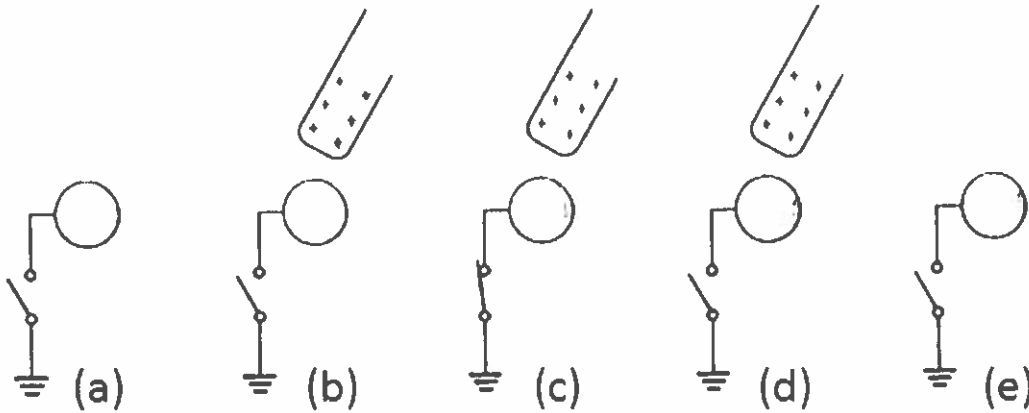**The next two questions pertain to the situation described below.**

A positively charged rod is brought close but does not touch an uncharged conducting sphere (as shown in steps a-b below). As a rod approaches, the sphere is connected to ground by a conducting wire (c). The grounding wire and rod are then removed (d-e).

5) What is the charge on the conducting sphere after the sequence of steps?

   a. *Zero*
   b. *Positive*
   c. *Negative*

6) Now the sequence of steps is repeated, starting with the same conducting sphere (uncharged), but without grounding the sphere. What is the charge on the sphere after the sequence of steps (a-c)?
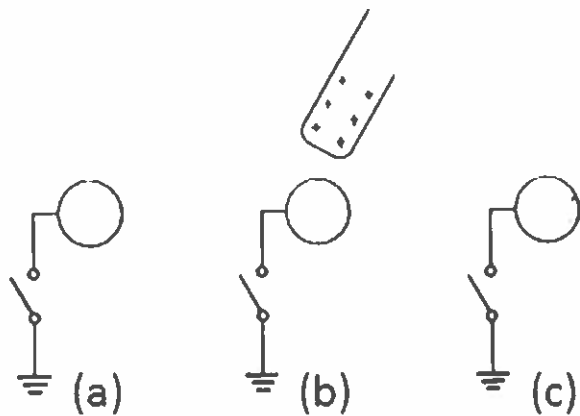
   a. *Zero*
   b. *Negative*
   c. *Positive*

The next question pertains to the following situation:

Three charges are located at (0,0), (7 m,0), and (0, 3m), as shown below. Each grid spacing is 1 meter.
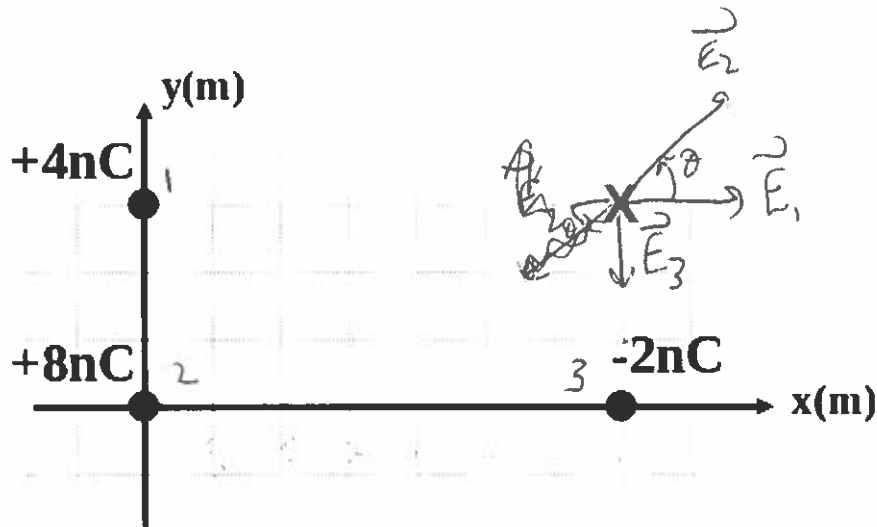
26. What is the net electric field at the point indicated at (7 m, 3 m)?

a. 0.76 V/m
b. 2.4 V/m
c. 5.9 V/m
d. 12 V/m
e. 39 V/m

$$|E_x| = |\vec{E_1}| + |\vec{E_2}|\cos\theta = \frac{kq_1}{r_1^2} + \frac{kq_2}{r_2^2}\cos\theta$$

$$|E_y| = |\vec{E_2}|\sin\theta - |E_3| = \frac{kq_2}{r_2^2}\sin\theta - \frac{kq_3}{r_3^2}$$

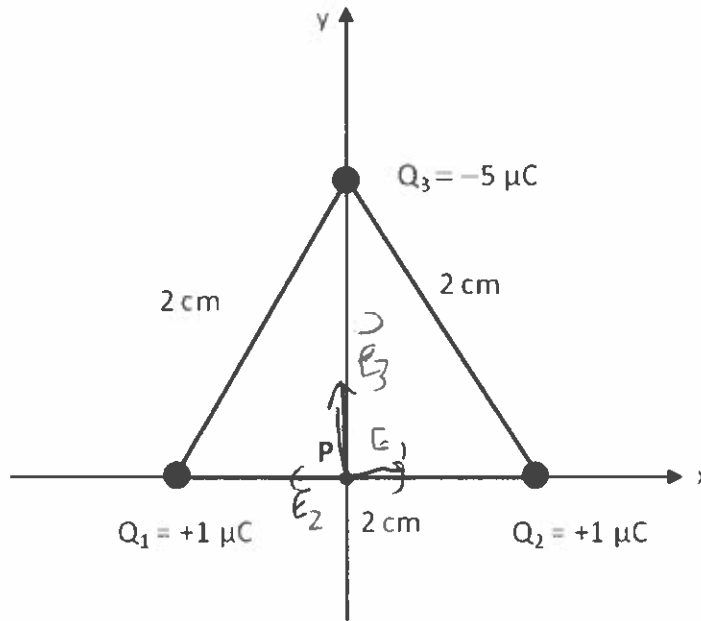$$|E_x| = 9\times10^9\left[\frac{4\times10^{-9}}{49} + \frac{8\times10^{-9}}{58}\left(\frac{7}{\sqrt{58}}\right)\right] = \frac{36}{49} + \frac{72}{58}\frac{7}{\sqrt{58}} \quad N/_C = 1.88 \, N/_C$$

$$|E_y| = 9\times10^9\left[\frac{8\times10^{-9}}{58}\frac{3}{\sqrt{58}} - \frac{2\times10^{-9}}{9}\right] = \left|\frac{72}{58}\frac{3}{\sqrt{58}} - 2\right| \quad N/_C = +1.51 \, N/_C$$

$$\sqrt{E_x^2 + E_y^2} = \sqrt{1.88^2 + 1.51^2} = 2.4 \quad N/_C$$

The next five questions pertain to the following situation.

