Useful numerical constants:

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 $= 9.11 \times 10^{-31} \text{ kg} = 0.511 \text{ MeV/c}^2$

$\frac{1}{4\pi \varepsilon_0} = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$

$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$

Acceleration due to gravity $g = 9.8 \text{ m/s}^2$

Index of refraction of air $= 1.00$

Powers of ten:

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1. A proton (charge = \(+e\); mass = \(M\)) and a deuteron (charge = \(+e\); mass = \(2M\)) enter the same magnetic field, and both move in circular paths. The radius of the proton’s path is twice that of the deuteron’s. It follows that the proton’s kinetic energy is

a) twice that of the deuteron’s  
b) half that of the deuteron’s  
c) eight times that of the deuteron’s  
d) four times that of the deuteron’s  
e) one-quarter of the deuteron’s

2. At \(x = 0\) a long straight wire carries current \(I\) INTO the plane of the paper. At \(x = D\), another long straight wire carries current \(2I\) INTO the plane of the paper. What is the direction of the force on the wire at the origin?

a) Towards the positive x-direction  
b) Towards the positive y-direction  
c) Out of the plane of the paper  
d) Towards the negative x-direction  
e) None of the other answers

3. In the preceding problem, at what point on the x-axis is the net magnetic field due to the two wires equal to zero? (Exclude points at infinity from consideration).

a) \(x = D\)  
b) \(x = D/2\)  
c) \(x = D/3\)  
d) \(x = -D\)  
e) \(x = -2D\)
4. A segment of a wire is in the shape of an arc of a circle of radius \( R \), and carries current \( I \) in the direction shown. The arc subtends a 45° angle. What is the contribution to the magnetic field at the center \( C \) by the current in the arc?

a) \( \mu_0 I/4R \) out of the paper
b) \( \mu_0 I/4R \) into the paper
c) \( \mu_0 I/2R \) into the paper
d) \( \mu_0 I/16R \) into the paper
e) \( \mu_0 I/16R \) out of the paper

5. A rectangular loop of wire of dimensions \( a \) and \( b \) is being pulled with speed \( v \) out of a uniform magnetic field \( B \) directed into the paper. If the loop has a resistance \( R \), what is the induced current in it, when it is partially out of the field as shown in the figure?

a) \( Bav/R \) clockwise
b) \( Bbv/R \) clockwise
c) Zero
d) \( Bav/R \) counterclockwise
e) \( Bbv/R \) counterclockwise
6. Two concentric circular loops of wire lie in the plane of the paper. The outer loop carries a current $I$. Which of the following is true?

- I: If $I$ is counterclockwise and constant, the induced current in the inner loop will be nonzero and clockwise.
- II: If $I$ is counterclockwise and increasing, the induced current in the inner loop will be nonzero and counterclockwise.
- III: If $I$ is clockwise and decreasing, the induced current in the inner loop will be nonzero and clockwise.

a) I and II are true; III is false
b) II and III are true; I is false
c) I and III are true; II is false
d) Only III is true
e) Only I is true

7. If the current through an inductor is INCREASING, which of the following statements will be true?

a) The self-induced emf is zero
b) The energy in the inductor remains constant
c) The inductance of the inductor is decreasing
d) The inductance of the inductor is increasing
e) None of the other statements are true
9. Which of the following statements are true?

• I: Electric utilities use a transformer to step up the voltage before transmission, so as to reduce power losses during transmission.
• II: Transformers work equally well with DC input as with AC.
• III: A step-up transformer increases both the voltage and the current.

a) I and II are true; III is not
b) Only I is true
c) I and III are true; II is not
d) Only II is true
e) None of the statements are true

10. An electromagnetic wave is traveling along the $+j$ direction. Its associated magnetic field is along the $-i$ direction at one instant. What is the direction of the associated electric field at that instant?

