INSTRUCTIONS, ETC.

1. *Do not open the exam until told to do so.*

2. Please fill in the top of this sheet now.

3. *Your instructor is not permitted to answer any questions during the exam or to assist you in interpreting any of the questions on the exam.*

4. There is *no* penalty for guessing.

5. The exam contains a few problems that deal with the same scenario. The answers do *not* depend upon one another.

6. During the exam you may use a calculator, a writing instrument, instructor-supplied scratch paper and one 8.5 x 11 inch equation sheet.

7. You are permitted to write on the exam.

8. While working the exam, please mark your answers on the exam by circling the letter corresponding to the best answer.

9. *After finishing the exam or at 1050, whichever is first,* please obtain a SCANTRON answer sheet from your instructor. Important instructions for filling out the SCANTRON answer sheet will be found on the exam after the last question. Fill out the answer sheet completely then turn in the exam, the answer sheet, scratch paper and your gouge sheet by 1055. The materials that you turn in represent your work on the exam and all of the materials are subject to evaluation.

**Prefixes:**

- mega (M) = $10^6$
- kilo (k) = $10^3$
- centi (c) = $10^{-2}$
- milli (m) = $10^{-3}$
- micro (μ) = $10^{-6}$
- nano (n) = $10^{-9}$
- pico (p) = $10^{-12}$

**Constants:**

- $\varepsilon_0 = 8.85 \times 10^{-12} \, \text{C}^2/\text{N} \cdot \text{m}^2$
- $\mu_0 = 4\pi \times 10^{-7} \, \text{T} \cdot \text{m/A}$
- $c = 3.00 \times 10^8 \, \text{m/s}$
- $e = 1.60 \times 10^{-19} \, \text{C}$
- $m_e = 9.11 \times 10^{-31} \, \text{kg}$
1. The nucleus of a gold atom has a charge of 79e. An alpha particle has a charge of 2e. The magnitude of the electric force on the alpha particle when it is $1.0 \times 10^{-14}$ m from the center of the nucleus (neglect effect of electrons) is closest to

A. 520 N  
B. 630 N  
C. 250 N  
D. 740 N  
E. 360 N

2. An electron is placed in an electric field of strength and direction $1500 \text{ N/C} \ i$. The acceleration of the electron due to the electric field is closest to

A. $-1.4 \times 10^{14} \text{ m/s}^2 \ j$  
B. $1.4 \times 10^{14} \text{ m/s}^2 \ i$  
C. $-1.4 \times 10^{14} \text{ m/s}^2 \ i$  
D. $2.6 \times 10^{14} \text{ m/s}^2 \ i$  
E. $-2.6 \times 10^{14} \text{ m/s}^2 \ i$

3. Two point charges are placed as shown. The magnitude of the electric field at point P is closest to

A. $3.1 \times 10^5 \text{ N/C}$  
B. $3.7 \times 10^5 \text{ N/C}$  
C. $4.3 \times 10^5 \text{ N/C}$  
D. $5.6 \times 10^5 \text{ N/C}$  
E. $6.1 \times 10^5 \text{ N/C}$
4. Consider the electric dipole shown in the diagram. The row in the table that shows the best direction of the electric field at points P$_1$ and P$_2$, respectively is

<table>
<thead>
<tr>
<th>Row</th>
<th>Direction of $\mathbf{E}$ at P$_1$</th>
<th>Direction of $\mathbf{E}$ at P$_2$</th>
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</thead>
<tbody>
<tr>
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<td>B</td>
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<tr>
<td>E</td>
<td>$\downarrow$</td>
<td>$\uparrow$</td>
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5. A spherical conducting shell has a total charge of $-12.0 \, \mu\text{C}$. In addition, a $+6.0 \, \mu\text{C}$ point charge is placed at the center of the shell’s cavity. The net electric flux through the gaussian surface shown in the figure is closest to

A. $2.0 \times 10^6 \, \text{N} \cdot \text{m}^2 / \text{C}$
B. $-2.0 \times 10^6 \, \text{N} \cdot \text{m}^2 / \text{C}$
C. $-1.4 \times 10^6 \, \text{N} \cdot \text{m}^2 / \text{C}$
D. $-6.8 \times 10^5 \, \text{N} \cdot \text{m}^2 / \text{C}$
E. $6.8 \times 10^5 \, \text{N} \cdot \text{m}^2 / \text{C}$