Three point charges are positioned on the vertices of an equilateral triangle as shown.

9. What is the direction of the electric field at the origin, **P**?

a. Along the positive y-axis.
b. Along the negative y-axis.

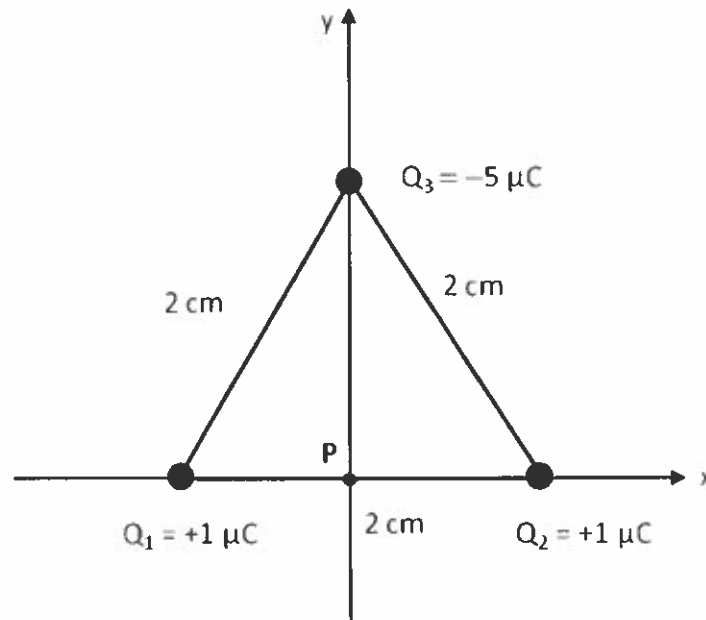10. What is the magnitude of the electric field E at the origin, **P**?

a. $E = 1.35 \times 10^7$ N/C
b. $E = 5.39 \times 10^8$ N/C
c. $E = 1.50 \times 10^8$ N/C
d. $E = 1.12 \times 10^8$ N/C
e. $E = 7.01 \times 10^8$ N/C

E is only from Q_3 ($|\vec{E}_1| = |\vec{E}_2|$ in opposite directions)

$\Rightarrow |\vec{E}| = \dfrac{k|Q_3|}{r_3^2} = \dfrac{9 \times 10^9 \cdot 5 \times 10^{-6} C}{(\sqrt{3} \times 10^{-2})^2}$

$= \dfrac{45 \times 10^3}{3 \times 10^{-4}} = 15 \times 10^7$ N/C

The next two questions continue from the previous page.

11. How much work W is required **by you** to assemble the three charges to this configuration?

a. $W = -0.0405$ J
b. $W = -4.05$ J
c. $W = 4.05$ J
d. $W = -202.3$ J
e. $W = 202.3$ J

Potential energy of configuration:

$$U = k\frac{q_1 q_2}{r_{12}} + k\frac{q_1 q_3}{r_{13}} + k\frac{q_2 q_3}{r_{23}}$$

$$= \frac{9\times10^9}{0.02}\left((1)(1)\cdot10^{-12} + (1)(-5)10^{-12} + (1)(-5)10^{-12} \right)$$

$$= \frac{9\times10^{-3}}{2\times10^{-2}}(-9) \ J = \frac{-81}{2}\cdot10^{-1} = -4.05 \ J$$

$\Rightarrow$ I had to do -4.05 J to assemble these charges

12. What is the electric potential V due to the three charges at origin, **P**?

a. $V = -202.3$ V
b. $V = -2.34$ V
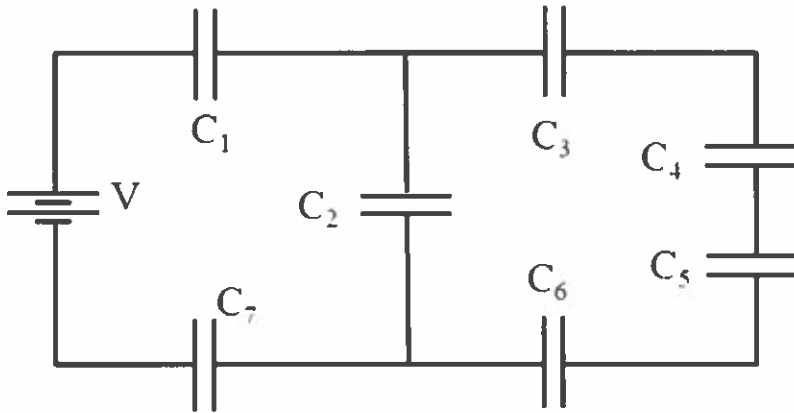c. $V = 1.35$ V
d. $V = -1.35\times10^5$ V
e. $V = -7.98\times10^5$ V

$$V_P = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} + \frac{kq_3}{r_3}$$

$$= 9\times10^9\left[\frac{1\cdot10^{-6}}{0.01} + \frac{1\cdot10^{-6}}{0.01} + \frac{(-5)10^{-6}}{\sqrt{3}\cdot0.01} \right]$$

$$= \frac{9\times10^3}{10^{-2}}\left[2 - \frac{5}{\sqrt{3}} \right]$$

$$= -7.98\times10^5 \ V$$

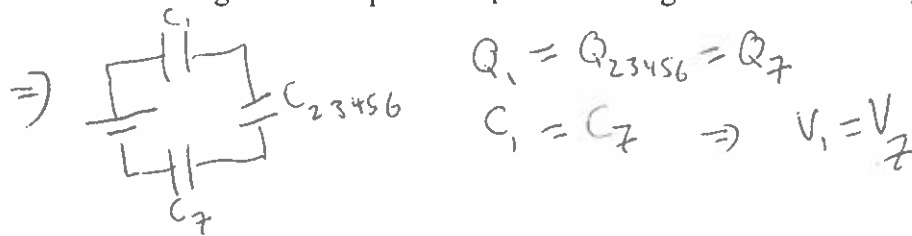**The next four questions pertain to the situation described below.**

Seven identical capacitors with capacitance C = 8.5 nF are connected to a 12 Volt battery as shown in the figure above.

19) Capacitors C_3 and C_6 are connected

   a. in parallel.
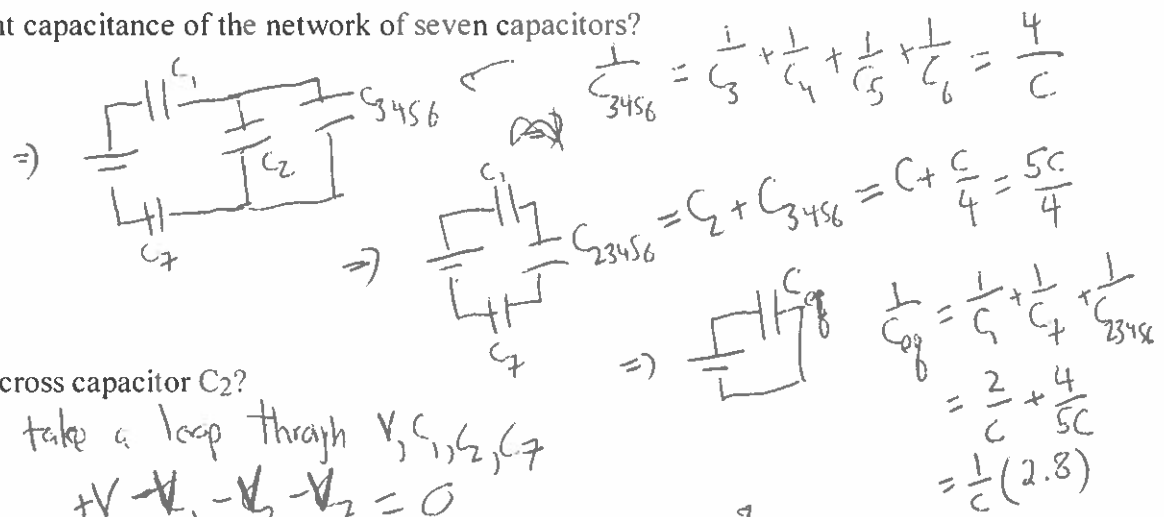   b. in series. *(circled)*
   c. neither in series nor in parallel.

