Induction: \[ \vec{d}\vec{B} = \frac{\mu_0}{4\pi} \frac{\partial \vec{E}}{\partial t} \]

Magnetism: \[ \vec{F} = q\vec{v} \times \vec{B} \]
\[ \vec{F} = i\vec{L} \times \vec{B} \]
\[ \mu = N_i A \]
\[ \tau = \vec{\mu} \times \vec{B} \]
\[ U = -\vec{\mu} \cdot \vec{B} \]
\[ d\vec{B} = \frac{\mu_0}{4\pi} \frac{\partial \vec{E}}{\partial t} \]
\[ \vec{B} = \frac{\mu_0}{2\pi R} \] (wire)
\[ \vec{B} = \frac{\mu_0 i}{2R} \] (loop center)
\[ \vec{B} = \frac{\mu_0 i N}{L} \] (solenoid)

Induction: \[ \Phi_B = \vec{n} \cdot \vec{B} dA \]
\[ \mathcal{E} = \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]
\[ L = N\Phi_B / i \] (definition)
\[ M = \mu_0 n^2 A \] (solenoid)
\[ \mathcal{E} = -L\frac{di}{dt} \]
\[ \mathcal{E}_1 = -M\frac{di_2}{dt} \]
\[ L = L_1 + L_2 \] (parallel)

Consistants: \[ e = 1.6 \times 10^{-19} \text{C} \quad m_p = 1.67 \times 10^{-27} \text{kg} \quad m_e = 9.1 \times 10^{-31} \text{kg} \quad c = 3 \times 10^8 \text{m/s} \quad \text{micro} = 10^{-6} \]
\[ \epsilon_o = 8.85 \times 10^{-12} \text{C}^2 / \text{N} \cdot \text{m}^2 \quad k = 1/(4\pi \epsilon_o) = 9 \times 10^9 \text{N} \cdot \text{m}^2 / \text{C}^2 \quad \mu_o = 4\pi \times 10^{-7} \text{T} \cdot \text{m} / \text{A} \quad \text{nano} = 10^{-9} \]

Coulomb’s Law: \[ |\vec{F}| = \frac{|q_1 q_2|}{4\pi \epsilon_o r^2} \] (point charge)

Electric field: \[ \vec{E} = \frac{q}{4\pi \epsilon_o r^2} \hat{r} \] (point charge)
\[ \vec{E} = \int \frac{dq}{4\pi \epsilon_o r^2} \hat{r} \] (general)
\[ E = \frac{\sigma}{2\epsilon_o} \] (plane)

Gauss’ law: \[ \Phi = \vec{n} \cdot \vec{E} \quad A = \int \vec{n} \cdot \vec{E} dA = \frac{q_{enc}}{\epsilon_o} \]

Energy: \[ W = \int \vec{F} \cdot d\vec{s} = \frac{1}{2} mv_f^2 - \frac{1}{2} mv_i^2 = K_f - K_i \]

For conservative forces \[ U_f - U_i = -\int \vec{F} \cdot d\vec{s} \rightarrow K_i + U_i = K_f + U_f \]

Electric potential: \[ V = \frac{U}{q} \quad V = \frac{q}{4\pi \epsilon_o r} \] (point charge)
\[ V = \int \frac{dq}{4\pi \epsilon_o r} \] (general)

Capacitors: \[ q = CV \quad C = \frac{K \epsilon_o A}{d} \] (parallel-plate)
\[ C = C_1 + C_2 \] (parallel)
\[ U = \frac{q^2}{2C} \quad u = \frac{1}{2} \epsilon_o E^2 \]
\[ \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \] (series)

Resistors: \[ i = \frac{dq}{dt} = jA \quad R = \frac{V}{i} \quad R = \frac{\rho L}{A} \] (wire)
\[ P = iV \quad R = R_1 + R_2 \] (series)
\[ q = CV(1 - e^{-t/RC}) \] (charging)
\[ q = q_0 e^{-t/RC} \] (discharging)
\[ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \] (parallel)

On my honor, I have neither given nor received unauthorized aid on this examination.
AC Circuits: \( \omega = \frac{1}{\sqrt{LC}} \) (LC circuit) \( E = E_m \sin(\omega t) \) \( i = I \sin(\omega t - \phi) \) (driven RLC) \( P_{\text{avg}} = \frac{1}{2} I E_m \cos \phi \) \( \cos \phi = \frac{R}{Z} \)

\[
\tan \phi = \frac{X_L - X_C}{R} \quad I = \frac{E_m}{Z} \quad Z = \sqrt{R^2 + (X_L - X_C)^2} \quad X_L = \omega L, \quad X_C = \frac{1}{\omega C}, \quad v_L = L \frac{di}{dt}, \quad v_C = \frac{q}{C}
\]

\[
q = Q_o e^{-R t/(2L)} \cos(\omega t + \phi) \quad \omega' = \left( \omega^2 - \frac{R}{(2L)^2} \right)^{1/2}
\]

First 2 Maxwell’s Eqs.: \( \oint \vec{E} \cdot \vec{n} dA = \frac{q_{\text{enc}}}{\epsilon_0} \quad \oint \vec{E} \cdot d\vec{s} = -N \frac{d\Phi_B}{dt} \)

