PRS Questions: Fields

Class 1
The above vector field is created by:

1. Two sources (equal strength)
2. Two sources (top stronger)
3. Two sources (bottom stronger)
4. Source & Sink (equal strength)
5. Source & Sink (top stronger)
6. Source & Sink (bottom stronger)
7. I don’t know
(3) Two sources, bottom stronger

Both sources because lines leaving one don’t enter the other. Bottom is stronger because it “pushes” further
The force between the two charges is:
1) Attractive
2) Repulsive
3) Can’t tell without more information
(2) Repulsive

One way to tell is to notice that they both must be sources (or sinks). Hence, as like particles repel, the force is repulsive.

You can also see this as tension in the field lines
Here there is an initial downward flow.

1. The point is a source
2. The point is a sink
3. I don’t know
(1) Source

It’s a source, because otherwise the downward flow would flow right into it.

NOTE: If the background were upward, then it would be just flowing right into it, so it would be a sink.
The “grass seeds” field plot above is a representation of the vector field:

1. \( \vec{F}(x, y) = x^2 \hat{i} + y^2 \hat{j} \)
2. \( \vec{F}(x, y) = y^2 \hat{i} + x^2 \hat{j} \)
3. \( \vec{F}(x, y) = x \hat{i} + y \hat{j} \)
4. \( \vec{F}(x, y) = -y \hat{i} + x \hat{j} \)
5. NOT SURE
Answer: 3. \( \vec{F}(x, y) = x \hat{i} + y \hat{j} \)

At any point in space the vector function given above points away from the origin, so 3 is the correct answer.
The “grass seeds” field plot above is a representation of the vector field:

1. \( \vec{F}(x, y) = x^2 \hat{i} + y^2 \hat{j} \)
2. \( \vec{F}(x, y) = y^2 \hat{i} + x^2 \hat{j} \)
3. \( \vec{F}(x, y) = x \hat{i} + y \hat{j} \)
4. \( \vec{F}(x, y) = -y \hat{i} + x \hat{j} \)
5. NOT SURE
Answer: 4. \( \mathbf{F}(x, y) = -y \mathbf{i} + x \mathbf{j} \)

Along the positive x-axis the grass seed textures are vertical. This means \( \mathbf{F} \) has only a \( y \) component along this axis, which means either answer 2 or 4. The answer must be 4 because 2 will give a positive \( x \)-component on the positive \( y \)-axis, and that component must be -. 
PRS Questions: Electric Fields

Class 2
Two opposite charges are placed on a line as shown below. The charge on the right is three times larger than the charge on the left. Other than at infinity, where is the electric field zero?

1. Between the two charges
2. To the right of the charge on the right
3. To the left of the charge on the left
4. The electric field is nowhere zero
(3) Zero is left of $q_L$

In between the charges the field is always from source to sink.

To the right of $q_R$, the field is dominated by $q_R$ (bigger & closer)

On the left, because the charge on the left is weaker, its “push” to its left will somewhere be balanced by $q_R$’s “pull” to the right
E-Field of Two Equal Charges

Electric field at point P is:

1. \( \vec{E}_1 = \frac{2k_eqs}{\left[s^2 + \frac{d^2}{4}\right]^{3/2}} \hat{j} \)

2. \( \vec{E}_2 = -\frac{2k_eqd}{\left[s^2 + \frac{d^2}{4}\right]^{3/2}} \hat{i} \)

3. \( \vec{E}_3 = \frac{2k_eqd}{\left[s^2 + \frac{d^2}{4}\right]^{3/2}} \hat{j} \)

4. \( \vec{E}_4 = -\frac{2k_eqs}{\left[s^2 + \frac{d^2}{4}\right]^{3/2}} \hat{i} \)

5. Don’t Know
E-Field of Two Equal Charges

There are a several ways to see this. For example, consider $d \to 0$. Then,

$$\vec{E} \to k_e \frac{2q}{s^2} \hat{j}$$

which is what we want (sitting above a point charge with charge $2q$).
Negative Charge

Place a negative charge in an electric field. It will move from
1. higher to lower electric potential and from lower to higher potential energy
2. higher to lower electric potential and from higher to lower potential energy
3. lower to higher electric potential and from lower to higher potential energy
4. lower to higher electric potential and from higher to lower potential energy
Negative Charge

(4) From lower to higher potential and higher to lower potential energy

Objects always move to reduce their potential energy. Negative charges do this by moving towards a higher potential:

\[ U = qV \]
PRS Questions: Electric Potential

Class 4
Potential and Energy

Which is true?
I. It takes positive work to bring like charges together.
II. Electric field lines always point in the direction of decreasing electric potential.
III. If a negative charge moves in the direction of the electric field, its electric potential energy decreases.