20) Compare the magnitude of the voltage across capacitor C_1 with the magnitude of the voltage across capacitor C_7

   a. $V_1 = V_7$ *(circled)*
   b. $V_1 > V_7$
   c. $V_1 < V_7$

(handwritten annotations)
$$Q_1 = Q_{23456} = Q_7$$
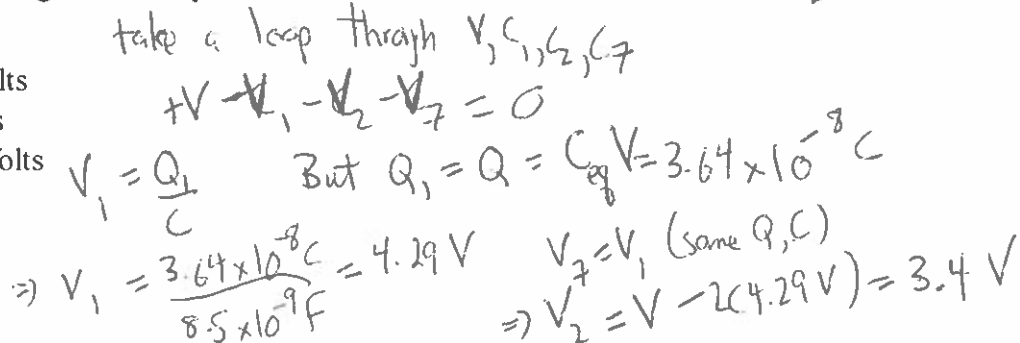$$C_1 = C_7 \implies V_1 = \frac{V}{7}$$
with diagram labeled C_1, C_{23456}, C_7

21) What is the equivalent capacitance of the network of seven capacitors?

   a. $C_{eq} = 9.92$ nF
   b. $C_{eq} = 9.07$ nF
   c. $C_{eq} = 23.8$ nF
   d. $C_{eq} = 3.04$ nF *(circled)*
   e. $C_{eq} = 1.21$ nF

(handwritten annotations)
$$\frac{1}{C_{3456}} = \frac{1}{C_3} + \frac{1}{C_4} + \frac{1}{C_5} + \frac{1}{C_6} = \frac{4}{C}$$
$$C_{23456} = C_2 + C_{3456} = C + \frac{C}{4} = \frac{5C}{4}$$
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_7} + \frac{1}{C_{23456}}$$
$$= \frac{2}{C} + \frac{4}{5C}$$
$$= \frac{1}{C}(2.8)$$

22) What is the voltage across capacitor C_2?

   a. $V_2 = 3.4$ Volts *(circled)*
   b. $V_2 = 4$ Volts
   c. $V_2 = 0.85$ Volts

(handwritten annotations)
take a loop through V, C_1, C_2, C_7
$$+V - V_1 - V_2 - V_7 = 0$$
$$V_1 = \frac{Q_1}{C} \quad \text{But } Q_1 = Q = C_{eq}V = 3.64 \times 10^{-8} C$$
$$\implies V_1 = \frac{3.64 \times 10^{-8} C}{8.5 \times 10^{-9} F} = 4.29 V$$
$$V_7 = V_1 \text{ (same } Q, C)$$
$$\implies V_2 = V - 2(4.29 V) = 3.4 V$$

7. Consider the circuit below. Which of the following equations is *incorrect*?
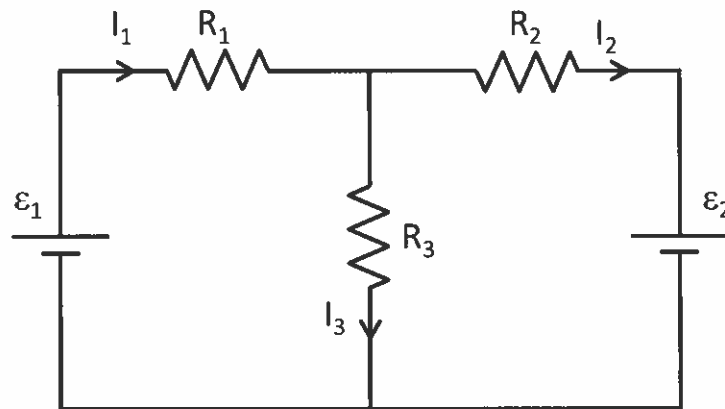
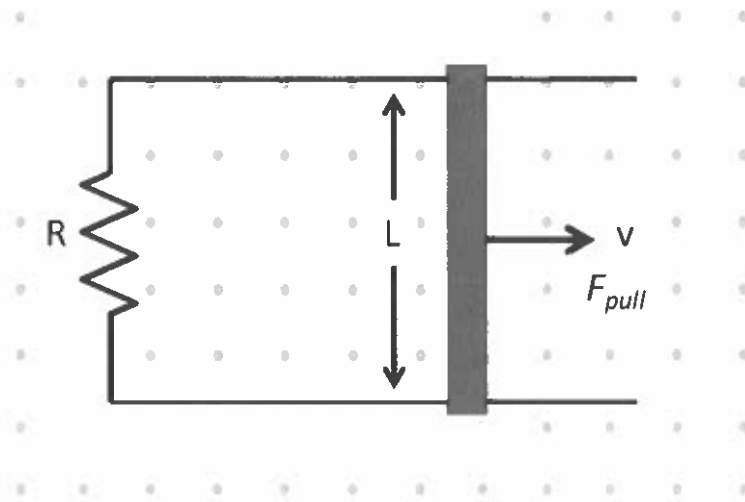a. $\varepsilon_1 - \varepsilon_2 - I_1 R_1 - I_2 R_2 = 0$
b. $\varepsilon_1 - I_1 R_1 - I_3 R_3 = 0$
c. $\varepsilon_2 - I_2 R_2 - I_3 R_3 = 0$

The next three questions pertain to the following situation:

A metal bar slides on a conducting track with width $L = 5$ cm and a resistor $R = 2\,\Omega$ in a uniform magnetic field $B = 0.1$ T out of the page. The bar is pulled to the right with a force $F_{pull} = 2 \times 10^{-5}$ N, such that the bar slides in that direction at a ***constant speed*** v.