a) $+i$
b) $-j$
c) $+k$
d) $-i$
e) None of the other answers

11. An astronaut of the future steps out of her spaceship into interstellar space. She fires a laser that provides $10^9 \text{ W}$ of power continuously for one minute! If the total mass of the astronaut and her equipment is $100 \text{ kg}$, how far does she move in that minute, assuming she started from rest?

a) More than $100 \text{ m}$
b) Less than $4 \text{ m}$
c) Between $40$ and $100 \text{ m}$
d) Between $4$ and $10 \text{ m}$
e) Between $10$ and $40 \text{ m}$

12. A $100 \text{ W}$ light bulb is radiating light in all directions. A panel of area $0.01 \text{ m}^2$ is located $5 \text{ m}$ from the bulb, and the light hits it perpendicularly. What is the radiation force on the panel, assuming that it completely absorbs the light hitting it?

a) About $3.3 \times 10^{-7} \text{ N}$
b) About $1.1 \times 10^{-11} \text{ N}$
c) About $3.3 \times 10^{-9} \text{ N}$
d) About $1.1 \times 10^{-8} \text{ N}$
e) About $3.3 \times 10^{-10} \text{ N}$
13. A ray of light goes from air into water. Which of the following is true?
   a) Its wavelength decreases
   b) Its frequency increases
   c) Its speed stays the same
   d) Its wavelength stays the same
   e) Its frequency decreases

14. A ray of light goes from air into a flat block of glass (index of refraction \( n = 1.5 \)) at an angle of 36° with the normal to the interface. After passing through the glass, at what angle to the normal will the ray emerge into air?

   a) 62°
   b) 23°
   c) 67°
   d) 36°
   e) The ray won’t emerge into air, because it will be totally internally reflected in the glass
15. A fish looking up at the water surface sees a circular hole surrounded by a mirror. How far below the water surface is the fish, if the radius of the hole is 2.1 \text{ m} and the index of refraction of water is 1.33?

a) About 1.8 \text{ m} \\
b) About 2.8 \text{ m} \\
c) About 2.4 \text{ m} \\
d) About 1.6 \text{ m} \\
e) About 2.1 \text{ m}

16. An object is placed a distance \( p \) in front of a concave mirror of focal length +3 cm. The image is on the same side of the mirror as the object, and lies 8 cm closer to the mirror than the object, i.e. the distance between the object and the image is 8 cm. In which of the following ranges does the value of \( p \) lie?

a) 8 < \( p \) \leq 11 cm \\
b) 11 < \( p \) \leq 14 cm \\
c) 14 < \( p \) \leq 17 cm \\
d) 17 < \( p \) \leq 20 cm \\
e) \( p \) > 20 cm

17. A convex mirror has a focal length \( f < 0 \). Which of the following statements about the image of a real object are true?

- I: The image must necessarily be virtual
- II: The image must necessarily be upright
- III: The image must necessarily be smaller than the object

a) All three statements are false \\
b) All three statements are true \\
c) I and II are true; III is false \\
d) III is true; I and II are false \\
e) II and III are true; I is false

18. An object is placed 3 cm from a lens. The image is found to lie 12 cm from the lens, on the same side as the object. What is the focal length \( f \) of the lens, and is the image upright or inverted?

a) \( f = +2.4 \text{ cm} \); upright image \\
b) \( f = -4.0 \text{ cm} \); upright image \\
c) \( f = +4.0 \text{ cm} \); upright image \\
d) \( f = +2.4 \text{ cm} \); inverted image \\
e) \( f = -2.4 \text{ cm} \); inverted image
19. See the figure for this question. Three lenses are shown. Which ones are converging \((f > 0)\) and which are diverging \((f < 0)\)?

a) All three are diverging
b) II is converging; I and III are diverging
c) I is converging; II and III are diverging
d) I and II are converging; III is diverging
e) I and III are converging; II is diverging

20. A diverging lens of focal length \(-10\, cm\) is placed 10\, cm to the right of an object. Another 10\, cm to the right of this lens is placed another diverging lens, also of focal \(-10\, cm\). Where does the final image lie?

