<table>
<thead>
<tr>
<th></th>
<th>Form A</th>
<th>Form B</th>
<th>Form C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>C</td>
<td>D</td>
<td>1) B</td>
</tr>
<tr>
<td>2)</td>
<td>C</td>
<td>A</td>
<td>2) D</td>
</tr>
<tr>
<td>3)</td>
<td>C</td>
<td>E</td>
<td>3) B</td>
</tr>
<tr>
<td>4)</td>
<td>E</td>
<td>D</td>
<td>4) E</td>
</tr>
<tr>
<td>5)</td>
<td>C</td>
<td>A</td>
<td>5) B</td>
</tr>
<tr>
<td>6)</td>
<td>B</td>
<td>C</td>
<td>6) D</td>
</tr>
<tr>
<td>7)</td>
<td>B</td>
<td>D</td>
<td>7) E</td>
</tr>
<tr>
<td>8)</td>
<td>C</td>
<td>A</td>
<td>8) D</td>
</tr>
<tr>
<td>9)</td>
<td>A</td>
<td>C</td>
<td>9) E</td>
</tr>
<tr>
<td>10)</td>
<td>D</td>
<td>C</td>
<td>10) C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Form A</th>
<th>Form B</th>
<th>Form C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>B</td>
<td>D</td>
<td>1) D</td>
</tr>
<tr>
<td>2)</td>
<td>E</td>
<td>A</td>
<td>2) A</td>
</tr>
<tr>
<td>3)</td>
<td>A</td>
<td>B</td>
<td>3) E</td>
</tr>
<tr>
<td>4)</td>
<td>B</td>
<td>A</td>
<td>4) B</td>
</tr>
<tr>
<td>5)</td>
<td>D</td>
<td>D</td>
<td>5) A</td>
</tr>
<tr>
<td>6)</td>
<td>D</td>
<td>B</td>
<td>6) A</td>
</tr>
<tr>
<td>7)</td>
<td>B</td>
<td>D</td>
<td>7) E</td>
</tr>
<tr>
<td>8)</td>
<td>A</td>
<td>C</td>
<td>8) C</td>
</tr>
<tr>
<td>9)</td>
<td>E</td>
<td>B</td>
<td>9) B</td>
</tr>
<tr>
<td>10)</td>
<td>A</td>
<td>A</td>
<td>10) A</td>
</tr>
</tbody>
</table>
MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question. Write your answer at the right. (2 points each)

1) A planar electromagnetic wave is propagating in the positive x-direction. At a certain point P and at a given instant, the electric field of the wave is given by \( E = -j82 \text{ mV/m} \). The magnetic vector of the wave, at the point \( P \) at that instant is closest to:

A) \((+2.7 \times 10^{-10} \text{ T}) \hat{k}\)
B) \((+2.7 \times 10^{-10} \text{ T}) \hat{j}\)
C) \((-2.7 \times 10^{-10} \text{ T}) \hat{k}\)
D) \((+6.8 \times 10^{-9} \text{ T}) \hat{k}\)
E) \((-6.8 \times 10^{-9} \text{ T}) \hat{j}\)

1) C

For magnitude use:

\[ B = \frac{E}{\varepsilon_0} = \frac{82 \times 10^{-3} \text{ V/m}}{3 \times 10^8 \text{ m/s}} = 2.7 \times 10^{-10} \text{ T} \]

For direction use. Poynting vector:

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

\[ \mathbf{\ell} = \left( -\frac{\mathbf{j}}{\phi} \right) \times \left( -\hat{k} \right) \]

2) When light travels from air into water,

A) its wavelength changes, but its velocity and frequency do not change.
B) its frequency changes, but its velocity and wavelength do not change.
C) its velocity and wavelength change, but its frequency does not change.
D) its velocity changes, but its frequency and wavelength do not change.
E) its velocity, wavelength, and frequency all change.

2) C
3) A ray in air is incident on a glass plate whose index of refraction is 1.58. The angle of refraction is one-half the angle of reflection. The angle of refraction is closest to:

A) 32°  B) 30°  C) 38°  D) 36°  E) 34°

\[ n_1 \sin \Theta_1 = n_2 \sin \Theta_2 \]

\[ \sin(2\Theta) = (1.58) \sin(\Theta) \]

\[ \frac{\sin(2\Theta)}{\sin(\Theta)} = 1.58 \rightarrow \Theta = 38° \]

If you don't remember any identities to solve this, just plug the choices into your calculator.