1. II only.
2. II and III only.
3. I, II and III.
4. I and II only.
5. I only.
Potential and Energy

(4) I and II Only

I. It takes positive work to bring like charges together. TRUE

II. Electric field lines always point in the direction of decreasing electric potential. TRUE

III. If a negative charge moves in the direction of the electric field, its electric potential energy decreases. FALSE – potential decreases so potential energy increases ($U = qV$)
Two Point Charges

The work done in moving a positive test charge from infinity to the point P midway between two charges of magnitude $+q$ and $-q$:

1. is positive.
2. is negative.
3. is zero.
4. can not be determined since not enough information is given.
5. I don’t know
Two Point Charges

(3) Work from \( \infty \) to \( P \) is zero

The potential at \( \infty \) is zero. The potential at \( P \) is zero because equal and opposite potentials are superimposed from the two point charges (remember: \( V \) is a scalar, not a vector)
The graph above shows a potential V as a function of x. The magnitude of the electric field for x > 0 is

1. larger than that for x < 0
2. smaller than that for x < 0
3. equal to that for x < 0
4. I don’t know
(2) The electric field for $x > 0$ is smaller than that for the electric field for $x < 0$ because the slope of the potential is smaller in the region $x > 0$ as compared to $x < 0$. **Translation:** The hill is steeper on the left than on the right.
The graph above shows a potential V as a function of x. Which is true?

1. \( E_x > 0 \) is \( > 0 \) and \( E_x < 0 \) is \( > 0 \)
2. \( E_x > 0 \) is \( > 0 \) and \( E_x < 0 \) is \( < 0 \)
3. \( E_x > 0 \) is \( < 0 \) and \( E_x < 0 \) is \( < 0 \)
4. \( E_x > 0 \) is \( < 0 \) and \( E_x < 0 \) is \( > 0 \)
5. I don’t know
(2) The electric field for $x > 0$ is in the positive $x$-direction, because as $x$ decreases for $x > 0$ the potential increases, which can only happen if the electric field opposes movement to smaller $x$ for $x > 0$. **Translation:** “Downhill” is to the left on the left and to the right on the right.
E Field from Slab

A positively charged, semi-infinite flat slab has thickness D.

The z-axis is perpendicular to the sheet, with center at \( z = 0 \).

At the plane’s center (\( z = 0 \)), \( \mathbf{E} \)
1. points in the positive z-direction
2. points in the negative z-direction
3. is zero
4. I don’t know
E Field from Slab

(3) At the center of the slab the electric field is 0.

Symmetry tell us this – the amount of charge above and below the center of the plane is equal hence the fields cancel.

Another way of saying this is that since you don’t know which way the field would point it must be 0.
E Field from Slab

A positively charged, semi-infinite flat slab has thickness D. The z-axis is perpendicular to the sheet, with its center at \( z = 0 \).

\[ \begin{array}{c}
\text{D} \\
\downarrow \\
\rho \\
\uparrow \end{array} \]

A distance \( z \) from its central plane,

1. \( E \) is constant
2. \( E \propto \frac{1}{z^2} \)
3. \( E \propto \frac{1}{z} \)
4. \( E \propto z \)
5. I don't know
E Field from Slab

(4) $E$ is proportional to $z$ inside the slab.

As you move away from the center, an imbalance is generated in the amount of charge below you and the amount above you. This imbalance grows linearly with $z$, and is what leads to the $E$ field that you see.

Once outside the slab, the imbalance stops changing so the field is constant.
PRS Questions:
Electric Dipoles

Class 4
Torque On A Dipole

An dipole is placed in an external field. In which situation(s) is the net torque on the dipole zero?

1. (a)
2. (c)
3. (b) and (d)
4. (a) and (c)
5. (c) and (d)
6. Don’t know
Torque On A Dipole
A dipole is placed in an external field. In which situation(s) is the net torque on the dipole zero?

Answer: 4. (a) and (c). An electric dipole in an electric field experiences a net torque only if it is at an angle to the direction of the external electric field. If it is parallel or anti-parallel to the field it feels no net torque.
Force On A Dipole

An dipole is placed in an external field. In which situation(s) is the net force on the dipole zero?