6. A conducting spherical shell of radius $r_o = 0.070 \, \text{m}$ has a uniform surface charge density of $\sigma = 2.0 \, \mu\text{C/m}^2$ on its outer surface. The magnitude of the electric field at points 0.050 m and 0.100 m (from center of shell), respectively are closest to

<table>
<thead>
<tr>
<th>Row</th>
<th>$E$ at 0.050 m from center</th>
<th>$E$ at 0.100 m from center</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>$1.1 \times 10^5 , \text{N/C}$</td>
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<tr>
<td>B</td>
<td>$1.8 \times 10^6 , \text{N/C}$</td>
<td>0</td>
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<tr>
<td>C</td>
<td>0</td>
<td>$1.8 \times 10^6 , \text{N/C}$</td>
</tr>
<tr>
<td>D</td>
<td>$1.1 \times 10^5 , \text{N/C}$</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>
7. Three charges are located as shown below. Taking the potential at infinity to be zero, the potential at the origin is closest to

A. $2.25 \times 10^4$ V  
B. $3.15 \times 10^4$ V  
C. $1.35 \times 10^4$ V  
D. $3.95 \times 10^4$ V  
E. $2.75 \times 10^4$ V

8. The electric field between two surfaces is given by $E = (500r^2) \hat{r}$ where $E$ is in V/m and $r$ is in m. As you move along in the direction of the electric field from $r = 1.0$ m to $r = 5.0$ m, the magnitude of the potential difference you move through is closest to

A. 12000 V  
B. 21000 V  
C. 14000 V  
D. 4000 V  
E. 8000 V

9. The work done by the electric force in moving a $-5.00 \, \mu C$ charge from a place where the electric potential is 0 V to a place where the electric potential is 150 V is closest to

A. $-750$ J  
B. $750$ J  
C. $-7.5 \times 10^{-4}$ J  
D. $7.5 \times 10^{-4}$ J  
E. 0
10. In a region of space, the electric potential, in volts, is given by \( V = (2y^2 - 3x^2z) \). The electric field in this region is

A. \( \mathbf{E} = (4y \mathbf{j} - 6xz \mathbf{k}) \) N/C

B. \( \mathbf{E} = (6xz \mathbf{i} - 4y \mathbf{j} + 3x^2 \mathbf{k}) \) N/C

C. \( \mathbf{E} = (3x^2 \mathbf{i} + 2y^2 \mathbf{j} - z \mathbf{k}) \) N/C

D. \( \mathbf{E} = (2y^2 \mathbf{i} - 0 \mathbf{j} - 3x^2z \mathbf{k}) \) N/C

E. \( \mathbf{E} = (0 \mathbf{i} + 2y^2 \mathbf{j} - 3x^2z \mathbf{k}) \) N/C

11. In the diagram below, the dashed lines are equipotentials. The region of space where the magnitude of the electric field is strongest is

\[
\begin{array}{cccccc}
A & B & C & D & E \\
0 \text{ V} & 1 \text{ V} & 2 \text{ V} & 3 \text{ V} & 4 \text{ V} & 5 \text{ V}
\end{array}
\]

For the next two problems, consider the circuit as shown below. The circuit is in electrostatic equilibrium.

12. The charge on the 3.00 \( \mu \text{F} \) capacitor is closest to

A. 24.0 \( \mu \text{C} \)

B. 507 \( \mu \text{C} \)

C. 338 \( \mu \text{C} \)

D. 143 \( \mu \text{C} \)

E. 45.0 \( \mu \text{C} \)

13. The total energy stored in the system of capacitors is closest to

A. 1.5 \text{ mJ} \quad \text{B. 1.4 mJ} \quad \text{C. 1.3 mJ} \quad \text{D. 1.2 mJ} \quad \text{E. 1.1 mJ}
14. The terminals of a 12.0 V battery are connected by a copper wire with resistivity $1.68 \times 10^{-8} \ \Omega \cdot \text{m}$ and cross-sectional area $2.00 \times 10^{-5} \ \text{m}^2$. If the power dissipated is $1.40 \times 10^3 \ \text{W}$, the length of the wire is closest to

