Name: ____ Total Points: _______

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Multiple choice questions [70 points]

Answer all of the following questions. Read each question carefully. **Fill the correct bubble on your scantron sheet**. All questions are worth the same amount of points. Each question has exactly one correct answer.

1. A beam of light is propagating in the x direction. The electric field vector

A. can oscillate in any direction in space.
B. must oscillate in the z direction
C. must oscillate in the x direction
D. must oscillate in the yz plane (The E field is in a plane perpendicular to the direction of propagation. But it can be in any direction in that plane)
E. must have a constant component in the x direction

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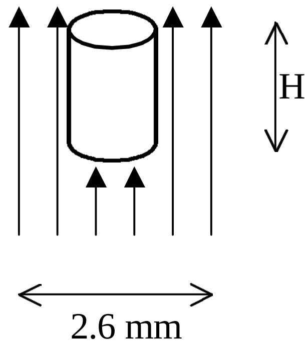
2. A laser beam of power 4.60 W and diameter 2.6 mm is directed upward at one circular face (of diameter d<2.6 mm) of a perfectly reflecting cylinder which is made to hover by the beam's radiation pressure. The cylinder's density is 1.2 g/cm^3. What is the cylinder's height H?



A. 0.25 μm

B. 0.49 μm

$$\begin{cases} mg = pA_{cylinder} \\ p = \dfrac{2\times Power}{cA_{beam}} \\ m = rA_{cylinder}H \end{cases} \Rightarrow H = \frac{2\times Power}{cA_{beam}gr} = \frac{2\times 4.6}{3\times 10^8 \times \frac{p}{4} \times (2.6\times 10^{-3})^2 \times 9.8 \times 1.2\times 10^3} = 4.9\times 10^{-7}\,m$$

C. 1.49 mm

D. 2.6 cm

E. The problem has no reasonable physical solution. One finds that the height H is of the order of the diameter of an atom (namely less 10^{-10}m)

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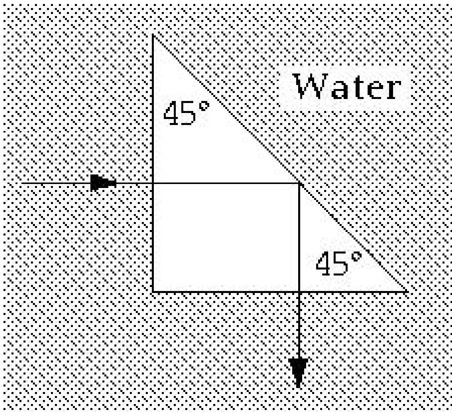
3.



For the prism immersed in water (n = 1.33), the minimum index of refraction that will produce total reflection of the indicated ray is approximately

A. 0.94
B 1.28
C. 1.50
D. 1.65
E. 1.88

Total reflection starts to appear when the transmitted ray makes a 90º angle with the normal:

$$n_g \sin 45 = 1.33 \sin 90 \Rightarrow n_g = 1.33 \times \sqrt{2} = 1.88$$

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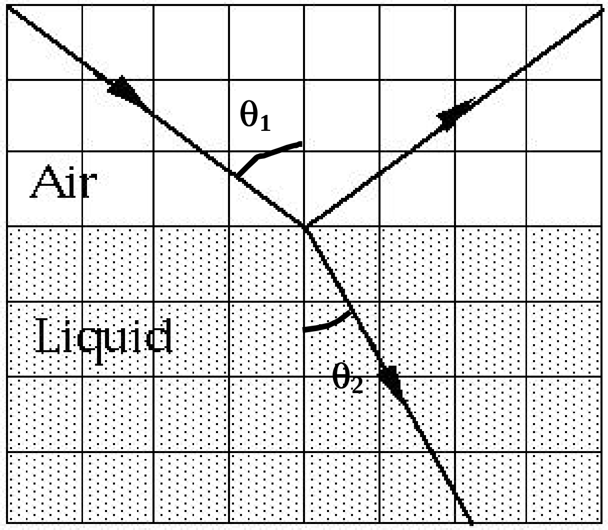
4.



A ray of light is shown reflected and refracted at the surface of a liquid. From the diagram you can determine that the speed of light in this liquid is approximately

A. 1.83 10^8 m/s

Recall that $n = \frac{c}{v}$. From the figure

$$\tan q_1 = \frac{4}{3} \Rightarrow q_1 = 51.1°$$

$$\tan q_2 = \frac{2.25}{4} \Rightarrow q_2 = 29.4°$$

$$\frac{c}{v}\sin q_2 = \sin q_1 \Rightarrow v = \frac{c \sin q_2}{\sin q_1} = \frac{3\times 10^8 \times 0.49}{0.8} = 1.83\times 10^8\, m/s$$