1. (a)
2. (c)
3. (b) and (d)
4. (a) and (c)
5. (c) and (d)
6. Don’t know
Force On A Dipole
An dipole is placed in an external field. In which situation(s) is the net force on the dipole zero?

Answer: 5. (c) and (d). An electric dipole in a uniform electric field experiences zero net force, and the field is uniform in (c) and (d).
PRS Questions: Conductors

Class 7
Hollow Conductors

A point charge +Q is placed at the center of the conductors. The induced charges are:

1. \( Q(I1) = Q(I2) = -Q; \)
   \( Q(O1) = Q(O2) = +Q \)

2. \( Q(I1) = Q(I2) = +Q; \)
   \( Q(O1) = Q(O2) = -Q \)

3. \( Q(I1) = -Q; \) \( Q(O1) = +Q \)
   \( Q(I2) = Q(O2) = 0 \)

4. \( Q(I1) = -Q; \) \( Q(O2) = +Q \)
   \( Q(O1) = Q(I2) = 0 \)
Hollow Conductors

(1) The inner faces are negative, the outer faces are positive.

Looking in from each conductor, the total charge must be zero (this gives the inner surfaces as $-Q$). But the conductors must remain neutral (which makes the outer surfaces have induced charge $+Q$).
Hollow Conductors

A point charge $+Q$ is placed at the center of the conductors. The potential at $O_1$ is:

1. Higher than at $I_1$
2. Lower than at $I_1$
3. The same as at $I_1$
Hollow Conductors

(3) O1 and I1 are at the same potential

A conductor is an equipotential surface. O1 and I1 are on the same conductor, hence at the same potential.
Hollow Conductors

A point charge $+Q$ is placed at the center of the conductors. The potential at $O_2$ is:

1. Higher than at $I_1$
2. Lower than at $I_1$
3. The same as at $I_1$
Hollow Conductors

(2) O2 is lower than I1

As you move away from the positive point charge at the center, the potential decreases.
Hollow Conductors

A point charge \( +Q \) is placed at the center of the conductors. If a wire is used to connect the two conductors, then positive charge will flow

1. From the inner to the outer conductor
2. From the outer to the inner conductor
3. Not at all
Hollow Conductors

(1) Positive charge flows outward

Positive charges always flow “downhill” – from high to low potential. Since the inner conductor is at a higher potential the charges will flow from the inner to the outer conductor.
Hollow Conductors

A point charge $+Q$ is placed at the center of the conductors, and a wire connects the two. If the wire and then the charge are removed, the potential at inner conductor is

1. Higher than at the outer conductor
2. Lower than at the outer conductor
3. The same as at the outer conductor
Hollow Conductors

(2) The inner conductor is now at a lower potential

With the positive charge in the center and a wire connecting the two conductors, positive charge will flow outwards, leaving a net negative charge on the inner conductor when the wire is removed.

Thus when the +Q is removed the inner sphere is at a lower potential.
PRS Questions: Capacitance

Class 7
Changing C Dimensions

A parallel-plate capacitor has plates with equal and opposite charges, separated by a distance \( d \). The capacitor is not connected to a battery.

Suppose the plates are pulled apart until separated by a distance \( D > d \). Does the potential difference between the plates:

1. Increase
2. Decrease
3. Stay the same
Changing C Dimensions

(1) Potential Increases

The electric field doesn’t change when you change the distance between the plates, so:

\[ V = E \cdot d \]

As \( d \) increases, \( V \) increases.
Changing C Dimensions

A parallel-plate capacitor, disconnected from a battery, has plates with equal and opposite charges, separated by a distance $d$. Suppose the plates are pulled apart until separated by a distance $D > d$. How does the final electrostatic energy stored in the capacitor compare to the initial energy?

1. The final stored energy is smaller
2. The final stored energy is larger
3. Stored energy does not change.
Changing C Dimensions

(2) The stored energy increases

As you pull apart the capacitor plates you are increasing the amount of space in which the E field is non-zero and hence increase the stored energy. Where does the extra energy come from? From the work you do pulling the plates apart.
PRS Questions: Dielectrics

Class 9
Dielectric in a Capacitor

A parallel plate capacitor is charged to a total charge $Q$ and the battery removed. A slab of material with dielectric constant $\kappa$ is inserted between the plates. The charge stored in the capacitor

1. Increases
2. Decreases
3. Stays the Same
Dielectric in a Capacitor

(3) The charge is unchanged

Since the capacitor is disconnected from a battery there is no way for the amount of charge on it to change.
Dielectric in a Capacitor