15. Calculate the magnitude of the current I in the sliding bar.

a. $I = 4$ mA
b. $I = 1.5$ mA
c. $I = 0.25$ mA
d. $I = 17.5$ mA
e. $I = 0$ mA

$\mathcal{E} = BL v = (0.1\,T)(0.05\,m)\,v$ But don't know v!

force on a wire: $F = ILB \sin\theta$

$2\times10^{-5}\,N = I \cdot (0.05)(0.1)(1)$

$\Rightarrow \quad I = \dfrac{2\times10^{-5}}{5\times10^{-2}} \dfrac{1}{10^{-1}} = 0.4 \cdot 10^{-2}\,A$

$= 4\,mA$

16. What is the correct expression for the speed v of the sliding bar?

a. $v = \dfrac{LB}{F_{pull}R}$

b. $v = \dfrac{F_{pull}R}{LB}$

c. $v = \dfrac{F_{pull}R}{(LB)^2}$

$F = ILB$

$F = \left(\dfrac{\mathcal{E}}{R}\right)LB$

$F = \left(\dfrac{BLv}{R}\right)LB$

$\Rightarrow \quad v = \dfrac{F \cdot R}{L^2 B^2}$

The following situation pertains to the next two questions:

A metal frame with an internal resistance of 1 mΩ enters a region of a uniform magnetic field $B = 1$ T. The area of the frame is 1 m^2. The velocity of the frame, v, is constant. At $t = 0$, the upper edge of the frame reaches the boundary of the magnetic field. From this point of time it takes 10 seconds for the frame to fully enter the magnetic field. After 30 seconds of uniform motion the frame exits the magnetic field region again.
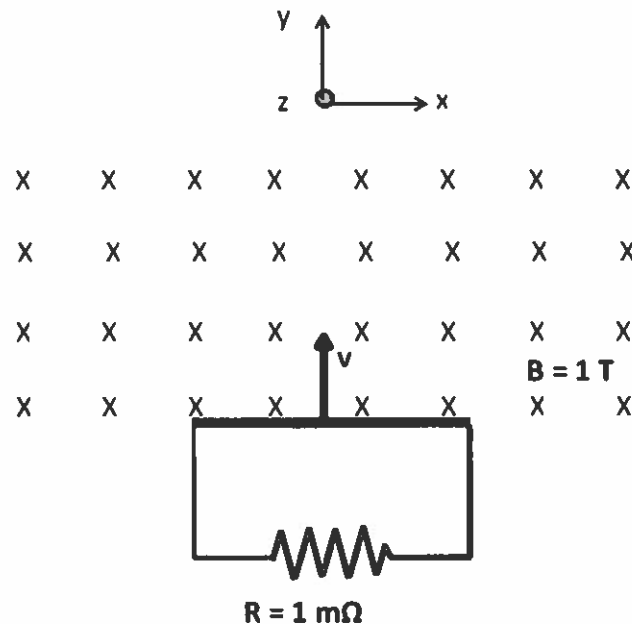

13. From Lenz's rule, what is the relation between the currents induced in the metal frame on entrance to and upon exit from the magnetic field?

a. Entrance: clockwise   Exit: clockwise
b. Entrance: clockwise   Exit: counterclockwise
c. Entrance: counterclockwise   Exit: clockwise

The next two questions pertain to the same situation.

10. A square loop (connected to a battery not shown in the picture) has a current I flowing in the loop as indicated below and lies in the x-y plane. The loop is in an external uniform magnetic field B which points in the x direction. The left side of the loop is labeled s. In which direction does the loop rotate?
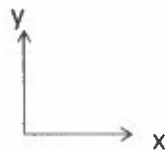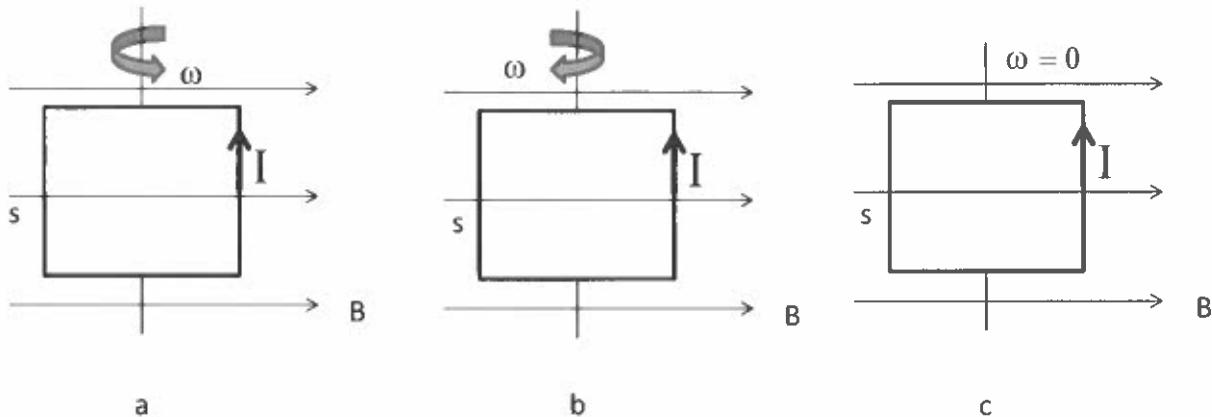
a. side s rotates out of the page
b. side s rotates into the page
c. the loop does not rotate

11. The current in the loop is I = 2.2 A, the side is 10 cm, the magnetic field B = 2 T and the number of turns in the loop N = 3. What is the magnitude of the torque on the loop?

a. τ = 0.023 N-m
b. τ = 0.974 N-m
c. τ = 0.132 N-m

$$\tau = N I A B \sin\phi$$
$$= (3)(2.2)(0.1)^2 \cdot 2$$
$$= (6.6)(2) \cdot 0.01$$
$$= 0.132 \quad N \cdot m$$

The next two questions pertain to the situation described below.

In the following figure, $E_1 = 12\ V$, $E_2 = 4\ V$, $R_1 = 7\ \Omega$, $R_2 = 12\ \Omega$, and $R_3 = 4\ \Omega$. Initially, the switch S is open.
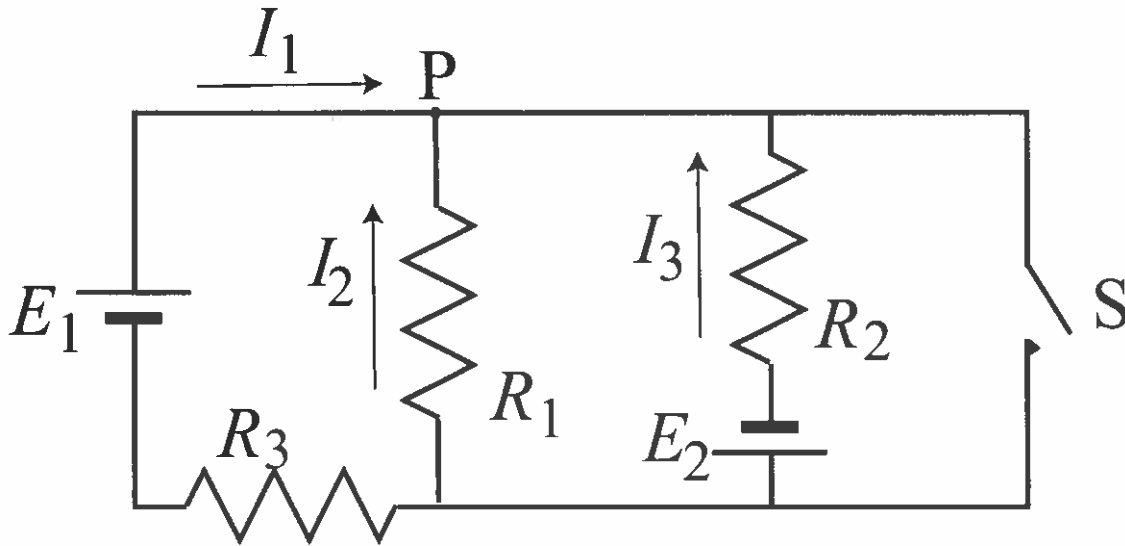
13) At junction P three currents I_1, I_2, and I_3 meet. Choose the correct relation among them from below.

a. $I_1 + I_2 + I_3 = 0$
b. $I_1 - I_2 - I_3 = 0$
c. $-I_1 + I_2 - I_3 = 0$
d. $I_1 - I_2 + I_3 = 0$
e. $I_1 + I_2 - I_3 = 0$

14) When the switch S is closed, what is the current I_3?

take a loop around right loop.