B 2.24 10^8 m/s

C. 2.50 10^8 m/s

D. 2.73 10^8 m/s

E. 3.00 10^8 m/s

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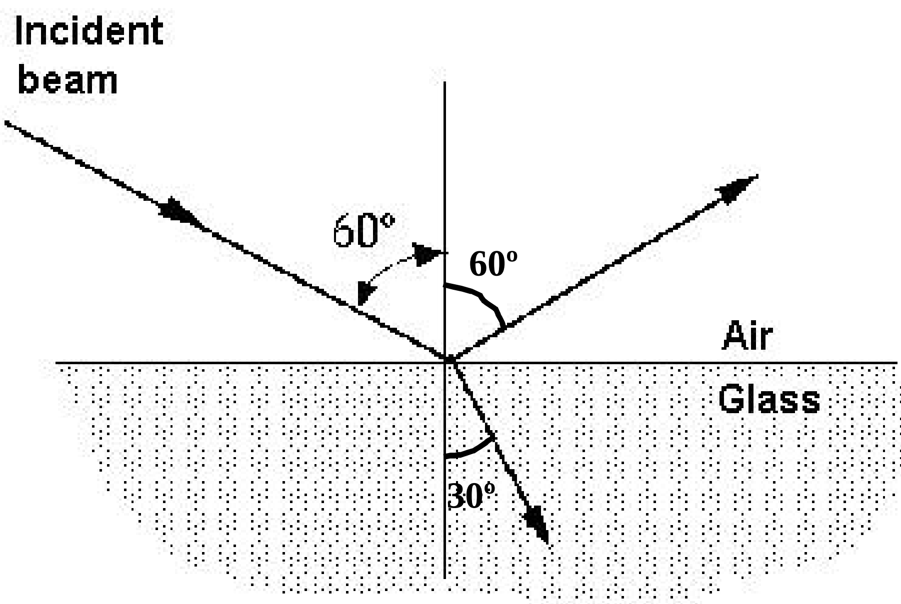
5.



If the incident beam in the figure is unpolarized and the reflected beam is completely plane polarized, the index of refraction of the glass must be

A. 1.16
B 1.33
C. 1.56
D. 1.73
The reflected and refracted rays make a right angle.
$\sin 60 = n \sin 30 \Rightarrow n = \sqrt{3}$
E. 2.00

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Questions 6 through 12 all refer to the same problem

An electromagnetic plane wave propagates through empty space. The magnetic field is given by $\vec{B}(z,t) = (B_{0x}\hat{i} + B_{0y}\hat{j})\sin(kz + wt)$. B_{0x} and B_{0y} are positive constants.

6. The direction of propagation of the wave is

A. x
B -x
C. y
D. z
E. -z
The space time dependence is kz+ωt. A crest at z_0 at t=0 ($kz_0=\pi/2$) is at $z=z_0- (\omega/k)t$ at time t (so that $kz+\omega t= kz_0=\pi/2$). Since z decreases at t increases, the crest moves in the –z direction.

7. What is the speed of the wave (λ is the wavelength)?

A. $\frac{w}{l}$

B. $\frac{k}{l}$

C. $\frac{w}{k}$ (From 6, $z_{crest}=z_0- (\omega/k)t$. Thus, $dz_{crest}/dt = -\omega/k$)

D. $\frac{w}{2pk}$

E. $\frac{k}{w}$

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8. What is the correct expression for the electric field?

A. $\vec{E}(z,t) = c(B_{0x}\hat{i} + B_{0y}\hat{j})\sin(kz + wt)$

B $\vec{E}(z,t) = c(-B_{0y}\hat{i} + B_{0x}\hat{j})\sin(kz + wt)$

Use $\left|\vec{E}\right| = c\left|\vec{B}\right|$ and $\vec{E}\times\vec{B} // -\hat{k}$ that is $\vec{E} = c\vec{B}\times(-\hat{k})$

C. $\vec{E}(z,t) = -c(B_{0x}\hat{i} + B_{0y}\hat{j})\sin(kz + wt)$

D. $\vec{E}(z,t) = c(B_{0y}\hat{i} - B_{0x}\hat{j})\sin(kz + wt)$

E. $\vec{E}(z,t) = cB_{0y}\hat{j}\sin(kz + wt)$

9. What can you say about the polarization of this plane wave?

A. The wave is unpolarized

B The wave is polarized but not linearly polarized

C. The wave is linearly polarized
$\vec{E}$ is always parallel to the constant vector $(-B_{0y}\hat{i} + B_{0x}\hat{j})$

D. The notion of polarization applies only to visible light. The wave is linearly polarized if it is a visible light wave.

E. Can't say anything about polarization without the values of B_{0x} and B_{0y}

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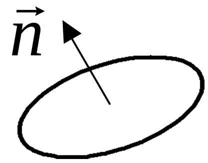
10. If the frequency of the wave is a radio frequency, what should be the direction of the normal $\vec{n}$ of a loop antenna to detect the largest signal from the wave?



A. $\vec{n}$ is parallel to $(B_{0x}\hat{i} + B_{0y}\hat{j})$

$\vec{B}$ must be along $\vec{n}$ to maximize the change of magnetic flux.