4) A beam of light is linearly polarized in a vertical plane and has an intensity \( I_0 \). The beam passes through an ideal polarizer and then through an ideal analyzer whose axis is set horizontally. If the axis of the polarizer is set at 60° with the vertical, the ratio of the intensity of the final beam to \( I_0 \) is closest to:

A) 0.25  B) 0.31  C) 0.43  D) 0.37  E) 0.19

\[ I = I_0 \cos^2(60°) \cos^2(30°) \]

\[ I = I_0 (0.188) \]
5) In Fig. 34.3, the thin lens forms a real image of the object 94.0 cm from the object. The focal length of the lens is closest to:

A) 25.5 cm  
B) 86.0 cm  
C) 22.0 cm  
D) 27.5 cm  
E) 55.8 cm

\[
\frac{1}{s'} + \frac{1}{\infty} = \frac{1}{f} \Rightarrow f = 22 \text{ cm}
\]

6) Suppose you wanted to start a fire using sunlight and a mirror. Which of the following statements is most accurate?

A) It would be best to use a plane mirror.
B) It would be best to use a concave mirror, with the object to be ignited positioned halfway between the mirror and its center of curvature.
C) It would be best to use a concave mirror, with the object to be ignited positioned at the center of curvature of the mirror.
D) It would be best to use a convex mirror.
E) One cannot start a fire using a mirror, since mirrors form only virtual images.

Parallel rays (from the sun) converge at the focus, which is halfway to the center of curvature.
7) Two radio antennas are 120 m apart on a north-south line. The two antennas radiate in phase at a frequency of 3.4 MHz. All radio measurements are made far from the antennas. The smallest angle, reckoned east of north from the antennas, at which constructive interference of two radio waves occurs, is closest to:

A) 34°  B) 33°  C) 38°  D) 30°  E) 47°

\[
\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{3.4 \times 10^6 \text{ Hz}} = 88.2 \text{ m}
\]

\[
d \sin \theta = m \lambda = (1) \lambda
\]

\[
\sin \theta = \frac{\lambda}{d} = \frac{88.2 \text{ m}}{120 \text{ m}}
\]

\[
\theta = 47.3^\circ \Rightarrow \phi = 90^\circ - \theta = 42.7^\circ
\]

8) An oil film (n = 1.48) of thickness 290 nm floating on water is illuminated with white light at normal incidence. What is the wavelength of the dominant color in the reflected light?

A) blue (470 nm)  B) blue-green (493 nm)  C) yellow (572 nm)  D) green (541 nm)  E) violet (404 nm)

Dominant color is the one with constructive interference.

Since \( n_{\text{oil}} > n_{\text{air}} \), there is a 180° \((\frac{3}{2})\) phase shift in the reflected beam.

The phase shift gives us \( \frac{1}{2} \lambda \), we need another \( \frac{1}{2} \lambda \) from the thickness of the film.

\[2t = \frac{\lambda}{2} \Rightarrow \lambda = 4t = 4(290 \text{ nm}) = 1160 \text{ nm} \]

This is too long, try the next one.

\[2t = \frac{3\lambda}{2} \Rightarrow \lambda = \frac{4t}{3} = 387 \text{ nm} \]

But this is the wavelength in oil.

\[\lambda_{\text{air}} = \lambda_{\text{oil}} \frac{n_{\text{oil}}}{n_{\text{air}}} = (387 \text{ nm}) \frac{1.48}{1} = 572 \text{ nm}\]
9) A single slit forms a diffraction pattern, with the first minimum at an angle of 40° from central maximum. Monochromatic light of 450-nm wavelength is used. The same slit, illuminated by a different monochromatic light source, produces a diffraction pattern with the second minimum at a 60° angle from the central maximum. The wavelength of this light, in nm, is closest to:

A) 303  B) 375  C) 357  D) 321  E) 339

Use the first wavelength to determine the slit width:

$$\lambda = \frac{a \sin \theta}{\sin (40^\circ)}$$

$$a = \frac{450 \times 10^{-9} \text{m}}{\sin (40^\circ)} = 7 \times 10^{-7} \text{m}$$

Then use the slit width to determine the second wavelength:

$$\lambda = \frac{a \sin \theta}{2} = \frac{(7 \times 10^{-7} \text{m})(\sin 60^\circ)/2}{2} = 303 \text{nm}$$

10) An erect object is 50 cm from a concave mirror of radius 60 cm. The character of the image is:

A) virtual and inverted  B) real and erect  C) indeterminate  D) real and inverted  E) virtual and erect
ESSAY. Write your answer in the space provided. Show your work for partial credit, but make sure your final answer is clear. (10 points each)

11) An object of height 2.00 cm is placed 1.5 m to the left of a converging lens of focal length \( f_1 = +1 \) m. A diverging lens of focal length \( f_2 = -0.5 \) m is 2 m to the right of the first lens. For the final image formed by the pair of lenses, calculate the following:

4pt+ (a) location (relative to the second lens),
1pt+ (b) nature (real or virtual),
1pt+ (c) orientation (erect or inverted), and
4pt+ (d) height.

![Diagram of two lenses and a ray diagram]

First image

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{1m}
\]

\[s' = 3m\]

\[M_1 = \frac{s'}{s} = \frac{-3m}{1.5} = -2\]

Second image

\[s = -1m \quad \text{(virtual object)}\]

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{-1m}
\]

\[s' = -1m\]

\[M_2 = \frac{-(-1)}{-1m} = -1\]

a) 1m behind second lens

b) virtual (opposite side from outgoing light)

c) erect \( (m_{tot} = m_1m_2 = (-2)(-1) = 2 > 0)\)

d) \((2)(2cm) = 4cm\)
12) Light of wavelength 475 nm in vacuum enters plastic as shown in Fig. 33.9. Measurements of the light in the plastic indicate that its wavelength there is 394 nm.

(a) What is the frequency of the light in the plastic?

(b) What is the index of refraction in the plastic?

(c) At what direction does the light travel with respect to the normal in the plastic?

(d) Is the ray reflected off of the plastic (not shown) phase shifted at the interface?

\[
\frac{f_{\text{air}}}{f_{\text{vac}}} = \frac{c}{\lambda_{\text{air}}} = \frac{3\times10^8 \text{ m/s}}{475 \times 10^{-9} \text{ m}} = 6.32 \times 10^{14} \text{ Hz}
\]

(a) \( f = 6.32 \times 10^{14} \text{ Hz} \) (\( f \) doesn't change)

b) \( n = \frac{c}{f \lambda} \)

\[
\frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} \Rightarrow n_{\text{plastic}} = \frac{n_{\text{air}} \lambda_{\text{air}}}{\lambda_{\text{plastic}}} = \frac{(1)(475)}{394} = \frac{1.21}{1.21}
\]

c) \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)

\[
\sin \theta_2 = \frac{\sin (29')}{1.21} \Rightarrow \theta_2 = 22.9^\circ
\]

d) Since \( n_{\text{plastic}} > n_{\text{air}} \), there is a phase shift.
MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question. Write your answer at the right. (2 points each)

1) A planar electromagnetic wave is propagating in the positive x–direction. At a certain point P and at a given instant, the electric field of the wave is given by \( E = -j12 \) mV/m. The Poynting vector at the point P at that instant is closest to:

A) \((-1.9 \times 10^{-7} \text{ W/m}^2) \hat{k}\)

B) \((+3.8 \times 10^{-7} \text{ W/m}^2) \hat{i}\)

C) \((-3.8 \times 10^{-7} \text{ W/m}^2) \hat{i}\)

D) \((+1.9 \times 10^{-7} \text{ W/m}^2) \hat{i}\)

E) \((-1.9 \times 10^{-7} \text{ W/m}^2) \hat{i}\)

For magnitude:

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

\[ B = \frac{E}{c} \]

\[ S = \frac{E^2}{c \mu_0} = \frac{(12 \times 10^{-3})^2}{(3 \times 10^8)(4 \pi \times 10^{-7})} = 3.9 \times 10^{-7} \text{ W/m}^2 \]

The direction of propagation is the direction of the Poynting vector \( +x \), or \( \hat{i} \).