Last 2 Maxwell’s Eqs.: \( \oint \vec{B} \cdot \vec{n} dA = 0 \quad \oint \vec{B} \cdot d\vec{s} = \mu_o \epsilon_o \frac{d\Phi_E}{dt} + \mu_o i_{\text{enc}} \quad i_d = \epsilon_o \frac{d\Phi_E}{dt} \)

EM Waves: \( c = \frac{E}{B} = \frac{1}{\sqrt{\mu_o \epsilon_o}} \quad \vec{S} = \frac{1}{\mu_o} \vec{E} \times \vec{B} \quad I = S_{\text{avg}} = \frac{1}{c \mu_o} E_{\text{rms}}^2 \quad E_{\text{rms}} = \frac{E_m}{\sqrt{2}} \quad I = \frac{P_s}{4\pi r^2} \)

\[
I = I_o \cos^2 \theta \quad n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \theta_c = \sin^{-1} \frac{n_2}{n_1} \quad \theta_B = \tan^{-1} \frac{n_2}{n_1}
\]

\[
\vec{E} = \vec{E}_m \sin(\vec{k} \cdot \vec{r} - \omega t) \quad \vec{B} = \vec{B}_m \sin(\vec{k} \cdot \vec{r} - \omega t) \quad \vec{E}_m \perp \vec{B}_m \perp \vec{k} \quad c = \omega/k = f \lambda
\]

\[
p_r = \frac{I}{c} \quad \text{(total absorption)} \quad p_r = \frac{2I}{c} \quad \text{(total reflection)} \quad p = \frac{U}{c} \quad \text{(mom. carried by EM radiation of energy U)}
\]
1. If the electric field in a plane electromagnetic wave is given by \( E(x, t) = 8500 \sin(33x - \omega t) \), in SI units, the frequency of the wave is:

(1) \( 2.1 \times 10^3 \) Hz  
(2) \( 5.3 \times 10^6 \) Hz  
(3) \( 9.9 \times 10^9 \) Hz  
(4) \( 6.2 \times 10^{11} \) Hz  
(5) \( 1.6 \times 10^9 \) Hz

2. Which of the following equations, along with a symmetry argument, can be used to calculate the magnetic field between the plates of a charging parallel plate capacitor with circular plates?

(1) \( \oint \vec{B} \cdot d\vec{s} = \mu_0 i + \mu_0 \epsilon_0 d\Phi_E/dt \)  
(2) \( \oint \vec{B} \cdot d\vec{A} = q_{\text{enc}}/\epsilon_0 \)  
(3) \( \oint \vec{B} \cdot d\vec{s} = -d\Phi_B/dt \)  
(4) \( \oint \vec{B} \cdot d\vec{A} = 0 \)  
(5) none of these

3. A cylindrical region contains a uniform electric field that is along the cylinder axis and is changing with time. If \( r \) is the distance from the cylinder axis the magnitude of the magnetic field within the region is:

(1) proportional to \( r \)  
(2) proportional to \( 1/r^2 \)  
(3) uniform  
(4) proportional to \( r^2 \)  
(5) proportional to \( 1/r \)

4. In the figure at right \( E = 120V \), \( R_1 = 10\Omega \), \( R_2 = 20\Omega \), \( R_3 = 30\Omega \), and \( L = 4H \). Immediately after switch S is closed, what is the current through \( R_2 \)?

(1) 4.5 A  
(2) 5.5 A  
(3) 6.0 A  
(4) 4.0 A  
(5) 5.0 A

5. What energy in eV is required to flip the spin of an electron in a magnetic field of 12.9 T from antiparallel alignment to parallel alignment? The magnitude of the magnetic moment of an electron is \( 9.27 \times 10^{-24} \) J/T, and an eV is \( 1.6 \times 10^{-19} \) J.

(1) \( 1.5 \times 10^{-3} \)  
(2) \( 3.7 \times 10^{-4} \)  
(3) \( 4.5 \times 10^{-3} \)  
(4) \( 7.5 \times 10^{-4} \)  
(5) \( 3.0 \times 10^{-3} \)

6. A 30 W light bulb is placed 1.8m below the surface of a pool of water (\( n = 1.333 \)). What is the diameter (in meters) of the circle on the surface of the water through which light is transmitted? (Some of the light is totally internally reflected.)

(1) 2.4  
(2) 4.1  
(3) 2.7  
(4) 4.8  
(5) 1.8

7. In an LC circuit the charge across the capacitor, \( q(t) \), is given by graph 2. Which graph represents the derivative of the current, \( di/dt \)?

(1) graph 1  
(2) graph 4  
(3) graph 3  
(4) none of the graphs  
(5) graph 2
8. A small rocket of mass 10 kg. emits an intense light beam as a rocket exhaust (because electromagnetic energy $U$ carries momentum $U/c$). What must be the minimum total power of the beam in gigawatts ($= 10^9$ W) needed to lift the rocket against the force of gravity at the earth’s surface? ($g = 9.8 \text{ m/s}^2$.)