a) 30\, cm to the right of the second lens
b) 3.3\, cm to the left of the second lens
c) 10\, cm to the right of the second lens
d) 6.0\, cm to the left of the second lens
e) 30\, cm to the left of the second lens

22. A double-slit experiment uses a slit spacing \(d\) and light of wavelength \(\lambda\). On a screen located a long distance \(L\) away \((L >> d)\), the interference pattern shows that adjacent bright fringes are separated by a small distance \(y\). If the slit spacing is then doubled, what will be the new separation between adjacent bright fringes?

a) \(4y\)
b) \(y/2\)
c) \(y/4\)
d) \(y\)
e) \(2y\)
25. 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) \(B_x = 0; \ B_y < 0; \ B_z < 0\)

26. A proton (charge = \(+e\); mass = \(M\)) and an alpha particle (charge = \(+2e\); mass = \(4M\)) 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
27. 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

28. 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
29. 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

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

30. 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?

a) Zero  
b) $Bbv/R$ clockwise  
c) $Bbv/R$ counterclockwise  
d) $Bav/R$ clockwise  
e) $Bav/R$ counterclockwise
31. 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

32. 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

33. 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

34. 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 $+i$

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

a) About $6.3 \times 10^{19} N/m^2$

b) About $6.3 \times 10^{17} N/m^2$

c) About $6.3 \times 10^{12} N/m^2$

d) About $4.5 \times 10^9 N/m^2$

e) About $4.5 \times 10^{-6} N/m^2$

36. A spaceship navigates through interstellar space by continuously emitting an electromagnetic beam of power $3 \times 10^{10} W$. If the ship’s mass is 2000 kg, what is its acceleration?

a) About 0.85 $m/s^2$

b) About 5.2 $m/s^2$

c) About 9.8 $m/s^2$

d) About 0.05 $m/s^2$

e) About 17.0 $m/s^2$

37. 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.

38. 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).

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
39. An underwater swimmer shines a flashlight at the water surface. The light beam makes an angle of $55^\circ$ 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?

a) $\theta < 25^\circ$
b) $25^\circ \leq \theta < 45^\circ$
c) $45^\circ \leq \theta < 70^\circ$
d) $70^\circ \leq \theta < 90^\circ$
e) The light will be totally internally reflected

40. 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
b) virtual, upright, bigger than the object
c) real, inverted, same size as the object
d) real, inverted, bigger than the object
e) virtual, upright, smaller than the object

41. 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 
b) $+4.0$ cm 
c) $+1.0$ cm 
d) $+0.6$ cm 
e) $-4.0$ cm

42. 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 
b) About 2.2 m 
c) About 2.8 m 
d) About 3.4 m 
e) About 4.1 m

43. 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.
b) Diverging lenses are thicker at the ends than at the middle.
c) A diverging lens always forms an enlarged image of a real object.
d) A diverging lens always forms an upright image of a real object.
e) Nearsighted people can use diverging lenses to correct this defect.
44. 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
   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

45. 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
   b) 7.9 \, cm
   c) 10.0 \, cm
   d) 17.1 \, cm
   e) 20.2 \, cm

46. 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
   b) 14 \, cm
   c) 83 \, cm
   d) 252 \, cm
   e) 28 \, cm
49. Light is normally incident on two polarizers that are crossed at an angle of 60 degrees. (It might help to know that cos(60) = 1/2.) What fraction of incident unpolarized light is transmitted through both polarizers?

a) 1/2 
b) 1/4 
c) 1/8 
d) 1/16 
e) It depends on whether the incident light is unpolarized linearly or circularly.

50. A beam of linearly polarized light strikes two polarizing sheets. The characteristic (i.e. polarizing) direction of the second sheet is oriented at 90° with respect to the initial polarization. The characteristic direction of the first sheet is at angle θ with respect to the initial polarization. If the θ = 30°, what fraction of the incident beam intensity is transmitted through the two polarizers?

a) .87 
b) .75 
c) .50 
d) .43 
e) .19