$E_2 - I_3 R_2 = 0$

a. $I_3 = 0\ A$
b. $I_3 = -0.57\ A$
c. $I_3 = -0.75\ A$
d. $I_3 = -0.33\ A$
e. $I_3 = -0.7\ A$

$\Rightarrow I_3 = \dfrac{-E_2}{R_2} = \dfrac{-4\ V}{12\ \Omega} = -0.33\ A$

The next two questions refer to the following situation:

As shown in the picture below, two long, straight wires are separated by 2m. The point P lies at the midpoint of the line connecting the two wires.
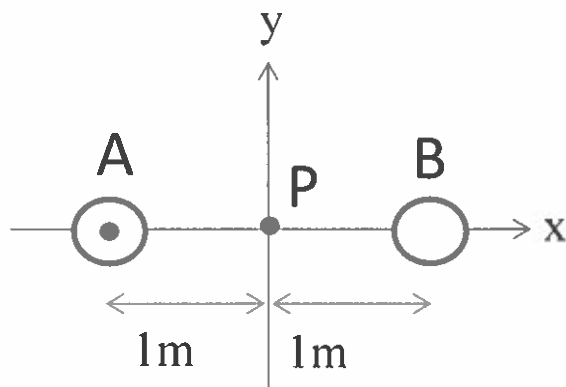
5. If the current through wire A is 1 A and no current flows through wire B, what is the magnitude of the magnetic field at point P?

a. 1×10^{-7} T
b. 2×10^{-7} T
c. 4×10^{-7} T
d. 3.14×10^{-7} T
e. 0.318×10^{-7} T

$$B = \frac{\mu_0 I}{2\pi R} = \frac{4\pi \times 10^{-7}}{2\pi} \cdot \frac{.1}{1}$$

6. What is the direction of the magnetic field at point P if 1A flows through wire B into the page?

a. Into the page
b. Out of the page
c. +y direction
d. −y direction
e. The magnetic field would be zero

The next two questions pertain to the following situation:

The picture below shows three wires oriented vertically, each spaced a distance d = 10 cm apart. Wire A has current I_A = 5 A pointing out of the page (+z direction) and Wire B has current I_B = 5 A pointing into of the page (-z direction). Wire C has unknown current and direction. Each wire is 10 m long.
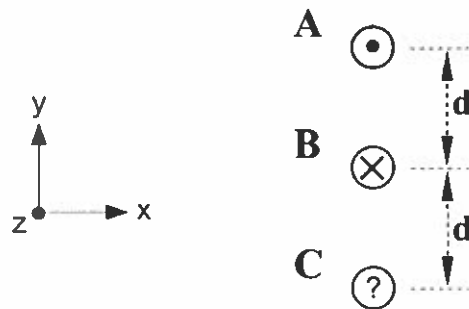
12. If we want current B to have a net force of zero on it, then in what direction should current C point?

opposite currents repel

a. out of the page
b. into the page
c. no current is necessary

$\Rightarrow$ A pushes B down
$\Rightarrow$ need C to push B up (i.e., also repel)

13. Assume the direction and magnitude of the current in wire C is such that the net force on wire B is zero. In which direction could an external magnetic field B_{ext} be applied so that there continues to be no net force on wire B?

a. +x   No force when B is || to I
b. +y
c. +z

14) **Figure repeated from previous page**

Consider the circuit shown below. Initially, both switches are open and the capacitor has been charged to 10 Volts. At time t=0 switch B is closed (switch A remains open).

$R_1 = 25\ \Omega$
$R_2 = 10\ \Omega$
$R_3 = 10\ \Omega$
$\mathcal{E} = 17\ V$
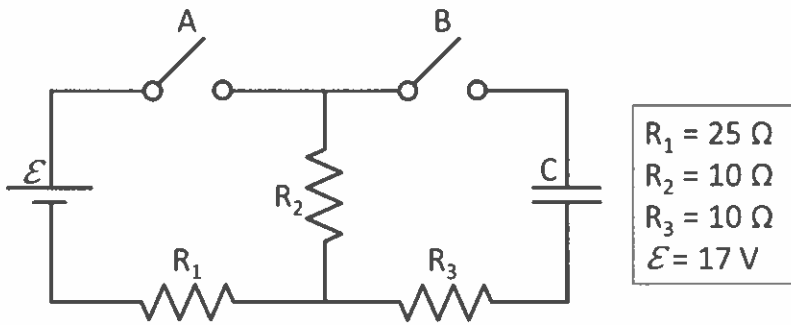
If it takes 12 μs for the charge on the capacitor to drop the 1/2 of its initial value, what is the capacitance of the capacitor C?

a. C = 1631 nF
b. C = 493 nF
c. C = 3370 nF
(d) C = 866 nF
e. C = 215 nF

$R_{eq} = R_2 + R_3 = 20\ \Omega$

$Q = Q_o e^{-t/RC}$

$Q = \dfrac{Q_o}{2} \Rightarrow \ln 2 = \dfrac{t}{RC}$

$C = \dfrac{(12 \times 10^{-6})}{20 \cdot \ln 2}$

$= 0.866 \times 10^{-6}\ F$

15) After a very long time, switch A is closed. Switch B remains closed. What is the magnitude of the current I_1 through resistor R_1 immediately after switch A is closed?