(1) 59 (2) 0 (3) 50 (4) 15 (5) 29

9. Of the three chief kinds of magnetic materials (diamagnetic, paramagnetic, and ferromagnetic) which are used to make permanent magnets?

(1) only paramagnetic (2) only diamagnetic (3) all three (4) only ferromagnetic (5) only paramagnetic and ferromagnetic

10. A transformer is to take an AC voltage of amplitude 120 V down to an AC voltage of amplitude 6 V. If the number of turns in the primary coil is 1000, how many turns are in the secondary coil?

(1) 50 (2) 500 (3) 20 (4) 20,000 (5) 1,000

11. A metal rod is forced to move with constant velocity along two parallel metal rails, which are connected with a strip of metal (see figure). A magnetic field of 0.5 T points out of the page. The separation between the rails is $L = 30 \text{ cm}$, the rod has resistance 40$\Omega$, and velocity 70 cm/s. What force must be applied to the rod to keep it moving at the constant velocity?

(1) $1 \times 10^{-4} \text{ N}$ (2) $5 \times 10^{-4} \text{ N}$ (3) $3 \times 10^{-4} \text{ N}$ (4) $4 \times 10^{-4} \text{ N}$ (5) $2 \times 10^{-4} \text{ N}$

12. For a driven LCR circuit the current and voltage as a function of time are given by the graphs in the figure. For this circuit is $X_L > X_C$ or $X_C > X_L$? Also, does one need to increase or decrease the driving frequency, $\omega_d$, in order to obtain resonance?

(1) $X_L > X_C$, decrease $\omega_d$ (2) $X_L < X_C$, decrease $\omega_d$ (3) $X_L > X_C$, increase $\omega_d$ (4) $X_L < X_C$, increase $\omega_d$ (5) none of the other answers are correct

13. Gauss' law for magnetism tells us:

(1) the net charge in any given volume (2) the magnetic field of a current element (3) that the line integral of a magnetic field around any closed loop must vanish (4) that magnetic monopoles do not exist (5) that charges must be moving to produce magnetic fields

14. A circular loop of wire has radius 20 cm. If the magnetic field inside the loop is uniform and has the time dependence, $B(t) = 1 + 2t + 3t^2$, where $t$ is measured in seconds and $B$ is measured in Tesla. What is the magnitude of the induced emf in the loop at time $t = 3s$?

(1) 20 V (2) 2.5 V (3) 1.7 V (4) 4.3 V (5) 3.0 V
15. The current $i$ in a long wire is going up as shown in the figure, but decreasing in magnitude. What is the direction of the induced current in the left loop and the right loop. (List the direction of the induced current in the left loop first.)

(1) counterclockwise, clockwise
(2) clockwise, counterclockwise
(3) counterclockwise, counterclockwise
(4) clockwise, clockwise
(5) There is no induced current.

16. The speed of light in vacuum depends on which of the following wave properties?

(1) Wavelength (2) None of these (3) Intensity (4) Frequency (5) Amplitude

17. An unpolarized beam of light with intensity $72 \text{ W/m}^2$ is incident on a stack of 3 polarizing sheets with each sheet’s polarization axis rotated an angle $\theta$ relative to that of the previous sheet. If the beam emerging from the stack has intensity $4 \text{ W/m}^2$, what is its intensity after it has passed through the first 2 sheets?

(1) $12 \text{ W/m}^2$ (2) $8 \text{ W/m}^2$ (3) $18 \text{ W/m}^2$ (4) $6 \text{ W/m}^2$ (5) $24 \text{ W/m}^2$

18. An LC circuit has $C = 8 \mu\text{F}$ and $L = 5 \text{ mH}$. If the maximum voltage on the capacitor is $3 \text{ V}$, what is the maximum current through the inductor?

(1) $0.24 \text{ A}$ (2) $0.48 \text{ A}$ (3) $0.12 \text{ A}$ (4) $0.96 \text{ A}$ (5) $0.06 \text{ A}$

19. The magnetic field is $2 \text{ T}$ into the page and $1 \text{ T}$ out of the page in regions 1 and 2 respectively (see figure). The magnitude of both fields is decreasing at a rate of $-0.005 \text{ T/s}$. If region 1 has area $0.3 \text{ m}^2$ and region 2 has area $0.6 \text{ m}^2$, what is $\oint \vec{E} \cdot d\vec{s}$ for the path of integration shown in the figure?

(1) $4.5 \times 10^{-3} \text{ V}$ (2) $-4.5 \times 10^{-3} \text{ V}$ (3) $-2.0 \times 10^{-3} \text{ V}$ (4) $1.5 \times 10^{-3} \text{ V}$ (5) $-1.5 \times 10^{-3} \text{ V}$

20. Consider an RLC circuit with driving emf amplitude $\varepsilon_m = 12 \text{ V}$, resistance $R = 6\Omega$, inductance $L = 1\text{H}$, and capacitance $C = 2.0\mu\text{F}$. Find the amplitude of the voltage across the resistor at resonance.

(1) $1400 \text{ V}$ (2) $120 \text{ V}$ (3) $2 \text{ V}$ (4) $12 \text{ V}$ (5) $700 \text{ V}$