A. 345 m
B. 234 m
C. 122 m
D. 456 m
E. 567 m

15. If the voltmeter reads $18.0 \pm 0.2 \ \text{V}$ and the ammeter reads $3.0 \pm 0.2 \ \text{A}$, the resistance of the resistor is best represented by

A. $6.0 \pm 0.7 \ \Omega$
B. $6.0 \pm 0.2 \ \Omega$
C. $6.0 \pm 0.5 \ \Omega$
D. $54 \pm 0.5 \ \Omega$
E. $54 \pm 0.2 \ \Omega$

16. The equivalent resistance between points a and b of the following resistor network is closest to

A. 6.0 \ \Omega
B. 2.0 \ \Omega
C. 1.0 \ \Omega
D. 4.0 \ \Omega
E. 13 \ \Omega
17. The magnitude of the readings on ammeters $A_1$ and $A_2$, respectively, are closest to

<table>
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<tr>
<th></th>
<th>reading on $A_1$</th>
<th>reading on $A_2$</th>
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</thead>
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<tr>
<td>A</td>
<td>0.030 A</td>
<td>0.006 A</td>
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<tr>
<td>B</td>
<td>0.030 A</td>
<td>0.038 A</td>
</tr>
<tr>
<td>C</td>
<td>0.030 A</td>
<td>0.024 A</td>
</tr>
<tr>
<td>D</td>
<td>0.19 A</td>
<td>0.015 A</td>
</tr>
<tr>
<td>E</td>
<td>0.19 A</td>
<td>0.038 A</td>
</tr>
</tbody>
</table>

18. For the given circuit, the current through the 5.0 $\Omega$ resistor is closest to

A. 0.46 A up the page
B. 0.46 A down the page
C. 0.85 A up the page
D. 0.85 A down the page
E. 0.00 A

19. Assume the switch for the given $RC$ circuit has been in position A for a very long time. Then, at time $t = 0$, the switch is placed in position B. The amount of charge on the capacitor at $t = 4.00 \times 10^{-2}$ s is closest to

A. $1.93 \times 10^{-5}$ C
B. $2.19 \times 10^{-5}$ C
C. $2.31 \times 10^{-5}$ C
D. $2.76 \times 10^{-5}$ C
E. $3.14 \times 10^{-5}$ C
20. The figure on the left shows a positively charged particle moving to the right in a magnetic field directed into the page. The figure on the right shows a magnetic force (directed into the page) acting on a negatively charged particle moving to the right. The row that most correctly gives the direction of the magnetic force on the positive particle (left diagram) and the direction of the magnetic field for the negative particle (right diagram) is

<table>
<thead>
<tr>
<th>Row</th>
<th>Direction of force on positive particle</th>
<th>Direction of magnetic field for negative particle</th>
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<td>E</td>
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21. A current loop has a dipole moment of $\mu = 2.0 \text{ A} \cdot \text{m}^2 \text{ i}$ and is placed in a magnetic field of $B = 3.0 \text{ T k}$. The torque on the loop and the potential energy, respectively, is best given by

<table>
<thead>
<tr>
<th></th>
<th>torque</th>
<th>potential energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.0 N·m j</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>6.0 J</td>
</tr>
<tr>
<td>C</td>
<td>−6.0 N·m j</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>−6.0 N·m i</td>
<td>6.0 J</td>
</tr>
<tr>
<td>E</td>
<td>−6.0 N·m j</td>
<td>−6.0 J</td>
</tr>
</tbody>
</table>

22. An electron moves in a circular path as shown in a region with a constant magnetic field. The direction of the magnetic field is

A. out of page
B. into page
C. to the right
D. to the left
E. towards the center of the circle
The next two problems deal with two parallel, current-carrying wires with currents as shown. The wires are perpendicular to the plane of the page and separated by a distance of 0.8 m.

\[
I_1 = 20 \, \text{A} \quad I_2 = 30 \, \text{A}
\]

