Your name sticker
⇒
with exam code

SIGN HERE

1. Use a #2 pencil to make entries on the answer sheet. Enter the following id information now, before the exam starts.
2. In the section labeled NAME (Last, First, M.I.) enter your last name, then fill in the empty circle for a blank, then enter your first name, another blank, and finally your middle initial.
3. Under STUDENT # enter your 9-digit RUID Number.
4. Under CODE enter the exam code given above.
5. Enter 227 under COURSE. You do not need to write anything else on the answer sheet for now, but you may continue to read the instructions.
6. During the exam, you are allowed three 8.5 x 11 inch sheets of paper with whatever you want written on them. NO calculators, NO cell phones.
7. The exam consists of 30 multiple-choice questions. For each question mark only one answer on the answer sheet. There is no deduction of points for an incorrect answer. If you cannot work out an answer, you should make an educated guess.
8. If you have questions or problems during the exam, you may raise your hand and a proctor will assist you. We will provide values of physical constants that are needed. It is your responsibility to know the relevant equations.
9. A proctor will check your name sticker and your student ID sometime during the exam. Please have them ready.
10. You are not allowed to help any other student, ask for help from anyone but a proctor, change your seat without permission from a proctor or use any electronic device. Doing so will result in a zero score for the exam.
11. When you are done with the exam, hand in only this cover sheet and your answer sheet.
12. Please sign above by the name sticker to indicate that you have read and understood these instructions.
Possibly useful constants:

\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2 \]
\[ k = 1/4\pi\varepsilon_0 = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2 \]
\[ \mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m} = 12.57 \times 10^{-7} \text{ T}\cdot\text{m} \]
\[ c = \text{speed of light} = 3.00 \times 10^8 \text{ m/s} \]
\[ -q_{\text{electron}} = q_{\text{proton}} = 1.602 \times 10^{-19} \text{ C} \]
\[ m_{\text{electron}} = \text{electron mass} = 9.11 \times 10^{-31} \text{ kg} \]
\[ m_{\text{proton}} = \text{proton mass} = 1.67 \times 10^{-27} \text{ kg} \]
\[ 1 \text{ eV} = 1.602 \times 10^{-19} \text{ J} \]

Circumference of a circle = \(2\pi r\); area of a circle is \(\pi r^2\)

Surface of a sphere = \(4\pi r^2\); volume of a sphere = \(\frac{4}{3}\pi r^3\)

Volume of cylinder = \(\pi r^2 h\)

\[
\sin(0^\circ) = \cos(90^\circ) = 0 \\
\sin(90^\circ) = \cos(0^\circ) = 1 \\
\sin(30^\circ) = \cos(60^\circ) = 1/2 \\
\sin(60^\circ) = \cos(30^\circ) = \sqrt{3}/2 \\
\sin(45^\circ) = \cos(45^\circ) = \sqrt{2}/2 \\
\]

\[
\frac{dx^n}{dx} = nx^{n-1} \\
f(x^n) = \frac{1}{n+1} x^{n+1} \text{ except when } n = -1. \text{ For } n = -1 \int dx/x = \ln x \\
\]

Some metric prefixes:

f = femto = \(10^{-15}\)

p = pico = \(10^{-12}\)

n = nano = \(10^{-9}\)

\(\mu\) = micro = \(10^{-6}\)

m = milli = \(10^{-3}\)

k = kilo = \(10^3\)

M = mega = \(10^6\)

G = giga = \(10^9\)
1. A square loop and a circular loop of equal area lie in a plane perpendicular to a uniform magnetic field. Each loop then rotates at the same frequency \( \omega \) about an axis in its plane passing through its center. In which loop will the root-mean-square average induced EMF be greater?

   a) The square.
   b) The circle.
   c) Depends upon the orientation of the axis in the square.
   d) Depends upon \( \omega \).
   e) The induced EMFs are the same.