(a) $I_1 = 0.567$ A
b. $I_1 = 0.165$ A
c. $I_1 = 0.202$ A
d. $I_1 = 0.446$ A
e. $I_1 = 0.930$ A

Immediately after, C is still uncharged, so acts like a wire

$\Rightarrow$ $R_{23} \Rightarrow \dfrac{1}{R_{23}} = \dfrac{1}{R_2} + \dfrac{1}{R_3}$

$\Rightarrow R_{23} = 5\ \Omega$

$R_{123} = R_1 + R_{23} = 30\ \Omega$

$I_{123} = \dfrac{V}{R_{123}} = \dfrac{17\ V}{30\ \Omega} = 0.567\ A$

All current goes through R_1

$\Rightarrow I_1 = I_{123}$

The next three questions pertain to the following situation:

The switch in the circuit shown below has been open for a long time so that the capacitor is initially uncharged.
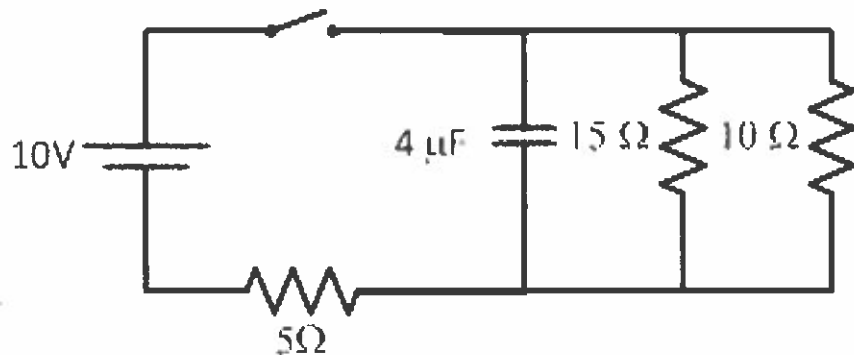
25. What is the current through the 5 Ω resistor <u>immediately</u> after the switch is closed?

a. 2.0 A
b. 0.9 A
c. 0 A

Initially C is a bare wire
$\Rightarrow +10V - I_5(5\Omega) = 0 \Rightarrow I_5 = 2 A$

26. What is the voltage across the capacitor after the switch has been closed for a <u>long time</u>?

a. 4.55 V
b. 5.45 V
c. 7.5 V
d. 8.2 V
e. 10 V

After a long time, $I_c = 0$

$\frac{1}{R_{eq}} = \frac{1}{10\Omega} + \frac{1}{15\Omega} = \frac{3}{30\Omega} + \frac{2}{30\Omega}$

$\Rightarrow R_{eq} = 6\Omega$

$\Rightarrow R_{eq} + 5\Omega = 11\Omega$

$I_{Battery} = I_5 = \frac{V}{R_{tot}} = \frac{10V}{11A} = 0.91 A$

$\Rightarrow V_5 = I_5 R_5 = (0.91A)(5\Omega) = 4.55 V$

$V_c + V_6 = V_B \Rightarrow V_c = 10V - 4.55 V$
$= 5.45 V$

27. The after the switch has been closed for a long time, it is then opened again. What is the current through the 15Ω after the switch has been open for 30μs?

a. 0.260 A
b. 0.257 A
c. 0.220 A
d. 0.104 A
e. 0.156 A

$R_{eq} = 6\Omega \Rightarrow RC = 24 \times 10^{-6} s$

$I = I_0 e^{-t/RC} = \left(\frac{V_{cap}}{R_{15}}\right) e^{-t/RC}$

$= \frac{5.45V}{15\Omega} e^{-\frac{30 \times 10^{-6}}{24 \times 10^{-6}}}$

The next two questions pertain to this situation:

A charged dust particle ($m = 3 \times 10^{-21}$ kg, $q = +1.6 \times 10^{-16}$ C) is accelerated from rest by an electric field through a 10^3 V potential difference. The magnetic field is zero in the electric field region. It then enters a region that contains a uniform 1.5 T magnetic field that points into the page. $E = 0$ in the magnetic field region.
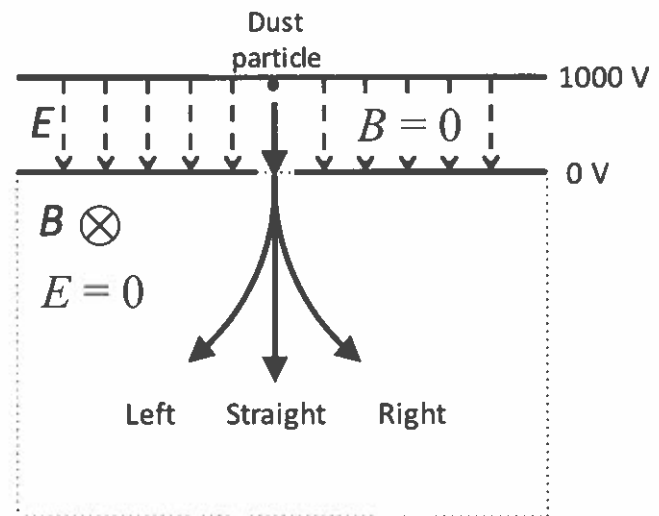
22. Which of the three paths shown in the figure does the dust particle follow?

a. Left
b. Straight
c. Right

23. What is the radius of curvature of the particle's motion in the magnetic field region?

a. $R = 0.022$ m
b. $R = 0.129$ m
c. $R = 1.53$ m
d. $R = 15.3$ m
e. $R = 1096$ m

$r = \dfrac{m v}{q B}$

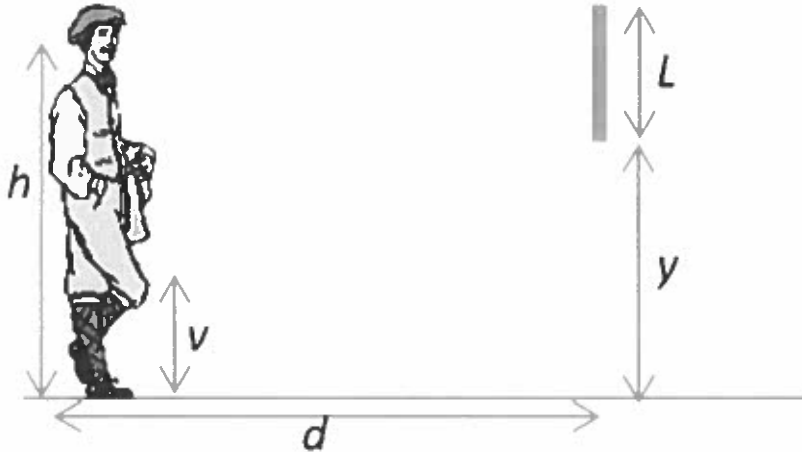Need v! $\dfrac{1}{2} m v^2 = q(\Delta V)$ ⊕

$\Rightarrow v^2 = \dfrac{2q \, \Delta V}{m}$ $\Rightarrow v = 10.3 \times 10^3$ m/s

$\Rightarrow r = \dfrac{3 \times 10^{-21} \cdot 10.3 \times 10^3}{1.6 \times 10^{-16} \cdot 1.5} = 0.129$ m
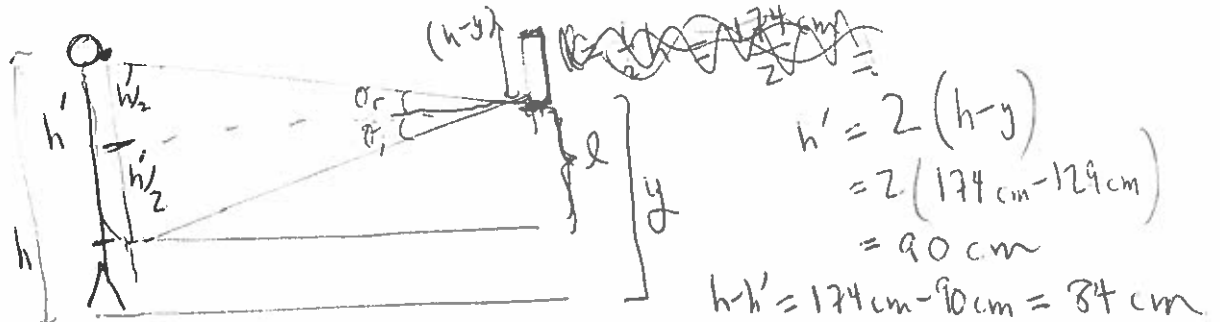
The next two questions pertain to the situation described below.

