnetic field) is:

\[ r_g = \frac{mv}{qB} \]

The particle executing the larger circular orbit will therefore have smaller charge \( q \).
A long cylindrical wire carries current $I$ upward, as shown below.

If I place an electron a distance $d$ from the wire as shown and release it what happens?

[1.] The electron begins circling the wire (clockwise looking down from above)

[2.] The electron begins circling the wire (counterclockwise looking down from above)

[3.] The electron starts moving toward the wire (in the plane of the page)

[4.] The electron starts moving away from the wire (in the plane of the page)

[5.] Nothing happens
Explanations:

**The correct answer is 5.** There is no force on the electron in this case. There is a magnetic field due to the current in the wire, but the electron is at rest, so it feels no force due to the magnetic field.
Two parallel wires have current flows +I and -I as shown in the figure.

What can you say about the force between the wires?

1) They will repel each other  
2) They will attract each other 
3) Nothing will happen 
4) Not enough information to answer
Correct answer: 1

The left wire will produce a magnetic field in the right wire that points out of the boards. A positive current flow will thus result in a force towards the right that is transferred onto the wires.
An electron is released from rest at the point shown below; between two charged plates, in a region of uniform field (out of the page). Which of the shown trajectories best represents the actual path taken by the electron?
The correct answer is 2. When initially at rest, the particle only felt the electric force, and was accelerated toward the positive plate, so $v$ was initially to the right. But as it gained velocity, the magnetic force, $qv \times B$, exerted a perpendicular acceleration, changing its direction of motion. Since $B$ is out of the page, the cross product, $v \times B$, is downward, but for a negatively charged particle, the deflection is upward. The magnetic force is always perpendicular to the velocity, so the trajectory must be curved.
A rectangular loop is placed in a uniform magnetic field with the plane of the loop perpendicular to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:

1. a net force.
2. a net torque.
3. a net force and a net torque.
4. neither a net force nor a net torque.
Explanation:

The answer is 4. Because the field is uniform, we know that the dipole (loop) experiences no net force. The dipole will only experience a net torque if the sine of the angle between the dipole moment vector and the field is non-zero. In this case, the dipole moment of the loop points along $\mathbf{B}$, and there is no net torque. You can also check this by finding the direction of the force on the loop at different points along the loop (right hand rule). In this case, the force points outward radially at all points on the loop (the magnetic field wants to stretch the loop out). These forces do not result in rotating the loop; hence the torque has to be zero.
A rectangular loop is placed in a uniform magnetic field with the plane of the loop parallel to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:

1. a net force.
2. a net torque.
3. a net force and a net torque.
4. neither a net force nor a net torque.
Explanation:

The answer is 2. Because the field is uniform, we know that the dipole (loop) experiences no net force. The dipole will only experience a net torque if the sine of the angle between the dipole moment vector and the field is non-zero. In this case, the dipole moment of the loop points perpendicular to $\mathbf{B}$, and therefore there is a torque. You can also check this by finding the direction of the force on the loop at different points along the loop (right hand rule). In this case, the force points into the page at the top of the loop and out of the page on the bottom of the loop (and is zero on the other two sides of the loop). Thus there is a tendency to rotate, and the torque is not zero.
Which of Maxwell’s equations can be used, along with a symmetry argument, to calculate the electric field of a point charge?

1. \( \oint \vec{E} \cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t} \)

2. \( \oint \vec{E} \cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t} \)

3. \( \oint \vec{B} \cdot d\vec{A} = \mu_0 I \)

4. \( \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0} \)

5. \( \oint \vec{B} \cdot d\vec{A} = 0 \)
Correct answer: 4 (Gauss law)

Explanation:

Maxwell equation, \( \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0} \), comes from Gauss’s Law and can be used to calculate the electric field of a point charge.

\[
\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0} \\
E \oint d\vec{A} = \frac{Q}{\varepsilon_0} \\
E \left(4\pi r^2\right) = \frac{Q}{\varepsilon_0} \\
E = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r^2},
\]

where \( \oint d\vec{A} = 4\pi r^2 \) is the surface area of a sphere of radius \( r \). The equation is also known as Coulomb’s Law.
Which of Maxwell’s equations can be used, along with a symmetry argument, to calculate magnetic field produced by a uniform time-varying electric field?