2) When light travels from air into water,

A) its frequency changes, but its velocity and wavelength do not change.

B) its wavelength changes, but its velocity and frequency do not change.

C) its velocity changes, but its frequency and wavelength do not change.

D) its velocity, wavelength, and frequency all change.

E) its velocity and wavelength change, but its frequency does not change.
3) A ray in glass is incident onto a water-glass interface, at an angle of incidence equal to half the critical angle for that interface. The indices of refraction for water and the glass are 1.33 and 1.60, respectively. The angle that the refracted ray in the water makes with the normal is closest to:

\[ \sin \Theta_c = \frac{n_{\text{water}}}{n_{\text{glass}}} \Rightarrow \Theta_c = 56.2^\circ \]

\[ n_1 \sin \Theta_1 = n_2 \sin \Theta_2 \]

\[ \sin \Theta_2 = \frac{1.6 \sin\left(\frac{56.2^\circ}{2}\right)}{1.33} \]

\[ \Theta_2 = 34.5^\circ \]

Situation 33.4

A beam of light is linearly polarized in a vertical plane and has an intensity \( I_0 \). The beam passes through an ideal polarizer and then through an ideal analyzer whose axis is set horizontally.

4) In Situation 33.4, the axis of the polarizer is set at 40° with the vertical. The ratio of the electric field in the final beam to that of the initial beam is closest to:

\[ \frac{I}{I_0} = I_0 \cos^2 40^\circ \cos^2 50^\circ \]

\[ = I_0 \left( \frac{3}{4} \right) \]

\[ I \propto E^2 \]

\[ E_0 = E \sqrt{\frac{3}{4}} = 0.49E \]
5) In Fig. 34.3, the thin lens forms an image 15.0 cm to the right of the object. The focal length of the lens is closest to:
A) +12.7 cm  B) -26.3 cm  C) -117 cm  D) +46.7 cm  E) +10.5 cm

The distance from the image is 35 - 15 = 20 cm.
Since the image is on the opposite side as the outgoing light, it is virtual.

\[
\frac{1}{35} + \frac{1}{-20} = \frac{1}{f} \quad \Rightarrow \quad f = -46.7
\]

6) In a compound microscope
A) both the objective and the eyepiece form real images.
B) The magnification is \( m_1 + m_2 \), where \( m_1 \) is the lateral magnification of the objective and \( m_2 \) is the angular magnification of the eyepiece.
C) Magnification is provided by the objective lens and not by the eyepiece. The eyepiece merely increases the resolution of the image viewed.
D) The image of the objective serves as the object for the eyepiece.
E) Magnification is provided by the objective and not by the eyepiece. The eyepiece merely increases the brightness of the image viewed.
7) Two radio antennas are 100 m apart on a north-south line. The two antennas radiate in phase at a frequency of 4.9 MHz. All radio measurements are made far from the antennas. The smallest angle, reckoned north of east from the antennas, at which destructive interference of the two radio waves occurs, is closest to:

A) $13^\circ$  
B) $18^\circ$  
C) $22^\circ$  
D) $27^\circ$  
E) $8.9^\circ$

\[ \lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{4.9 \times 10^6 \text{Hz}} = 61.2 \text{m} \]

\[ \sin \theta = \frac{\lambda}{2d} \]

\[ \sin \theta = \frac{61.2 \text{m}}{2(100 \text{m})} \]

\[ \theta = 17.8^\circ \]

8) An oil film ($n = 1.48$) of thickness 290 nm floating on water is illuminated with white light at normal incidence. What is the wavelength of the dominant color in the reflected light?

A) yellow (572 nm)  
B) blue (470 nm)  
C) blue-green (493 nm)  
D) green (541 nm)  
E) violet (404 nm)

Dominant color is the one with constructive interference.

Since oil > air, there is a phase shift at the first interface.