A man stands a distance $d = 240$ cm in front of a virtical flat mirror of length $L = 45$ cm that is hung a distance $y = 129$ cm above the ground as shown in the figure. The mans eyes are a distance $h = 174$ cm above the ground.

1) What is lowest point above the ground, that he can see his image reflection in the mirror?

a. $v = 130$ cm
b. $v = 84$ cm
c. $v = 66$ cm
d. $v = 150$ cm
e. $v = 45$ cm

$$h' = 2(h-y)$$
$$= 2(174\,cm - 129\,cm)$$
$$= 90\,cm$$
$$h - h' = 174\,cm - 90\,cm = 84\,cm$$

2) If the man takes a step closer to the mirror, the lowest point above the ground he can see his image reflected in the mirror

a. increase.
b. decrease.
c. remain the same.

The next two questions pertain to the following situation.

An object (black arrow) is located in front of a *convex* spherical mirror of radius $R = 35$ cm, as shown in the figure below. The tip of the arrow is located at $(x_0, y_0) = (16$ cm, -6 cm) from the mirror.
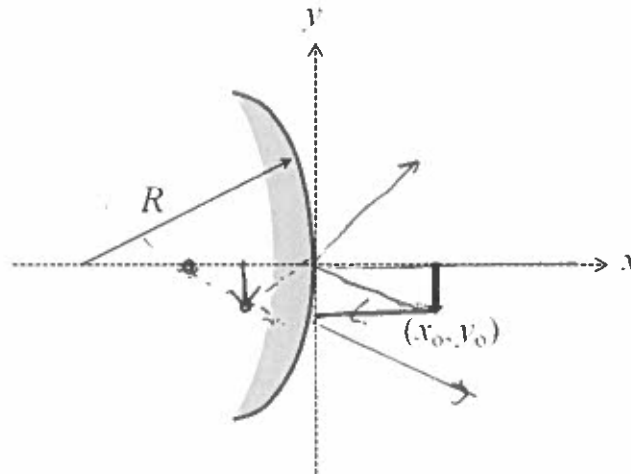
1. What is x_i, the x-coordinate of the image of the tip of the arrow?

$\textcircled{a}$ $x_i = -8.4$ cm
b. $x_i = -11.0$ cm
c. $x_i = +18.7$ cm

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \Rightarrow \frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$f = -\frac{R}{2}$

$= \frac{-2}{35 cm} - \frac{1}{16 cm}$

$\Rightarrow d_i = -8.36$ cm

2. The object arrow is now moved such that the *image* distance doubles. What is $y_{i,new}$, the new y-coordinate of the image of the tip of the arrow?

a. $y_{i,new} = -3.13$ cm
b. $y_{i,new} = +0.16$ cm
$\textcircled{c}$ $y_{i,new} = -0.27$ cm
d. $y_{i,new} = +6.35$ cm
e. $y_{i,new} = -12.7$ cm
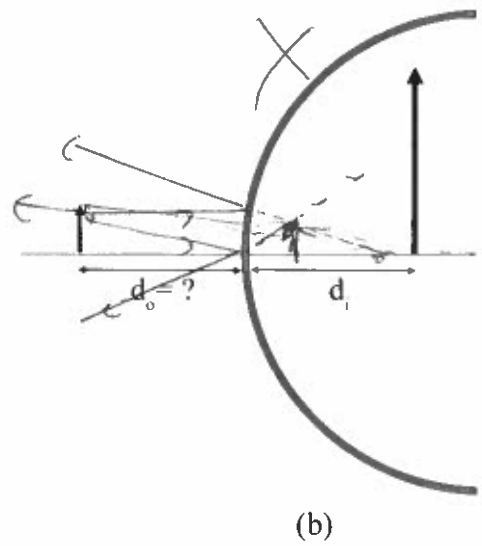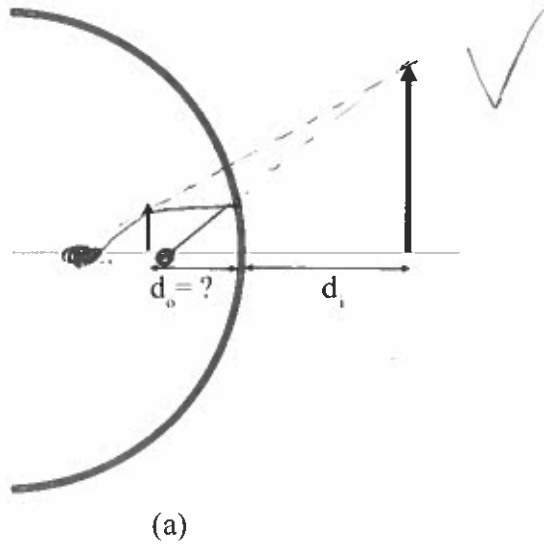
$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$d_i = (-8.36 cm) 2 = -16.72 cm$

$\Rightarrow \frac{1}{d_o} = -\frac{2}{35 cm} + \frac{1}{16.72 cm} \Rightarrow d_o = 375.13$ cm

$y_{i,new} = y_o \cdot \left| \frac{d_i}{d_o} \right| = -0.267 cm$

The next two questions pertain to the same situation.

(a)   (b)

2. A virtual image is formed 15 cm behind a mirror. The image's magnification m is measured to be +5. Determine whether the mirror is concave or convex.

a. convex
b. concave

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$= \frac{5}{-d_i} + \frac{1}{d_i} = \frac{1}{d_i}\left(\frac{4}{5}\right) = \frac{-4}{-15}$$

$$m = -\frac{d_i}{d_o} \implies d_o = \frac{(-d_i)}{5} =$$

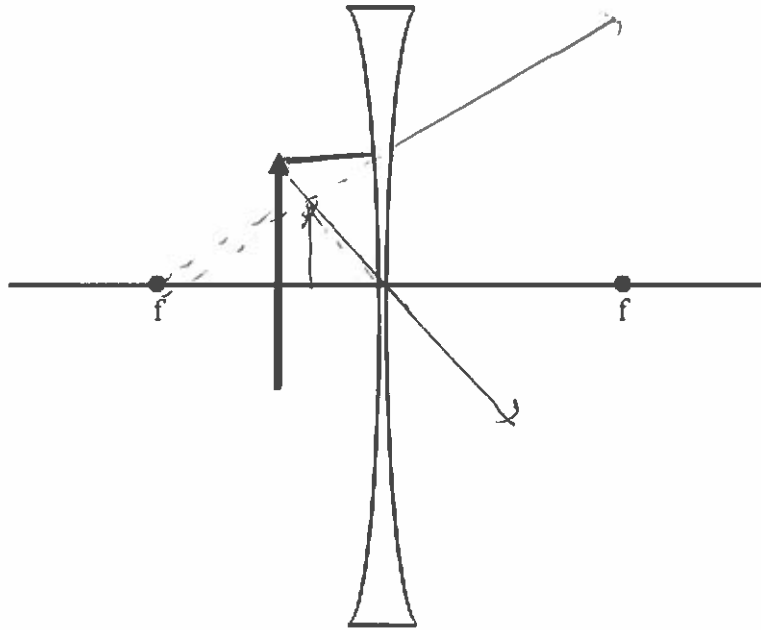In general: virtual, upright, magnified, must be concave!

$$f > 0 \implies \text{concave}$$

3. What is the radius of curvature of the mirror?

a. 5 cm
b. 15 cm
c. 7.5 cm

$$f = \frac{15}{4} \text{ cm} \implies R = 2f = 7.5 \text{ cm}$$

The next three questions pertain to the following situation.

