Solutions

Physics 272– Final Exam
Wednesday, May 9, 2012
Prof. Mohan Kalekar

Your name sticker with exam code

1. The exam will last from 1:30pm to 3:00pm. 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 labelled NAME, 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 Student ID Number. Under COURSE enter 272. Under CODE enter the exam code given above.

4. During the exam, you may use pencils, a calculator, and ONE $8\frac{1}{2} \times 11$" sheet of paper with formulas and notes.

5. There are 24 multiple-choice questions on the exam. For each question, mark only one answer on the answer sheet. There is no subtraction of points for an incorrect answer, so even if you cannot work out the answer to a question, you should make an educated guess. At the end of the exam, hand in only the answer sheet. Retain this question paper for future reference and study.

6. Useful numerical constants are given on the next page. Before starting the exam, make sure that your copy contains the page of constants and all 24 questions. Bring your exam to the proctor if this is not the case.
Acceleration due to gravity $g = 9.8 \text{ m/s}^2$
Elementary charge $e = 1.6 \times 10^{-19} \text{ C}$
Proton charge $= 1.6 \times 10^{-19} \text{ C}$
Electron charge $= -1.6 \times 10^{-19} \text{ C}$
1 electron volt (eV) $= 1.6 \times 10^{-19} \text{ J}$
Proton mass $= 1.673 \times 10^{-27} \text{ kg} = 938.3 \text{ MeV/c}^2$
Electron mass $= 9.11 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV/c}^2$
$1/4\pi\varepsilon_0 = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$
$
\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m}/\text{A}$
Index of refraction of air $= 1.00$

Powers of ten:

<table>
<thead>
<tr>
<th>femto(f)</th>
<th>pico(p)</th>
<th>nano(n)</th>
<th>micro(\mu)</th>
<th>milli(m)</th>
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<tbody>
<tr>
<td>$10^{-15}$</td>
<td>$10^{-12}$</td>
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<td>$10^{-3}$</td>
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<td>centi(c)</td>
<td>kilo(k)</td>
<td>Mega(M)</td>
<td>Giga(G)</td>
<td>Tera(T)</td>
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<td>$10^{-2}$</td>
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**Question 3**

**Question 4**

**Question 5**

**Question 6**
\[ B_x : \text{can be anything, since it doesn't contribute to force.} \]
\[ B_y : F(\hat{z}) = (+e)(+1)(-\hat{y}) \times \vec{B} \]
\[ \implies \vec{B} = -B_y \hat{z} \]

1. A proton is moving in the negative x-direction. It enters a magnetic field, and the magnetic force on the proton is ENTIRELY in the positive z-direction. If the components of the magnetic field are \( (B_x, B_y, B_z) \), which of the following is possible?
   a) \( B_x = 0; B_y > 0; B_z = 0 \)
   b) \( B_x = 0; B_y < 0; B_z > 0 \)
   c) \( B_x > 0; B_y = 0; B_z = 0 \)
   d) \( B_x < 0; B_y < 0; B_z = 0 \)
   e) \( B_x = 0; B_y < 0; B_z < 0 \)

2. A proton (charge = +e; mass = \( M \)) and an alpha particle (charge = +2e; mass = 4\( M \)) both enter the same magnetic field, and both move in circular paths. The radius of the alpha particle's path is half that of the proton's path. Then the momentum of the alpha particle is
   a) equal to that of the proton
   b) twice that of the proton
   c) four times that of the proton
   d) eight times that of the proton
   e) sixteen times that of the proton

3. See the figure for this question. At \( y = +a \), a long straight wire carries current \( I \) OUT of the plane of the paper. At \( y = -a \), another long straight wire carries current \( I \) INTO the plane of the paper. At any point \( P \) on the positive x-axis, what is the direction of the magnetic field?
   a) In the positive y-direction
   b) In the negative x-direction
   c) Not along either the x- or y-axes
   d) In the positive x-direction
   e) In the negative y-direction

4. See the figure for this question. Note the direction of the current \( I \) in the loop, which consists of two straight segments and two semicircular segments (radii \( R_1 \) and \( R_2 \)) with a common center at \( C \). The magnetic field at \( C \) is \( \mu_0 I/4 \) times
   a) \( (1/R_1) + 1/R_2 \) into the paper
   b) \( (1/R_1) + 1/R_2 \) out of the paper
   c) \( (1/R_1) - 1/R_2 \) into the paper
   d) \( (1/R_1) - 1/R_2 \) out of the paper
   e) None of the other answers