2. Two coils are close to each other, with one connected to a current source which produces a current of \( I_1(t) = 3t^2 + 5 \) amps, where \( t \) is expressed in seconds. If at time \( t = 3 \) seconds the voltage \( V_2 = 0.18 \) V, what is the mutual inductance \( M \) of the two coils?

   \[
   \mathcal{E}_2 = -M \frac{dI_1}{dt}
   \]

   a) \( M = 5.6 \) mH
   b) \( M = 10 \) mH
   c) \( M = 20 \) mH
   d) \( M = 30 \) mH
   e) \( M = 60 \) mH

   \[
   M = \frac{\mathcal{E}_2}{\frac{dI_1}{dt}} = \frac{0.18}{6(3\text{A})} = 10^{-2} \text{H} = 10 \text{ mH}.
   \]

3. For the circuit shown, which condition gives the maximum voltage across the capacitor?

   a) \( X_C = \frac{1}{\omega C} = X_L = \omega L \)
   b) \( \omega = 0 \)
   c) \( \omega = \infty \)
   d) \( C/L \) is very very large.
   e) \( L/C \) is very very large.
4. Equal but opposite charges \( Q \) are placed on the plates of an air-filled parallel-plate capacitor. The plates are then pulled apart to twice their original separation. Which of the following statement(s) is TRUE?

i. The energy stored in the capacitor has doubled. \( \text{False} \)
ii. The electric field between the plates has increased.
iii. The potential difference between the plates has doubled.

a) Only (ii) and (iii) are true.
b) Only (iii) is true.
c) Only (i) and (iii) are true.
d) Only (ii) is true.
e) Only (i) is true.

\[ \begin{align*}
U &= \frac{Q^2}{2C} \\
C_1 &= \frac{\varepsilon_0 A}{d} \\
V &= \frac{Q}{C} \\
C_2 &= \frac{\varepsilon_0 A}{2d}.
\end{align*} \]

5. A slender rod with a length \( L \) rotates with an angular speed \( \omega \) about an axis through its center and perpendicular to the rod. The plane of rotation of the rod is perpendicular to a uniform magnetic field \( B \). What is the potential difference between the two ends of the rod?

a) \( \omega L^2 B / 2 \)
b) \( \omega L^2 B \)
c) \( \omega LB / 2 \)
(d) zero
e) \( 2\omega L^2 B \)

6. A toroidal inductor is created when a long solenoid that is much longer than its radius is bent into a circle so that its ends meet and its external shape is that of a very skinny doughnut. Suppose a toroid is created from a solenoid of cross-sectional area \( A \) and length \( D \) wound with \( N \) turns of wire. What is the inductance \( L \) of the toroid?

a) \( L = \mu_0 N^2 A / 2\pi D \)
b) \( L = \mu_0 N^2 A / D^2 \)
(c) \( L = \mu_0 N^2 A / D \)
d) \( L = \mu_0 NA / D \)
e) \( L = \mu_0 NA / 2\pi D \)

\[ \begin{align*}
L &= N \frac{\Phi_B}{\lambda} = \frac{\mu_0 N^2 A}{D} \\
\Phi_B &= BA \left( \frac{\mu_0 NI}{D} \right) A
\end{align*} \]
7. An insulating spherical shell of inner radius \( a \) and outer radius \( b \) is uniformly charged with a positive charge density. The radial component of the electric field, \( E_r(r) \) is best depicted by which figure?

![Diagrams of electric fields](image)

- a) \( E \) decreases linearly as \( r \) increases from \( a \) to \( b \)
- b) \( E \) increases linearly as \( r \) increases from \( a \) to \( b \)
- c) \( E \) decreases as \( r \) increases from \( a \) to \( b \)
- d) \( E \) increases as \( r \) increases from \( a \) to \( b \)
- e) \( E \) remains constant as \( r \) increases from \( a \) to \( b \)

8. A cylindrical wire has a resistance \( R \) and resistivity \( \rho \). If its length and diameter are both cut in half, its resistance will now be:

- a) \( 4R \ \Omega \)
- b) \( 2R \ \Omega \)
- c) \( R \ \Omega \)
- d) \( R/2 \ \Omega \)
- e) \( R/4 \ \Omega \)

\[
R_1 = \rho \frac{L}{A} = \frac{\rho L}{\pi \left(\frac{d}{2}\right)^2}
\]

\[
R_2 = \frac{\pi \left(\frac{d}{2}\right)}{L} \frac{\rho}{\pi \left(\frac{d}{2}\right)^2}
\]

\[
R_2 = \frac{1}{2} R_1
\]
9. A long metal bar of length $L=1.0$ m is pulled to the right at a steady speed $v = 5.0$ m/s perpendicular to a uniform magnetic field of magnitude $B = 0.7$ T. The bar rides on parallel metal rails connected through a resistance of $R = 20 \ \Omega$, as shown in the figure, so that the apparatus makes a complete circuit. The resistance of the bar and the rails can be neglected. What are the magnitude of the EMF induced in the circuit and the direction of the current in the circuit?

a) $EMF = 3.5$ V, current is counterclockwise.

b) $EMF = 3.5$ V, current is clockwise.

c) $EMF = 35$ V, current is counterclockwise.

d) $EMF = 35$ V, current is clockwise.

e) $EMF = 5/7$ V, current is counterclockwise.

\[ E = -\frac{\mathbf{d} \mathbf{B} \cdot \mathbf{L}}{dt} = -B \mathbf{N} \times \mathbf{L} \]

\[ = - (0.7 \times 10^{-8}) (5 \times 1 \text{ m}) \]

\[ = -3.5 \text{ V} \]

10. You want to construct an inductor that can store the amount of energy that a 200-W light bulb converts to light and heat in 1 minute. If the current in the inductor is $I = 10$ A, what inductance $L$ would yield an inductor that stores the same amount of energy as the light bulb converts in 1 minute?

a) $L = 240$ H

b) $L = 2400$ H

c) $L = 1200$ H

d) $L = 40.0$ H

e) $L = 20.0$ H

\[ U = \frac{1}{2} LI^2 = \frac{200 \text{ J}}{s} \times \frac{60 \text{ s}}{\text{min}}. \]

\[ L = \frac{2(200)(60)}{10^2} = 240 \text{ H} \]

11. An electric dipole with dipole moment $\mathbf{p}$ is in a uniform electric field $\mathbf{E}$. For which of the orientation(s) of the dipole is the torque on the dipole zero and for which orientation(s) is the orientation stable?

a) The torque is zero when $\mathbf{p}$ is aligned in the opposite direction as $\mathbf{E}$ and this configuration is stable.

b) The torque is zero when $\mathbf{p}$ is aligned in the same or opposite direction as $\mathbf{E}$ and both configurations are stable.

c) The torque is zero when $\mathbf{p}$ is perpendicular to the direction of $\mathbf{E}$ and this configuration is stable.

d) The torque is zero when $\mathbf{p}$ is aligned in the same direction as $\mathbf{E}$ and this configuration is stable.

e) The torque is never zero.

\[ \tau = \mathbf{p} \times \mathbf{E} = pE \sin \theta \]

\[ U = -\mathbf{p} \cdot \mathbf{E} \]

\[ \tau = 0 \text{ when } \theta = 0 \text{ and } U = U_{\text{min}}. \]
12. What is the equivalent resistance (measured in $\Omega$) of the segment of a circuit in the figure if $R_1 = 2R$ and $R_2 = R_3 = R_4 = R$?

a) $\frac{5R}{3}$
b) $\frac{8R}{3}$
c) $\frac{3R}{8}$
d) $5R$
e) $\frac{5R}{2}$

$$R_{eq} = \frac{R_1 + \frac{R_4(R_2 + R_3)}{R_2 + R_3 + R_4}}{2R + \frac{R_2R_3}{R_2 + R_3 + R_4}} = \frac{5R}{3}$$

13. Which of the following equations implies that you get a greater EMF the faster you rotate the coils of a generator?

a) $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$
b) $\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$
c) $\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$
d) $\oint \vec{B} \cdot d\vec{A} = 0$
e) $\oint \vec{B} \cdot d\vec{l} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_B}{dt}$