A parallel plate capacitor is charged to a total charge Q and the battery removed. A slab of material with dielectric constant $\kappa$ in inserted between the plates. The energy stored in the capacitor

1. Increases
2. Decreases
3. Stays the Same
Dielectric in a Capacitor

(2) The energy stored decreases

The dielectric reduces the electric field and hence reduces the amount of energy stored in the field.
Dielectric in a Capacitor

A parallel plate capacitor is charged to a total charge $Q$ and the battery removed. A slab of material with dielectric constant $\kappa$ is inserted between the plates. The force on the dielectric

1. pulls in the dielectric
2. pushes out the dielectric
3. is zero
Dielectric in a Capacitor

(1) The dielectric is pulled into the capacitor

We just saw that the energy is reduced by the introduction of a dielectric. Since systems want to reduce their energy, the dielectric will be sucked into the capacitor.

Alternatively, since opposing charges are induced on the dielectric surfaces close to the plates, the attraction between these will lead to the attractive force.
A parallel plate capacitor is connected to a battery and charged to a total charge $Q$. A slab of material with dielectric constant $\kappa$ in inserted between the plates. The **charge** stored in the capacitor

1. Increases
2. Decreases
3. Stays the Same
Dielectric in a Capacitor

(1) The stored charge increases

In order to keep the voltage the same, since the capacitance increases the charge stored must also increase ($Q = CV$)

More intuitively, since opposing charges are induced on the dielectric surfaces close to the plates, extra charge will be attracted into the capacitor.
Dielectric in a Capacitor

A parallel plate capacitor is connected to a battery. A slab of material with dielectric constant $\kappa$ in partially inserted between the plates. The electric field in the dielectric

1. is larger than the E field to the left
2. is smaller than the E field to the left
3. is the same as the E field to the left
Dielectric in a Capacitor

(3) The E field in the dielectric is the same as the E field outside the dielectric

This might seem wrong since dielectrics decrease electric fields. However, the potential difference between the plates is fixed and $V=Ed$, whether going through the dielectric or not. So $E=V/d$ in both regions.

How? Charge will move to the right (by the dielectric) while it is being inserted.
PRS Questions:
Light Bulbs

Class 10
Bulbs and Batteries

An ideal battery is hooked to a light bulb with wires. A second identical light bulb is connected in parallel to the first light bulb. After the second light bulb is connected, the current from the battery compared to when only one bulb was connected.

1. Is Higher
2. Is Lower
3. Is The Same
4. Don’t know
Bulbs and Batteries

(1) More current flows from the battery

There are several ways to see this:

(A) The equivalent resistance of the two light bulbs in parallel is half that of one of the bulbs, and since the resistance is lower the current is higher, for a given voltage.

(B) The battery must keep two resistances at the same potential \( \Rightarrow \) I doubles.
Bulbs and Batteries

An ideal battery is hooked to a light bulb with wires. A second identical light bulb is connected in parallel to the first light bulb. After the second light bulb is connected, the power output from the battery (compared to when only one bulb was connected)

1. Is four times higher
2. Is twice as high
3. Is the same
4. Is half as much
5. Is one quarter as much
6. Don’t know
Bulbs and Batteries

(2) Twice as much

The current from the battery must double (it must raise two light bulbs to the same voltage difference) and

\[ P = IV \]
Bulbs and Batteries

An ideal battery is hooked to a light bulb with wires. A second identical light bulb is connected in series with the first light bulb. After the second light bulb is connected, the light from the first bulb (compared to when only one bulb was connected)

1. is four times as bright
2. is twice as bright
3. is the same
4. is half as bright
5. is one quarter as bright
Bulbs and Batteries

(5) The light is \( \frac{1}{4} \) as bright

The resistance in the circuit doubled so the current is cut in half. This means that the power delivered by the battery is half what it was. But that power is further divided between two bulbs now.