   Straight segments:
   \[ \vec{d}s \times \hat{n} = 0 \implies \vec{B} = 0 \]

   Semicircles:
   \[ B = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{s}}{R^2} = \frac{\mu_0 I \pi R}{4\pi R^2} = \frac{\mu_0 I}{4R} \]
   \[ \vec{B}_1 \text{ is OUT} \quad \vec{B}_2 \text{ is INTO.} \]
5. See the figure for this question. A long straight wire carries current $i$. Note the direction of the current. A rectangular wire loop lies to the left of it. Which of the following changes will induce a COUNTERCLOCKWISE current in the rectangular loop?

- I: Moving the loop to the right, towards the straight wire
- II: Moving the loop up in the plane of the paper, i.e. parallel to the straight wire
- III: Keeping the loop stationary, but increasing the current in the straight wire

\[ \text{I: Increasing outward flux} \Rightarrow \text{CW induced current.} \]
\[ \text{II: No change in flux} \Rightarrow \text{no induced current.} \]
\[ \text{III: Increasing outward flux} \Rightarrow \text{CW induced current.} \]

a) I only
b) All three
c) I and III only
d) III only
e) None of the three

6. See the figure for this question. A metal rail with a sliding metal rod is in a uniform, constant magnetic field $B$ directed into the plane of the paper. The rod is sliding at speed $v$ to the right. If the resistance of the assembly is $R$, what will be the induced current?

\[ \phi B = BA \bar{L} \]
\[ I = \frac{\frac{d\phi_B}{dt}}{R} = \frac{B \bar{v} \frac{d\alpha}{dt}}{R} = \frac{B \bar{v}}{R} \]

a) Zero
b) $B\bar{b}v/R$ clockwise
c) $B\bar{b}v/R$ counterclockwise
d) $B\bar{a}v/R$ clockwise
e) $B\bar{a}v/R$ counterclockwise

7. The current in a solenoid is increasing at a rate of 0.25 A/s. If the self-induced emf is $8 \times 10^{-4}$ V, what is the solenoid's inductance?

a) About 0.2 mH
b) About 3.2 mH
c) About 8.0 mH
d) About 0.8 mH
e) About 2.0 mH

\[ \frac{d}{dt} \Rightarrow L = \frac{\frac{8 \times 10^{-4}}{0.25}}{0.25} = 3.2 \times 10^{-3} \text{ H.} \]
8. The primary side of a transformer has 250 turns, an rms current of 15 mA, and an rms voltage of 24 V. If the secondary rms voltage is 72 V, what are the number of turns and the rms current in the secondary?

a) 750 turns and 45 mA
b) 750 turns and 15 mA
c) 750 turns and 5 mA
d) 83 turns and 45 mA
e) 83 turns and 5 mA

\[ N_s = N_p \frac{V_s}{V_p} = \frac{(250)(72)}{24} = 750 \text{D.} \]

\[ I_s = \frac{V_p I_p}{V_s} = \frac{(24)(15)}{72} = 5 \text{ mA.} \]

9. Which of the following statements is false?

a) Transformers can't work with DC input
b) Electric utilities use transformers so as to reduce power losses during transmission
c) Electric utilities use transformers to step down the voltage before transmission
d) A step-down transformer decreases the voltage
e) A step-down transformer increases the current

10. An electromagnetic wave has its associated electric field pointing along the \(-j\) direction. Which of the following sets are possible directions for the associated magnetic field \(B\) and the Poynting vector \(S\)?

- I: \(B\) along \(+k\); \(S\) along \(-i\)
- II: \(B\) along \(-i\); \(S\) along \(-k\)
- III \(B\) along \(-k\); \(S\) along \(+i\)

\[ \vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B} \]

a) All three are possible
b) I and II are possible; III is not
c) I and III are possible; II is not
d) III is possible; I and II are not
e) II and III are possible; I is not

11. The sun radiates \(3.8 \times 10^{26} \text{ W}\) of power in all directions. Sunlight shines perpendicularly on a solar panel of area \(2.0 \text{ m}^2\) located on the earth, which is \(1.5 \times 10^{11} \text{ m}\) from the sun. What is the radiation pressure on the panel, assuming that it completely absorbs the sunlight hitting it?