14. Two identical concentric loops are arranged as shown in the Figure. One loop has a steady current flowing through it (provided by the power supply). When the power is turned off, will the two loops briefly attract or repel each other?

a) There is no induced current.
b) They will neither repel nor attract each other.
c) They will attract each other.
d) The answer depends on the direction of current in loop 1.
e) They will repel each other.
15. The radial electric field produced by a certain spherically symmetric charge distribution centered at the origin is given by

\[ E_r(r) = 10r^2 \text{ V/m} \]

where \( r \) is the distance from the origin measured in meters. The total charge \( Q \) contained inside a sphere surrounding the origin of radius \( R \) is:

a) \( Q = 40\pi\varepsilon_0 R^4 \)

b) \( Q = 40\pi\varepsilon_0 R^2 \)

c) \( Q = 10\pi\varepsilon_0 R^4 \)

d) \( Q = 10\pi\varepsilon_0 R^2 \)

e) \( Q = 40\pi R^4 \)

\[ \oint E\cdot dA = E(4\pi R^2) = \frac{Q}{\varepsilon_0} \]

\[ Q = (10 R^2)(4\pi R^2)\varepsilon_0 \]

\[ = 40\pi \varepsilon_0 R^4 \]

16. In the figure the battery has EMF of 50 V and negligible internal resistance. The four resistors have the same value \( R_1 = R_2 = R_3 = R_4 = 6 \) Ω. What is the current \( I \) through \( R_1 \)?

\[ R_{eq} = \frac{R}{R_1} = \frac{R}{R_4} = \frac{R}{R_2 + R_3 + R_4} \]

\[ R = \frac{R_2 R_3}{R_2 + R_3} + R_4 \]

\[ \frac{R_1 R_2}{R_1 + R_2} = \frac{5}{3} \]

\[ U = IR_{eq} \Rightarrow I = \frac{U}{R_{eq}} = \frac{50V}{(\frac{5}{3})(6\Omega)} = 5A \]

17. According to Maxwell’s equations, which of the following is a consequence of a time dependent (as opposed to a static) electric field?

a) A magnetic field.

b) Joule heating.

c) A resistance.

d) Increasing magnetic flux through any surface surrounding the region of changing electric field.

e) Electromagnetic induction.
18. An \( L-R-C \) series circuit has an inductance \( L \) (measured in H), a resistance \( R \) (measured in \( \Omega \)), a capacitance \( C \) (measured in F) and carries an rms current \( I \) with a frequency \( f \) (measured in Hz). What is the impedance \( Z \) of the circuit (measured in \( \Omega \))? 

\[
\begin{align*}
\text{a) } Z &= \sqrt{R^2 + (fL - 1/(2\pi fC))^2} \\
\text{b) } Z &= \sqrt{R^2 + (L/2\pi f - (2\pi fC))^2} \\
\text{c) } Z &= \sqrt{R^2 + (2\pi fL - 1/(2\pi fC))^2} \\
\text{d) } Z &= R^2 + (2\pi fL - 1/(2\pi fC))^2 \\
\text{e) } Z &= \sqrt{R^2 + 2\pi fL - 1/(2\pi fC))^2}
\end{align*}
\]

\[
Z = \sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2} = \sqrt{R^2 + (2\pi f L - \frac{1}{2\pi fC})^2}.
\]

19. A small conducting spherical shell with inner radius \( a \) and outer radius \( b \) is concentric with a larger conducting spherical shell with inner radius \( c \) and outer radius \( d \). The inner shell has total charge \( +2q \), and the outer shell has charge \( -2q \). What is the total charge on the inner surface of the large shell and the outer surface of the large shell?