23. The force per unit length on each wire is closest to

A. \(5.0 \times 10^{-5} \, \text{N/m} \) toward the other
B. \(5.0 \times 10^{-5} \, \text{N/m} \) away from the other
C. \(1.5 \times 10^{-4} \, \text{N/m} \) toward the other
D. \(1.5 \times 10^{-4} \, \text{N/m} \) away from the other
E. \(7.5 \times 10^{-5} \, \text{N/m} \) away from the other

24. The magnetic field at a point midway between the wires is closest to

A. 0
B. \(5.0 \times 10^{-3} \, \text{T} \) down the page
C. \(5.0 \times 10^{-3} \, \text{T} \) up the page
D. \(2.5 \times 10^{-3} \, \text{T} \) down the page
E. \(2.5 \times 10^{-3} \, \text{T} \) up the page

25. A current of 3.0 A is running through a 0.20 m long solenoid. If the magnitude of the magnetic field in the middle of the solenoid is \(1.0 \times 10^{-3} \, \text{T} \), the number of loops in the solenoid is closest to

A. 36
B. 82
C. 76
D. 53
E. 45
In the next two problems, a 6-turn conducting circular coil of radius 0.20 m is in a 0.50 T magnetic field pointing into the page. The coil is then stretched such that its area is reduced by one half in 0.30 s.

26. The direction of the induced current is

A. counter clockwise
B. clockwise
C. into the page
D. out of the page
E. 0

27. The magnitude of the average induced emf is closest to

A. 0.41 V
B. 0.83 V
C. 0.52 V
D. 0.13 V
E. 0.63 V

28. The north pole of a magnet is moving toward a coil as shown. The following is true concerning potentials \( V_b \) and \( V_a \):

A. \( V_b = V_a \)
B. \( V_b > V_a \)
C. \( V_b < V_a \)
D. \( V_b \geq V_a \)
E. \( V_b \leq V_a \)
29. A 2.0 A current flows through a 0.20 m long solenoid with a cross sectional area of 0.060 m² and 200 turns. The total energy stored in the solenoid (inductor) is closest to

A. 4.0×10⁻² J
B. 5.0×10⁻² J
C. 1.0×10⁻² J
D. 2.0×10⁻² J
E. 3.0×10⁻² J

30. An LC circuit produces electromagnetic oscillations with a frequency of 1.50×10⁶ Hz. If the capacitance is 2.00 nF, the inductance in the circuit is closest to

A. 1.98×10⁻⁶ H
B. 4.35×10⁻⁶ H
C. 3.47×10⁻⁴ H
D. 5.63×10⁻⁶ H
E. 2.22×10⁻⁴ H

31. In the circuit shown, the capacitor is initially charged by a source which is then removed from the circuit. After the switch is closed, the charge on the capacitor oscillates at a frequency closest to

A. 0.21 kHz
B. 1.45 kHz
C. 1.32 kHz
D. 8.29 kHz
E. 5.63 kHz

![Circuit Diagram]
The next two problems deal with an electromagnetic wave in a vacuum. The electric field is given by:

\[ E_y = 40.0 \sin[(1.40 \times 10^7 \text{ m}^{-1})x - (4.20 \times 10^{15} \text{ rad/s})t]\]

where 40.0 has units of V/m, \( x \) has units of m, and \( t \) has units of s.

32. The wavelength and direction of travel of the wave are closest to

A. 449 nm in the positive \( x \) direction
B. 449 nm in the negative \( x \) direction
C. 333 nm in the positive \( x \) direction
D. 333 nm in the negative \( x \) direction
E. 282 nm in the positive \( x \) direction

33. If the electromagnetic wave is fully reflected by a surface, the radiation pressure is closest to

A. \( 2.03 \times 10^{-8} \text{ N/m}^2 \)
B. \( 3.45 \times 10^{-7} \text{ N/m}^2 \)
C. \( 1.42 \times 10^{-8} \text{ N/m}^2 \)
D. \( 7.08 \times 10^{-9} \text{ N/m}^2 \)
E. \( 5.63 \times 10^{-9} \text{ N/m}^2 \)