a) About \(6.3 \times 10^{10} \text{ N/m}^2\)
b) About \(6.3 \times 10^{11} \text{ N/m}^2\)
c) About \(6.3 \times 10^{12} \text{ N/m}^2\)
d) About \(4.5 \times 10^9 \text{ N/m}^2\)
e) About \(4.5 \times 10^{-6} \text{ N/m}^2\)

\[ I = \frac{\text{Power emitted}}{4\pi r^2} = \frac{3 \times 10^{26}}{4\pi (1.5 \times 10^{11})^2} = 1.344 \text{ W/m}^2. \]

\[ \text{Pressure} = \frac{I}{c} = \frac{1.344}{3 \times 10^8} = 4.5 \times 10^{-6} \text{ N/m}^2. \]
12. A spaceship navigates through interstellar space by continuously emitting an electromagnetic beam of power $3 \times 10^{10} \text{ W}$. If the ship’s mass is 2000 kg, what is its acceleration?

\[
F = \frac{\text{Power}}{c} = \frac{3 \times 10^{10}}{3 \times 10^8} = 100 \text{ N},
\]

\[
a = \frac{F}{m} = \frac{100}{2000} = 0.05 \text{ m/s}^2.
\]

a) About 0.85 m/s²  
b) About 5.2 m/s²  
c) About 9.8 m/s²  
d) About 0.05 m/s²  
e) About 17.0 m/s²

13. Which of the following statements is false?

a) The brilliance of a diamond is due to its high index of refraction and the phenomenon of total internal reflection.

b) When light goes from air into glass, its wavelength decreases.

c) When light goes from air into glass, its frequency stays the same.

d) Sound waves have a smaller wavelength than that of visible light.

e) A fish under water looking up at the surface sees a circular hole surrounded by a mirror.

14. See the figure for this question. A cylindrical tank with opaque sides but an open top has a diameter of 4.0 m and is completely filled with water (index of refraction = 1.33). When the setting sun reaches an angle of 28° above the horizon, sunlight ceases to illuminate any part of the bottom of the tank. How deep is the tank? (Note that 28° above the horizon is 62° from directly overhead).

\[d = \frac{4.0}{\tan 41.6°} = 4.5 \text{ m}.
\]

a) About 1.5 m  
b) About 4.5 m  
c) About 6.0 m  
d) About 10.6 m  
e) About 2.1 m

15. An underwater swimmer shines a flashlight at the water surface. The light beam makes an angle of 55° relative to the normal to the surface. If the index of refraction of water is 1.33, at what angle \(\theta\) (relative to the normal) will the light emerge into air?

\[1.33 \sin 55° = 1 \cdot \sin \theta
\]

a) \(\theta < 25°\)  
b) \(25° \leq \theta < 45°\)  
c) \(45° \leq \theta < 70°\)  
d) \(70° \leq \theta < 90°\)  
e) The light will be totally internally reflected
16. A concave mirror has a focal length \( f > 0 \). An object is placed a distance \( 2f \) from the mirror. Then the image will be

a) real, inverted, smaller than the object
\[
\frac{1}{i} + \frac{1}{o} = \frac{1}{s} \\
\Rightarrow \frac{1}{i} = \frac{1}{s} - \frac{1}{2f} = \frac{1}{2s} \\
i = 2s \text{ Real.}
\]

b) virtual, upright, bigger than the object
\[
m = -\frac{s}{2f} = -\frac{2s}{2s} = -1.
\]

17. A mirror forms an image that is virtual, one-quarter of the size of the object, and is 3 cm from the mirror. What is the focal length of the mirror?

a) +2.4 cm \( i < 0 \) and \( m = -\frac{s}{p} = +\frac{1}{4} \) \( \Rightarrow i = -\frac{1}{4}p \).

b) +4.0 cm

c) +1.0 cm \( \Rightarrow i = -\frac{s}{p} = -3 \) cm and \( p = +12 \) cm.

d) +0.6 cm

e) -4.0 cm \( \frac{1}{p} + \frac{1}{-3} = \frac{1}{s} = -\frac{3}{12} = -\frac{1}{4} \) \( \Rightarrow s = -4 \) cm.