\[
\begin{align*}
\text{a) } +2q \text{ and } +2q, \text{ respectively} \\
\text{b) } -2q \text{ and } -2q, \text{ respectively} \\
\text{c) } +2q \text{ and } 0, \text{ respectively} \\
\text{d) } -2q \text{ and } 0, \text{ respectively} \\
\text{e) } 0 \text{ and } -2q, \text{ respectively}
\end{align*}
\]

20. In the figure, which is the correct expression for the time dependence of the charge in an \( R-C \) circuit with EMF \( V \) when the capacitor is charging?

\[
\begin{align*}
\text{a) } q &= Q_f(1 - \exp(-t/\tau)) \text{ where } \tau = 1/RC \text{ and } Q_f = CV \\
\text{b) } q &= Q_f(1 - \exp(-t/\tau)) \text{ where } \tau = RC \text{ and } Q_f = CV \\
\text{c) } q &= Q_f(\exp(-t/\tau)) \text{ where } \tau = RC \text{ and } Q_f = V/C \\
\text{d) } q &= Q_f(\exp(-t/\tau)) \text{ where } \tau = 1/RC \text{ and } Q_f = V/C \\
\text{e) } q &= Q_f(1 - \exp(-t/\tau)) \text{ where } \tau = RC \text{ and } Q_f = V/C
\end{align*}
\]

\[
\text{RC circuit charging: } q = Q_f(1 - e^{-t/\tau}) \text{ when } \tau = RC. \\
Q_f = CV
\]
21. Which of the following is FALSE?

a) Maxwell's displacement current must be added to the ordinary current in Ampere's law to make the law complete.

b) Time-varying electric fields give rise to magnetic fields, and time-varying magnetic fields give rise to electric fields.

c) The magnetic flux through a closed surface is always zero.

d) Maxwell's displacement current is necessary for the existence of electromagnetic waves.

e) Maxwell's displacement current exists only where a magnetic field changes with time.

22. A transformer connected to an AC line with an rms voltage of 120 V supplies an rms voltage of 12 V to a portable electronic device. The load resistance in the secondary is 4.00 Ω. What resistance connected directly across the source line (which has a voltage of 120 V) would draw the same power as the transformer?

\[ V_1 I_1 = V_2 I_2 \]

\[ V_1 \left( \frac{V_1}{R_1} \right) = V_2 \left( \frac{V_2}{R_2} \right) \]

\[ R_1 = \left( \frac{V_1}{V_2} \right)^2 R_2 = 400 \text{Ω} \]

23. Which of the following statements about the electric field and electric potential is TRUE?

a) The electric field is the direction in which a charge moves in a vacuum. FALSE

b) The electric field is equal to -1 times the voltage gradient. TRUE

c) Charged particles are always repelled from regions of high electric potential. FALSE

d) Gauss's law states that the surface integral of the electric potential is directly proportional to the enclosed charge. FALSE

e) Electric field lines begin at a negative charge and terminate at a positive charge. FALSE
24. An electron and a proton in the same uniform magnetic field trace out circles of the same radius, one clockwise and the other counterclockwise. What is the ratio of electron to proton momenta? (Note: mass of proton ≈ 2000 mass of electron.)

   a) \( \approx 2000 \)
   b) \( \approx 5 \times 10^{-4} \)
   c) \( 1 \)
   d) It depends on the radius of the circle.
   e) It depends on the magnetic field.

\[ \frac{m_e v_e^2}{r} = q v_e B \Rightarrow p = m_e v = \frac{q B r}{r} \]

\[ p_{\text{proton}} = \frac{q B r}{r} \Rightarrow \frac{p_{\text{proton}}}{p_{\text{electron}}} = 1 \]

25. A wooden ring whose mean radius is \( r = 0.10 \text{ m} \) is wound with a closely spaced toroidal winding of 400 turns. What is the magnitude of the magnetic field \( B \) at the center of the cross section of the windings when the current in the windings is 2.0 A? (Note: \( \mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m} \))

   a) \( B = 8 \times 10^{-4} \text{ T} \)
   b) \( B = 32\pi \times 10^{-5} \text{ T} \)
   c) \( B = 16 \times 10^{-4} \text{ T} \)
   d) \( B = 8 \times 10^{-5} \text{ T} \)
   e) \( B = 16\pi \times 10^{-4} \text{ T} \)

\[ B_{\text{toroid}} = \frac{\mu_0 N I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{ T} \cdot \text{m}) \times 400 \times (2A)}{2\pi \times (10^{-1} \text{ m})} = 10 \times 10^4 \text{ T} \]