34. Which of the following statements is \textit{false} according to Maxwell’s equations?

A. A changing electric field produces a magnetic field.
B. A changing magnetic field produces an electric field.
C. The net flux of the electric field through a closed surface is proportional to the amount of charge enclosed within the surface.
D. The net flux of the magnetic field through a closed surface is proportional to the amount of charge enclosed within the surface.
E. The equations incorporate the experimental observation that there are no magnetic monopoles in nature.
35. An object is placed in front of a concave mirror, as shown. The image is

A. real, upright and larger than object.
B. real, inverted and smaller than object.
C. virtual, upright and smaller than object.
D. virtual, inverted and larger than object.
E. virtual, upright and larger than object.

For the next two problems, a diver shines a light upward from beneath the surface of a swimming pool.

36. If the diver shines the light at an angle of 29° to the vertical, the angle the light leaves the water, relative to the vertical, is closest to

A. 49°
B. 25°
C. 34°
D. 40°
E. 28°

37. The minimum angle to the vertical at which the diver would need to shine the light so that no light leaves the water is closest to

A. 25°
B. 34°
C. 40°
D. 49°
E. 28°
38. An object is placed 30 cm to the left of a diverging lens with a focal length of $-20$ cm. The image is

A. real, upright and 12 cm to the left of the lens
B. real, inverted and 10 cm to the right of the lens
C. virtual, upright and 12 cm to the left of the lens
D. virtual, inverted and 10 cm to the right of the lens
E. virtual, upright and 10 cm to the left of the lens

39. Two converging lenses are placed 60 cm apart. The focal length of the first lens is 20 cm and the focal length of the second lens is 10 cm. An object is placed 40 cm to the left of the first lens, as shown. The final image is

A. upright and 20 cm to the right of lens 2
B. inverted and 25 cm to the left of lens 2
C. upright and 25 cm to the right of lens 2
D. inverted and 20 cm to the right of lens 1
E. upright and 20 cm to the right of lens 1
40. Monochromatic light of wavelength 537 nm strikes a screen containing 2 slits that are 5.0 μm apart and 2.0 m from a viewing screen. The distance on the screen from the center of the interference pattern to the second order maximum is closest to

A. 99 cm  
B. 62 cm  
C. 30 cm  
D. 44 cm  
E. 53 cm

41. You notice that when white light strikes the surface of a coated lens at normal incidence the reflected light appears greenish blue and is brightest at wavelengths centered at 500 nm. The minimum thickness of the lens coating is closest to

A. 96 nm  
B. 192 nm  
C. 288 nm  
D. 540 nm  
E. 630 nm

42. A Michelson interferometer can be used to make very precise displacement measurements. If a 540 nm laser is used as the light source and if moving one of the mirrors results in 600 fringes passing by a reference line, the displacement of movable mirror is closest to

A. 135 μm  
B. 270 μm  
C. 185 μm  
D. 240 μm  
E. 162 μm
43. Light of wavelength 440 nm passes through a slit 5.0 μm wide. The angular width of the central maximum on a screen 2.0 m away is closest to

A. 8.0°
B. 9.0°
C. 10°
D. 11°
E. 12°

44. A 5000 line/cm grating produces a third-order fringe at a 46° angle. The wavelength of light used and the maximum order observed are closest to

A. 480 nm; 3rd order
B. 480 nm; 4th order
C. 120 nm; 4th order
D. 120 nm; 2nd order
E. 120 nm; 3rd order

45. Unpolarized light of intensity $I$ is incident upon the first of two successive ideal Polaroid sheets (filters). The intensity of the transmitted light is 40% of the initial intensity. The angle $\theta$, between the transmission axes of the filters is closest to

A. 51°
B. 27°
C. 35°
D. 60°
E. 42°
Instructions for filling out the SCANTRON answer sheet

1. Please fill out the form completely, but only write or mark in the spaces provided.

2. Please fill in the bubbles completely as shown in the example on the form. If you make a mistake, either erase completely or obtain a new form.

"I think you should be more explicit here in step two."

Enjoy your summer!
<table>
<thead>
<tr>
<th>Question</th>
<th>Version A</th>
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<tbody>
<tr>
<td>1</td>
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