Alternatively,

\[ P = I^2 R \]
PRS Questions: RC Circuits

Class 12
An uncharged capacitor is connected to a dc voltage source via a switch. A resistor is placed in series with the capacitor. The switch is initially open. At $t = 0$, the switch is closed. A very long time after the switch is closed, the current in the circuit is

1. nearly zero
2. at a maximum and decreasing
3. nearly constant but non-zero
After a long time the current is 0

Eventually the capacitor gets “full” – the voltage increase provided by the battery is equal to the voltage drop across the capacitor. The voltage drop across the resistor at this point is 0 – no current is flowing.
Consider the above circuit, with an initially uncharged capacitor and two identical resistors. At the instant the switch is closed:

1. $I_R = I_C = 0$
2. $I_R = I_C = \frac{\varepsilon}{R}$
3. $I_R = \frac{\varepsilon}{2R}$; $I_C = 0$
4. $I_R = 0$; $I_C = \frac{\varepsilon}{R}$
5. $I_R = \frac{\varepsilon}{2R}$; $I_C = \frac{\varepsilon}{R}$
Initially there is no charge on the capacitor and hence no voltage drop across it – it looks like a short. Thus all current will flow through it rather than through the bottom resistor. So the circuit looks like:

\[ I_R = 0; \quad I_C = \frac{\varepsilon}{R} \]
PRS Questions: Lorentz Force

Class 14
Force on Charged Particle

What direction is the force on a positive charge when entering a uniform B field in the direction indicated?

1) up
2) down
3) left
4) right
5) into page
6) out of page
7) there is no net force
Force on Charged Particle

(6) Force is out of the page
Force on Charged Particle

What direction is the force on a negative charge when entering a uniform B field in the direction indicated?

1) up  
2) down  
3) left  
4) right  
5) into page  
6) out of page  
7) there is no net force
Force on Charged Particle

(2) Force on the negative charge is down

\[ F = q(B \cdot v) \]
Rail Gun

A bar is free to slide on two parallel rails. A current I flows through the bar in the direction shown. An external magnetic field points out of the page. The bar in the center of the figure will:

1) move left
2) move right
3) stay in place
Rail Gun

(2) The rail will move to the right

\[ \vec{F}_B = \vec{I} \times \vec{B} \], and up cross out is right
PRS Questions: Magnetic Dipole

Class 15
Dipole in Field

The coil above will rotate
1. clockwise
2. counterclockwise
3. stay in the orientation shown because the total force is zero
Dipole in Field

Answer: 1. The coil above will rotate clockwise because the $I ds \times B$ forces shown produce a torque $r \times F$ into the page. This implies clockwise rotation.
A Helmholtz coil is hooked up with current running parallel in both coils. A magnetic dipole is placed along the z-axis at the point $z = 0$ with the magnetic moment pointing in the $+x$ direction. Which of the following statements is true?

1. Force & torque on the dipole are zero
2. Force on the dipole is zero and torque on the dipole is non-zero
3. Force & torque on the dipole are nonzero
4. The force on the dipole is non-zero and the torque on the dipole is zero
Helmholtz Coil

(2) Zero force, non-zero torque

In a Helmholtz coil with parallel currents, the field is uniform at the center. There will be a torque to align the dipole with the field (along the z-axis) but no force, since the field has no gradient.
Iron Filings

Above is an iron filings representation of the magnetic field created by two loops of current. Which is true?
1. Currents are parallel (bigger in top); loops attracted
2. Currents are parallel (bigger in bottom); loops repelled
3. Currents are anti-parallel (bigger in bottom); loops attracted
4. Currents are anti-parallel (bigger in top); loops repelled
5. None of the above
Iron Filings

(5) None of the above
Loops are repelling so currents must be anti-parallel. But the field zero is above the top loop, so the field from the bottom is stronger, so the current must be bigger in the bottom loop.

So:
Currents are anti-parallel (bigger in bottom); loops repelled
The current carrying coil above will move
1. upwards
2. downwards
3. stay where it is because the total force is zero
Dipole in Field

Answer: 2. The coil above will move downward because the $I \, ds \times B$ forces shown produce a net force downward.
The current-carrying coil above will move
1. upwards
2. downwards
3. stay where it is because the total force is zero
Answer: 2. The coil above will move downward because the $I \, ds \times B$ forces shown produce a net force downward
Free dipoles attract because:
1. The force between dipoles is always attractive independent of orientation.
2. A dipole will always move towards stronger field, independent of orientation.
3. The torque on the dipole aligns it with the local field and the dipole will then move toward stronger field strength.
Answer: 3. Free dipoles attract because the torque on a dipole aligns the dipole with the local field and the dipole then moves toward stronger field strength—that is closer to another dipole. If the dipole were anti-aligned with the local field then it would move toward regions of weaker field strength.
Bent Wire