26. The resonant frequency of a certain \( L - C \) circuit is \( 10^5 \text{ Hz} \). If the capacitance and inductance each increase by a factor of 5, what will be the new resonant frequency \( \omega_0 \)?

   a) \( \omega_0 = (1/25) \times 10^6 \text{ Hz} \)
   b) \( \omega_0 = (1/5) \times 10^6 \text{ Hz} \)
   c) \( \omega_0 = 1 \times 10^6 \text{ Hz} \)
   d) \( \omega_0 = 5 \times 10^5 \text{ Hz} \)
   e) \( \omega_0 = 25 \times 10^5 \text{ Hz} \)

\[ \omega_0 \text{ initially} = \sqrt{\frac{1}{LC}} = \frac{1}{\sqrt{5}} \text{ Hz} \]

\[ \omega_0 \text{ finally} = \sqrt{\frac{1}{5LC}} = \frac{1}{5} \sqrt{\frac{1}{LC}} = \frac{1}{5} \times 10^5 \text{ Hz} \]
27. Three charges are positioned along the x axis, as shown in the figure. A charge of \(-q\) is positioned at \(x = -a\), a charge of \(+q\) is positioned at \(x = a\), and a charge of \(-2q\) is positioned at \(x = 2a\). What is the potential \(V\) at the origin, \(x = 0\), if the potential is 0 at \(r = \infty\)?

\[
V = \frac{-q}{4\pi \varepsilon_0 a} + \frac{q}{8\pi \varepsilon_0 a} + \frac{-2q}{2a}
\]

\[
= \frac{-q}{4\pi \varepsilon_0 a}
\]

28. An inductor with inductance \(L = 2.0\) H and a resistor with resistance \(R = 5.0\) \(\Omega\) are connected in series to the terminals of a battery with an EMF of 10.0 V and negligible internal resistance. What is the initial rate of increase of current in the circuit?

\[\mathcal{E} = -L \frac{dI}{dt} \Rightarrow \frac{dI}{dt} = \frac{\mathcal{E}}{L} = \frac{10.0}{2.0} = 5.0\ A/s\]

29. When a certain series \(L - R - C\) circuit is driven at an angular frequency \(\omega_d\), the inductive reactance is 75 \(\Omega\), the capacitive reactance is 100 \(\Omega\) and the resistance is 25 \(\Omega\). If the resonant frequency is \(\omega_0\), which statement is TRUE?

\(a\) \(\omega_d > \omega_0\), and the current leads the applied EMF.

\(b\) \(\omega_d < \omega_0\), and the current leads the applied EMF.

\(c\) \(\omega_d > \omega_0\), and the current leads the applied EMF.

\(d\) \(\omega_d < \omega_0\), and the current lags the applied EMF.

\(e\) \(\omega_d = \omega_0\), and the current and applied EMF are in phase.

\[
\omega L - \frac{1}{\omega C} = X_L - X_C = 75\ \Omega - 100\ \Omega < 0
\]

\[
\Rightarrow \omega_d < \omega_0
\]

And behaves similar to capacitor \(\Rightarrow\) current leads EMF.
30. In the figure, an irregular loop of wire carrying a current lies in the plane of the paper. Suppose that the loop is distorted into some other shape while remaining in the same plane. Point P is still within the loop. Which of the following is a TRUE statement concerning this situation?

a) The magnetic field at point P will always lie in the plane of the paper.
b) It is possible that the magnetic field at point P is zero.
c) The magnetic field at point P will not change in magnitude when the loop is distorted.
d) The magnetic field at point P will not change in direction when the loop is distorted.
e) None of the other statements are true.