18. A camera lens with 50 mm focal length is used to take a picture of a person 1.6 m tall. How far from the camera must the person stand so that the image size on film is 24 mm?

a) About 1.9 m

\[
l_i = \frac{i}{p} = \frac{24 \times 10^{-3}}{1.6} = 0.015
\]

b) About 2.2 m

c) About 2.8 m

d) About 3.4 m

\[
\Rightarrow \frac{1}{p} + \frac{1}{0.015} = \frac{1}{s} \Rightarrow p = 3.4 \text{ m.}
\]

e) About 4.1 m

19. Diverging lenses have focal length \( f < 0 \). Which of the following statements is false?

a) A diverging lens always forms a virtual image of a real object.

\[
\Rightarrow \frac{1}{i} = \frac{f}{p} - \frac{1}{p} < 0.
\]

b) Diverging lenses are thicker at the ends than at the middle.

\[
n = -\frac{s}{p} = \frac{s}{s-p}
\]

c) A diverging lens always forms an enlarged image of a real object.

\[
\Rightarrow |m| < 1.
\]

d) A diverging lens always forms an upright image of a real object.

e) Nearsighted people can use diverging lenses to correct this defect.

20. A diverging lens of focal length \(-6.0\) cm is placed 12.0 cm to the right of an object. A converging lens of focal length \(+8.0\) cm is placed 10.0 cm to the right of the diverging lens. Where does the final image lie?

a) About 5.1 cm to the left of the converging lens

\[
\Rightarrow \frac{1}{i_2} + \frac{1}{i_1} = \frac{1}{s} \\
i_1 = -4.0 \text{ cm.}
\]

b) About 18.7 cm to the right of the converging lens

c) About 3.4 cm to the right of the converging lens

d) About 24.0 cm to the left of the converging lens

e) About 5.1 cm to the right of the converging lens

\[
P_2 = 10.0 - (-4.0) = +14.0 \text{ cm,}
\]

\[
\frac{1}{+14.0} + \frac{1}{i_2} = \frac{1}{+8.0} \Rightarrow i_2 = +18.7 \text{ cm,}
\]
21. In a darkened room, a burning candle is placed 25 cm from a wall. A converging lens of focal length 6.0 cm is placed somewhere between the candle and the wall, such that the image of the flame is focussed on the wall. Which of the following is one of the possible distances of the candle from the lens?

a) 4.8 cm  
\[ \frac{1}{P} + \frac{1}{\hat{v}} = \frac{1}{6} \]  and  \[ \hat{v} = 25 - P \]

b) 7.9 cm

\[ \Rightarrow \frac{1}{P} + \frac{1}{25 - P} = \frac{1}{6} \Rightarrow \frac{25}{P(25-P)} = \frac{1}{6} \]

c) 10.0 cm

d) 17.1 cm

e) 20.2 cm  \[ 25P - P^2 = 150 \Rightarrow P = 10 \text{ cm or 15 cm.} \]  
\[ \text{Both okay!} \]

22. In a double-slit experiment, the third-order \( (m = 3) \) bright fringe on a distant screen is located 4.2 mm from the central maximum. The distance between the slits is 200 times the wavelength of the incident light. What is the distance between the slits and the screen?

a) 172 cm  \[ d \sin \theta = m \lambda \]  and  \[ \sin \theta \propto \frac{x}{L} \]

b) 14 cm

c) 83 cm

d) 252 cm

e) 28 cm  \[ \Rightarrow L = 280 \text{ mm} = 28 \text{ cm}. \]

23. Light of wavelength 546.1 nm is incident upon a diffraction grating and forms a third-order \( (m = 3) \) principal maximum at an angle of 81°. How many lines per mm are there in the grating?

\[ \Rightarrow \text{a) About 600 lines per mm} \]

\[ d = \frac{m \lambda}{\sin \theta} = \frac{(3)(546.1)}{\sin 81°} = 1659 \text{ nm.} \]

\[ \text{b) About 16 lines per mm} \]

c) About 166 lines per mm

d) About 1660 lines per mm

e) About 16600 lines per mm

\[ \Rightarrow \frac{1}{d} = \frac{1}{1659} = 603 \text{ lines/mm.} \]

24. A spy satellite circles the earth at an altitude of 200 km and carries out surveillance with a telescopic camera having a lens diameter of 35 cm. In light of wavelength 550 nm, what is the closest that two objects on earth can be and still be distinguished by this camera?

\[ \Rightarrow \text{a) About 38 cm} \]

\[ \theta_R \approx \frac{X}{L} = 1.22 \frac{\lambda}{D} \]

\[ \text{b) About 260 cm} \]

c) About 745 cm

d) About 13 cm

e) About 5 cm  \[ X = \frac{(1.22)(550 \times 10^{-9})(200 \times 10^3)}{0.35} \]

\[ = 0.38 \text{ m} \]