The phase shift gives us $\frac{1}{2} \lambda$, we need another $\frac{1}{2} \lambda$ from the thickness of the film.

\[ 2t = \frac{\lambda}{2} \Rightarrow \lambda = 4t = 4(290 \text{nm}) = 1160 \text{nm} \]  
This is too long, try the next one.

\[ 2t = \frac{3\lambda}{2} \Rightarrow \lambda = \frac{4t}{3} = 387 \text{nm} \]  
But this is the wavelength in oil.

\[ \lambda_{\text{air}} = \frac{\lambda_{\text{oil}}}{n_{\text{oil}}} = \frac{387 \text{nm}}{1.48} = 527 \text{nm} \]
9) A single slit forms a diffraction pattern, with the first minimum at an angle of 40° from central maximum. Monochromatic light of 450-nm wavelength is used. The same slit, illuminated by a different monochromatic light source, produces a diffraction pattern with the second minimum at a 60° angle from the central maximum. The wavelength of this light, in nm, is closest to:
   A) 375  B) 339  C) 321  D) 357  E) 303

   Use the first wavelength to determine the slit width
   \[ a \sin \theta = \lambda \]
   \[ a = \frac{450 \times 10^{-9} \text{ m}}{\sin 40°} = 7.0 \times 10^{-7} \text{ m} \]

   Then use the slit width to determine the second wavelength
   \[ \lambda = \frac{a \sin \theta}{2} = \left( \frac{7 \times 10^{-7} \text{ m}}{\sin 60°} \right) / 2 \]
   \[ = 303 \text{ nm} \]

10) An erect object is 50 cm from a concave mirror of radius 60 cm. The character of the image is:
    A) real and inverted
    B) virtual and inverted
    C) real and erect
    D) indeterminate
    E) virtual and erect
ESSAY. Write your answer in the space provided. Show your work for partial credit, but make sure your final answer is clear. (10 points each)

11) An object of height 2.00 cm is placed 1.5 m to the left of a converging lens of focal length $f_1 = +1$ m. A diverging lens of focal length $f_2 = -0.5$ m is 2 m to the right of the first lens. For the final image formed by the pair of lenses, calculate the following:

(a) location (relative to the second lens),
(b) nature (real or virtual),
(c) orientation (erect or inverted), and
(d) height.

\[ \frac{1}{1.5} + \frac{1}{s'} = \frac{1}{1m} \]

\[ s' = 3m \]

\[ M_1 = \frac{-s'}{s} = \frac{-3m}{1.5} = -2 \]

Second image

\[ s = -1m \text{ (virtual object)} \]

\[ \frac{1}{-1} + \frac{1}{s'} = \frac{1}{-0.5} \]

\[ s' = -1m \]

\[ M_2 = \frac{-(-1)}{-1m} = -1 \]

(a) 1m behind second lens
b) virtual (opposite side from outgoing light)
c) erect (\( m_{tot} = m_1m_2 = (-2)(-1) = 2 > 0 \))
d) \((2)(2cm) = 4cm\)
12) Light of wavelength 475 nm in vacuum enters plastic as shown in Fig. 33.9. Measurements of the light in the plastic indicate that its wavelength there is 394 nm.

(a) What is the frequency of the light in the plastic?
(b) What is the index of refraction in the plastic?
(c) At what direction does the light travel with respect to the normal in the plastic?
(d) Is the ray reflected off of the plastic (not shown) phase shifted at the interface?

\[
\lambda_{\text{vac}} = \frac{c}{\lambda_{\text{vac}}} = \frac{3 \times 10^8 \text{m/s}}{475 \times 10^{-9} \text{m}} = 6.32 \times 10^{14} \text{ Hz}
\]

(a) \( f = 6.32 \times 10^{14} \text{ Hz} \) \((f \text{ doesn't change})\)

b) \( \eta_1 = \frac{c}{\lambda_1} \)

\[
\frac{\lambda_1}{\lambda_2} \Rightarrow \eta_{\text{plastic}} = \frac{\eta_{\text{vac}} \lambda_{\text{vac}}}{\lambda_{\text{plastic}}} = \frac{(1)(475)}{394} = 1.21
\]

c) \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)

\[
\sin \theta_2 = \frac{\sin (28^\circ)}{1.21} \Rightarrow \theta_2 = 22.9^\circ
\]

d) Since \( \eta_{\text{plastic}} > \eta_{\text{vac}} \), there is a phase shift.