B $\vec{n}$ is parallel to $(-B_{0y}\hat{i} + B_{0x}\hat{j})$

C. $\vec{n}$ is parallel to $B_{0x}\hat{i}$

D. $\vec{n}$ is parallel to $B_{0y}\hat{j}$

E. $\vec{n}$ is parallel to $(B_{0x}\hat{i} - B_{0y}\hat{j})$

11. At point z, what is the time average value of the intensity of the wave?

A. $\frac{c}{m_0}(B_{0x}^2 + B_{0y}^2)$

B $\frac{c}{2m_0}(B_{0x}^2 + B_{0y}^2)$

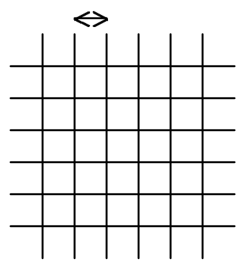
$$I_{average} = \left|\frac{\vec{E}\times\vec{B}}{m_0}\right|_{time\ average} = \frac{c}{m_0}(B_{0x}^2 + B_{0y}^2) < \sin^2(kz+wt) >_{time\ average} = \frac{c}{2m_0}(B_{0x}^2 + B_{0y}^2)$$

C. $\frac{c}{2m_0}(B_{0x}^2 + B_{0y}^2)\cos^2(kz)$

D. $\frac{c}{2m_0}(B_{0x}^2 + B_{0y}^2)\sin^2(kz)$

E. 0

12. The loop antenna of the previous question is placed inside of a Faraday cage (a box made out of wire mesh).
The size of the mesh is d.



How should the wavelength of the radio wave compare with d so that the signal could still be detected inside of the Faraday cage?

A. $d \ll \lambda$
B $d \gg \lambda$
(Recall the video shown in class)
C. The wave is always detected no matter what d is
D. The wave is never detected no matter what d is

Questions 13 and 14 refer to the same problem

A beam of light polarized in the x direction is traveling in the z direction. It passes through a polarizer, travels some distance, and reaches an analyzer . You can orient the polarization axis of the analyzer only in the x or the y direction.
You find that the intensity is 3 times smaller when the polarization axis of the analyzer is in the y direction than it is when the polarization axis is in the x direction ($\frac{I_x}{I_y} = 3$)

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13. What is the angle between the polarization axis of the polarizer and the x axis?

A. 0°

B 30°

If θ is the angle of the polarizer's polarization axis with the x axis, and I the intensity of the light beam between the polarizer and the analyzer,

$$\left.\begin{array}{l} I_x = I\cos^2 q \\ I_y = I\sin^2 q \end{array}\right\} \Rightarrow \tan q = \frac{1}{\sqrt{3}}$$

C. 45°

D. 60°

E. 80°

14. Suppose that the original light beam were polarized in the y direction, everything else remaining the same. What ratio $\frac{I_x}{I_y}$ would you have observed?

A. 1/2

B 3

Using polarized light would change the beam intensity I between the polarizer and the analyzer. But it would not change the ratio $\frac{I_x}{I_y}$ (as long as I is not 0 which is the case here).

C. 3/2

D. 1

E. 1/6

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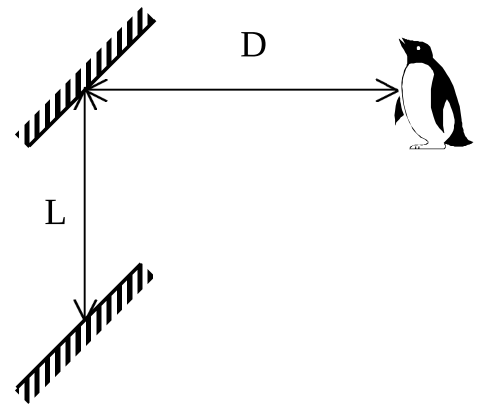
PROBLEM [30 points]



The figure shows an idealized submarine periscope that consists of two parallel plane mirrors set at 45 degrees to the vertical periscope axis and separated by a distance L. A penguin is sighted at a distance D from the middle point of the top mirror.

1). [15 pts] On the next page, draw a ray diagram to locate the image of the penguin given by the periscope (represent the penguin with an arrow). Draw 2 rays coming from the top of the arrow and 2 rays coming from the bottom of the arrow.

2). [3 pts] Is the image seen by a submarine officer real or virtual? Explain.

The image is virtual. There is no light ray at the location of the image.

3). [3 pts] Does the image have the same orientation as the penguin or is it inverted?

The image has the same orientation as the penguin (see diagram)

4). [3 pts] Is the image size less than, the same or greater than the object size? Explain.

The image has the same size (a plane mirror has a magnification equal to 1).

5). [6 pts] What is the distance between the image and the bottom mirror? Show your work.

The image of the penguin in the top mirror is a distance D from the top mirror. That image is used as the object to construct the image of the penguin in the second mirror. It is a distance D+L from the bottom mirror.
Thus the image of the penguin is a distance D+L from the bottom mirror.

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