1. \[ \oint \vec{B} \cdot d\vec{s} = 0 \]

2. \[ \oint \vec{B} \cdot d\vec{A} = \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t} \]

3. \[ \oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t} \]

4. \[ \oint \vec{E} \cdot d\vec{A} = -\frac{\partial \Phi_B}{\partial t} \]

5. \[ \oint \vec{E} \cdot d\vec{s} = -\frac{\partial \Phi_B}{\partial t} \]
The correct answer is 3

To calculate the magnetic field produced by a uniform time-varying electric field, we can simply use \[ \oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t}. \]
Which of Maxwell’s equations can be used, along with a symmetry argument, to calculate that magnetic field lines form closed loops?

1. \[ \int \vec{B} \cdot d\vec{s} = 0 \]

2. \[ \int \vec{B} \cdot d\vec{A} = \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t} \]

3. \[ \int \vec{B} \cdot d\vec{A} = \mu_0 I \]

4. \[ \int \vec{E} \cdot d\vec{s} = \frac{Q}{\varepsilon_0} \]

5. \[ \int \vec{B} \cdot d\vec{A} = 0 \]
Correct answer is 5:

Unlike the electric field produced by point charge(s), the magnetic field lines form closed loops and always give a zero on the right hand side of Maxwell equation $\oint \vec{B} \cdot d\vec{A} = 0$. 
Which of Maxwell’s equations can be used, along with a symmetry argument, to calculate the magnetic field of a long straight current-carrying wire?

1. $\phi \mathbf{B} \cdot d\mathbf{s} = 0$

2. $\phi \mathbf{B} \cdot d\mathbf{A} = \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t}$

3. $\phi \mathbf{B} \cdot d\mathbf{A} = \mu_0 I$

4. $\phi \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t}$

5. $\phi \mathbf{B} \cdot d\mathbf{A} = 0$
Correct answer is 4

Explanation:
Here we just use Ampere’s Law, namely
\[ \oint \vec{B} \cdot d\vec{s} = \mu_0 I. \]
Which of Maxwell’s equations can be used, along with a symmetry argument, to calculate electric field produced by a uniform time-varying magnetic field?

1. $\oint \vec{B} \cdot \, d\vec{s} = 0$
2. $\oint \vec{E} \cdot \, d\vec{s} = -\frac{\partial \Phi_B}{\partial t}$
3. $\oint \vec{B} \cdot \, d\vec{A} = \mu_0 I$
4. $\oint \vec{E} \cdot \, d\vec{s} = \frac{Q}{\varepsilon_0}$
5. $\oint \vec{B} \cdot \, d\vec{s} = \mu_0 I + \mu_0 \varepsilon_0 \frac{\partial \Phi_E}{\partial t}$
Correct answer: 2

Faraday's Law, \( \int \vec{E} \cdot d\vec{s} = - \frac{\partial \Phi_B}{\partial t} \),
can be used here to calculate the electric field produced by a uniform time-varying magnetic field.
A circular loop of wire is positioned half in and half out of a square region of uniform B field directed into the page.

To induce a clockwise current in this loop you must:

1. Move it in +x direction
2. Move it in -x direction
3. Move it in +z direction
4. Increase the strength of B
5. Decrease the strength of B
Correct answer: 1 and 5

According to the right and rule: moving a positive charge sitting on the left side of the loop in the -x direction with a field in the -z direction will produce a force in the -y direction (downwards). Since there is no field on the right side
Maxwell’s equations predict that the speed of light in Vacuum is

1) Greater for visible light than for radio waves
2) Greater for radio waves than for visible light
3) Independent of frequency
4) A function of the distance from the source
5) A function of the size of the source
Correct answer: 3

Application of Faraday’s law and Ampere’s law to EM Radiation results in the prediction that the speed of light is

\[ c = \frac{1}{\left(\varepsilon_0 \mu_0\right)^{1/2}} \]

Independent of frequency.