The magnetic field at point P

1. points towards the +x direction
2. points towards the +y direction
3. points towards the +z direction
4. points towards the -x direction
5. points towards the -y direction
6. points towards the -z direction
7. points nowhere because it is zero
**Bent Wire**

(6) B is in the \(-z\) direction

The vertical line segment contributes nothing to the field at P (it is parallel to the displacement). The horizontal segment makes a field into the page.
PRS Questions:
Faraday’s Law

Class 20
Loop in Changing Field

The magnetic field through a circular wire loop is pointed upwards and decreasing with time. The induced current in the coil is

1. Clockwise as seen from the top
2. Counterclockwise

\[ \Phi \text{ is up and decreasing} \]

\[ \frac{d\vec{B}}{dt} < 0 \]
Loop in Changing Field

(2) Current is counter-clockwise.

This produces an “induced” B field pointing up over the area of the loop.

The “induced” B field opposes the decreasing flux through the loop – Lenz’s Law
Experiment 9  Prediction 1-1

Suppose you move the loop from well above the magnet to well below the magnet at a constant speed. Predict the shape of a graph of the magnetic flux through the loop as a function of time, taking the direction of $\mathbf{dA} = dA \mathbf{\hat{n}}$ for the loop as upward.
Suppose you move the loop from well above the magnet to well below the magnet at a constant speed. Predict the shape of a graph of the current through the loop as a function of time, taking the positive direction for current in the loop to be counter-clockwise when viewed looking down on the apparatus from above.
Suppose you move the loop from well below the magnet to well above the magnet at a constant speed. Predict the shape of a graph of the magnetic flux through the loop as a function of time, taking the direction of $d\vec{A} = dA\hat{n}$ for the loop as upward.
Suppose you move the loop from well below the magnet to well above the magnet at a constant speed. Predict the shape of a graph of the current through the loop as a function of time, taking the positive direction for current in the loop to be counter-clockwise when viewed looking down on the apparatus from above.
Faraday’s Law: Loop

A coil moves up from underneath a magnet with its north pole pointing upward. The current in the coil and the force on the coil:

1. Current clockwise; force up
2. Current counterclockwise; force up
3. Current clockwise; force down
4. Current counterclockwise; force down
Faraday’s Law: Loop

(3) Current is clockwise; force is down

The clockwise current creates a self-field downward, trying to offset the increase of magnetic flux through the coil as it moves upward into stronger fields (Lenz’s Law).

The $I \, dl \times B$ force on the coil is a force which is trying to keep the flux through the coil from increasing by slowing it down (Lenz’s Law again).
Faraday’s Law: Rails

A conducting rod moves along conducting rails in a magnetic field which is out of the page. The current in the rod and the force on the rod are:

1. Current up and force to left
2. Current down and force to left
3. Current up and force to right
4. Current down and force to right
Faraday’s Law: Rails

(3) Current is up; force on rod is to right.

The clockwise current creates a self-field into the page – the current tries to offset the increase of magnetic flux in the loop due to the moving rod (Lenz’s Law).

The $I \, dl \times B$ force on the rod is a force which is trying to keep the flux through the circuit from increasing by slowing the rod down (Lenz’s Law again).
Faraday’s Law: Loop

A circuit in the form of a rectangular piece of wire is pulled away from a long wire carrying current $I$ in the direction shown in the sketch. The induced current in the rectangular circuit is

1. Clockwise
2. Counterclockwise
3. Neither, the current is zero
(1) Clockwise. The magnetic field due to the current in the long wire is into the page, and the flux through the rectangular circuit due to that field decreases as the circuit moves away. So the induced current is clockwise, so as to generate an induced B field into the page that is trying to keep the magnetic flux into the page from decreasing.

Note: $I \, dl \times B$ force is left on the left segment and right on the right, but the force on the left is bigger. So the net force on the rectangular circuit is to the left, again trying to keep the flux from decreasing by slowing the circuit’s motion.
Faraday’s Law: Generator

A square coil rotates in a magnetic field directed to the right. At the time shown, the current in the square, when looking down from the top of the square loop, will be

1. Counterclockwise.
2. Clockwise
Faraday’s Law: Generator

(1) Current is counterclockwise. The flux through the loop decreases as the normal rotates away from the B field. To try to keep that flux from decreasing, the induced current in the square will be CCW, to produce an induced B field in the loop along the normal in the loop and therefore trying to keep the magnetic flux from decreasing (Lenz’s Law).

The $I\,dl \times B$ force on the sides of the square loop will be such as to produce a torque that tries to stop it from rotating (Lenz’s Law).
PRS Questions: Inductors & LR Circuits

Class 23 & 25
Consider the above circuit, in which the switch S has been closed a very long time. At $t = 0$, the switch is opened. Immediately after the switch is opened the current in the inductor is equal to

1. $\mathcal{E}/R$

2. $\mathcal{E}/2R$

3. Zero

4. Don’t have a clue
(1) The current stays at what is was just before throwing the switch.

After a very long time, the inductor looked like a wire, so there was just a current $\varepsilon/R$ through it.
Consider an inductor connected to a battery with emf $\mathcal{E}$ and a resistor $R$. The switch S has been in position $b$ for a very long time. At $t = 0$, the switch is thrown to position $a$. The current $I$ through the resistor for $t > 0$ is:

1. $\frac{\mathcal{E}}{R} e^{-\frac{Rt}{L}}$
2. $\frac{\mathcal{E}}{R} \left\{ 1 - e^{-\frac{Rt}{L}} \right\}$
3. Zero
4. Don’t have a clue
The current as a function of time looks like:

\[ \frac{\varepsilon}{R} e^{-\frac{Rt}{L}} \]
Driving a Motor

Consider a motor (a loop of wire rotating in a B field) which is driven at a constant rate by a battery through a resistor.

Now grab the motor and prevent it from rotating. What happens to the current in the circuit?

1. Increases
2. Decreases
3. Remains the Same
Driving a Motor – Answer

(1) Current Increases

When the motor is rotating in a magnetic field an EMF is generated which opposes the motion, that is, it reduces the current. When the motor is stopped that back EMF disappears and the full voltage of the battery is now dropped across the resistor – the current increases. For some motors this increase is very significant, and a stalled motor can lead to huge currents that burn out the windings (e.g. your blender).
PRS Questions:
Undriven RLC Circuits

Class 25
Consider the above LC circuit. At the time shown the current has its maximum value. At this time

1. The charge on the capacitor has its maximum value
2. The magnetic field is zero
3. The electric field has its maximum value
4. The charge on the capacitor is zero
5. Don’t have a clue
Answer: 4. The current is a maximum when the charge on the capacitor is zero.

Current and charge are exactly 90 degrees out of phase in an ideal LC circuit (no resistance), so when the current is maximum the charge must be identically zero.
In the above LC circuit the current is in the direction shown and the charges on the capacitor have the signs shown. At this time,

1. I is increasing and Q is increasing
2. I is increasing and Q is decreasing
3. I is decreasing and Q is increasing
4. I is decreasing and Q is decreasing
5. Don’t have a clue
Answer: 2. I is increasing and Q is decreasing.

If the current is positive in the direction shown, then the capacitor must be discharging. Therefore Q is decreasing. But since Q on the right plate is positive, I must be increasing, since we are in the first quarter period of the discharge of the capacitor, when Q is decreasing and positive and I is increasing and positive.
PRS Questions: Driven RLC Circuits

Class 26
The graph shows the current versus the voltage in a driven RLC circuit at a particular driving frequency. Is this frequency above or below the resonance frequency of the circuit?

1. Above the resonance frequency
2. Below the resonance frequency
3. Don’t have a clue
Answer: 1. Above the resonance frequency

The current lags the voltage. This means that $\omega L > 1/\omega C$. Thus the frequency satisfies $\omega^2 > 1/LC$.
The graph shows the current versus the voltage in a driven RLC circuit at a given driving frequency. In order to tune the circuit to maximum current, we should

1. Increase the frequency
2. Decrease the frequency
3. Leave it where it is! It is tuned
4. We don’t have enough information to say
Answer: 2. Decrease Frequency

Based on the direction in which the above loop is traced out, we see that the voltage leads. So we are inductor like. So we are above resonance. So we need to decrease the frequency to get to resonance (which is maximum current).
The top (pink) curve is $I$ in an RLC circuit. What is the green curve and are we above or below resonance?

1. Green $=$ V Resistor, Above Res
2. Green $=$ V Capacitor, Below Res
3. Green $=$ V Inductor, Above Res
4. None of the above
Answer: 4. None of the above

The green voltage lags the current so it is the capacitor voltage. The bottom curve is the power supply voltage, and it leads, so we are above resonance.
LRC Circuit

An LRC circuit is made with an inductor with an iron core. It has a resonance frequency $\omega_0$. The iron core is removed. Which is correct?

(1) Both the maximum energy stored in the inductor at any point in the cycle and the resonance frequency increase.

(2) $U_{\text{Max,L}}$ decreases, $\omega_0$ increases

(3) $U_{\text{Max,L}}$ increases, $\omega_0$ decreases

(4) Both $U_{\text{Max,L}}$, $\omega_0$ decrease.

(5) Neither $U_{\text{Max,L}}$, $\omega_0$ change
LRC Circuit

(2) $U_{\text{Max},L}$ decreases, $\omega_0$ increases

Removing the core decreases the inductance.

$U_{\text{Max},L} = \frac{1}{2} LI^2 \quad \text{Decreases}$

$\omega_0 = \frac{1}{\sqrt{LC}} \quad \text{Increases}$
PRS Questions: Displacement/Poynting

Class 28
The plot above shows a side and a top view of a capacitor with charge $Q$ with electric and magnetic fields $E$ and $B$ at time $t$. The charge $Q$ is:

1. Increasing in time
2. Constant in time.
3. Decreasing in time.
4. Don’t have a clue.
Answer: 1. The charge $Q$ is increasing

The direction of the Poynting Flux $S (=E \times B)$ inside the capacitor is inward. Therefore electromagnetic energy is flowing inward, and the energy in the electric field inside is increasing. Thus $Q$ must be increasing, since $E$ is proportional to $Q$. 
The plot above shows a side and a top view of a solenoid carrying current $I$ with electric and magnetic fields $E$ and $B$ at time $t$. In the solenoid, the current $I$ is:

1. Increasing in time
2. Constant in time.
3. Decreasing in time.
4. Don’t have a clue.
Answer: 3. The current I is decreasing.

The Poynting Flux $S (= E \times B)$ inside the solenoid is outward from the center of the solenoid. Therefore electromagnetic energy is flowing outward, and the energy in the magnetic field inside is decreasing. Thus I must be decreasing, since B is proportional to I.
In the above LC circuit, I is as shown and the E field in the capacitor points as shown. What are the directions of the Poynting vectors in C & L?

1. Into C, Out of L
2. Into L, Out of C
3. Into both
4. Out of both
5. Poynting vector is 0 in one or both
Answer: 1. Into C, Out of L

We are charging the capacitor since the current is flowing into the positively charged plate. So energy is flowing into the capacitor and out of the inductor.
Coherent, monochromatic plane waves:

In the Figure above, the fringe at point P on the screen will be:

1. An interference maximum
2. An interference minimum
3. Don’t have a clue
Answer: 2. Interference minimum.

The two waves arrive at point $P$ exactly 180 degrees or half a wavelength out of phase.
Coherent monochromatic plane waves impinge on two apertures separated by a distance $d$. An approximate formula for the path length difference between the two rays shown is

1. $d \sin \theta$
2. $L \sin \theta$
3. $d \cos \theta$
4. $L \cos \theta$
5. Don’t have a clue.
Answer: 1. \[ \delta = d \sin \theta \]

The difference between the two paths can be seen to have this value by geometrical construction (using the triangle show in yellow).
Coherent monochromatic plane waves impinge on two long narrow apertures (width $a$) that are separated by a distance $d$ ($d >> a$). The resulting pattern on a screen far away is shown above. Which structure in the pattern above is due to the finite width $a$ of the apertures?

1. The distantly-spaced zeroes of the envelope, as indicated by the length $A$ above.
2. The closely-spaced zeroes of the rapidly varying fringes with length $B$ above.
3. Don’t have a clue.
Answer: 1. The distantly-spaced zeroes of the envelope are determined by the width \( a \ll d \) of the apertures, which is much smaller than the separation \( d \) of the apertures. The much larger distance \( d \) determines the “fine-scale” structure in the graph above.
Coherent monochromatic plane waves impinge on two long narrow (width $a$) apertures separated by a distance $d$. The resulting pattern on a screen far away is shown above. For this arrangement:

1. The value of $d/a$ is about 1/8
2. The value of $d/a$ is about 1/4
3. The value of $d/a$ is about 4
4. The value of $d/a$ is about 8
5. Don’t have a clue.
Answer: 4. The value of $d/a$ is about 8.

$d$ determines spacing of the “fine-scale” zeroes (spacing proportional to $1/d$). $a$ determines spacing of envelope zeroes (spacing proportional to $1/a$). So there are $d/a$ fine-scale zeroes in the rapid fluctuations before we get to the first zero in the envelope. Here there are 8.