An object is placed 3 cm in front of a diverging lens with focal length f = -7 cm.

19. What is the magnification of the resulting image?

a. -4.3
b. -0.7
c. +0.7
d. +2.0
e. +4.3

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = -\frac{1}{7\,cm} - \frac{1}{3\,cm}$$

$$= -\frac{10}{21}\frac{1}{cm}$$

$$\Rightarrow d_i = -2.1\,cm$$

$$m = -\frac{d_i}{d_o} = \frac{+2.1\,cm}{3\,cm}$$

$$= +0.7$$

20. Is the image upright or inverted?
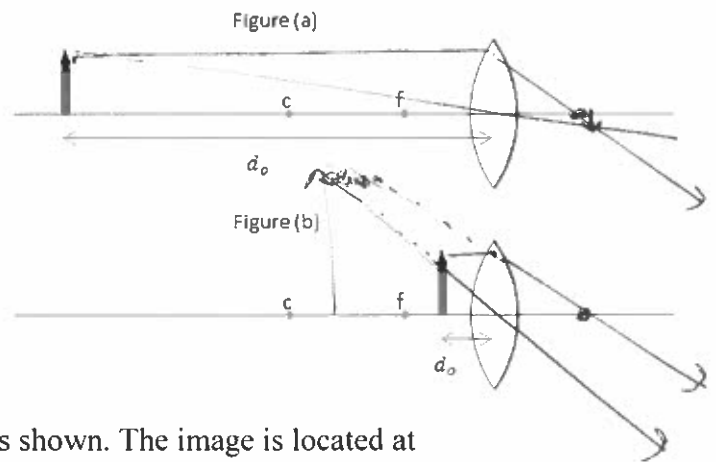
a. upright
b. inverted

diverging always upright

21. Is the image real or virtual?

a. real
b. virtual

divergly always virtual

The next four questions pertain to the situation described below.

A candle is placed before a converging lens as shown. The lens has a focal length of $f = 2.4\ cm$.

Figure (a)

Figure (b)

6) The candle is first placed at a distance $d_o = 14.8\ cm$ as shown. The image is located at

    a. $d_i = 2.07\ cm$
    (b.) $d_i = 2.86\ cm$
    c. *no image is formed*

7) The resulting image is also

    (a.) *inverted*
    b. *neither*
    c. *upright*

8) Now the candle is placed at $d_o = 1.2\ cm$. Now the image is located at

    (a.) $d_i = -2.4\ cm$
    b. $d_i = -0.8\ cm$
    c. *no image is formed*

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{2.4\,cm} - \frac{1}{1.2\,cm}$$

$$= \frac{1}{2.4\,cm} - \frac{2}{2.4\,cm}$$

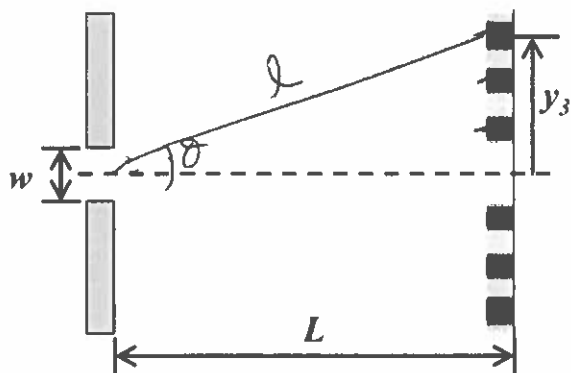$$= -\frac{1}{2.4\,cm} \quad \Rightarrow\quad d_i = -2.4\,cm$$

9) This new image is also

    a. *real*
    b. *neither*
    (c.) *virtual*

Inside f, convo sig lens $\Rightarrow$ virtual image $(d_i < 0)$

A rectangular aperture of width $w = 865$ μm is illuminated by light of wavelength $\lambda = 620$ nm. A diffraction pattern is shown on a screen a distance $L = 3.9$ m away as shown in the figure.

24) At what position y_3 will the third-order (m = 3) diffraction minimum be observed?

a. $y_3 = 8.39$ mm
b. $y_3 = 41.9$ mm
c. $y_3 = 2.1$ mm
d. $y_3 = 3.35$ mm
e. $y_3 = 21$ mm

$a \sin\theta = m\lambda$

$\Rightarrow \sin\theta = \dfrac{m\lambda}{a} = \dfrac{3 \cdot 620\times10^{-9}\,m}{865\times10^{-6}\,m} = \cancel{0.00215}$

We could just use small angle approximation, $\sin\theta \to \theta$, $y_3 \sim L\theta$

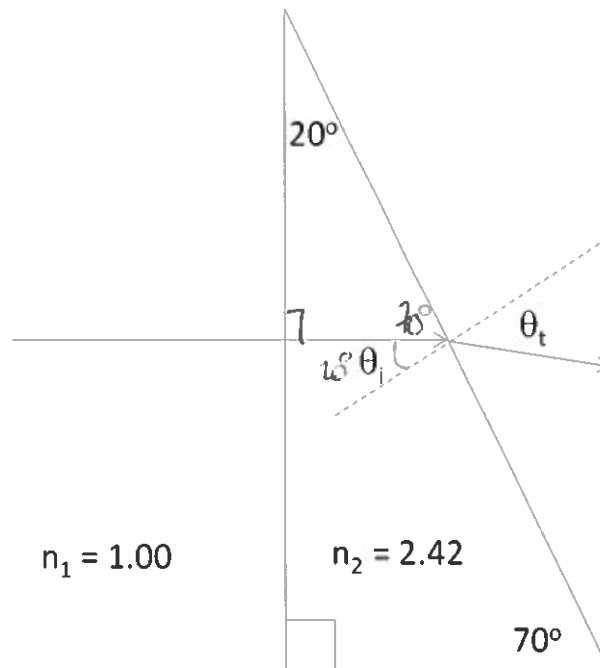OR $\quad \dfrac{y_3 \, \ell}{\ell} = \sin\theta \qquad \dfrac{y_3}{L} = \tan\theta$

$\Rightarrow y_3 = L \tan\theta = L \cdot \tan\left[\sin^{-1}\left(\cancel{0.00215}\right)\right]$

$= 0.0084\,m$

The next two questions pertain to the following situation.

20°

$n_1 = 1.00$ $n_2 = 2.42$

70°

26. A ray of light impinges normally upon a right-angle prism as shown in the diagram above. The prism is made of diamond with an index of refraction $n_2 = 2.42$. What is the transmitted angle θ_t with respect to the surface normal on the transmission side?

a. $\theta_t = 55.9°$
b. $\theta_t = 12.1°$
c. $\theta_t = 62.3°$
d. $\theta_t = 34.2°$
e. $\theta_t = 73.2°$

$$n_2 \sin\theta_2 = n_1 \sin\theta_t$$
$$\sin\theta_t = \frac{n_2}{n_1} \sin(20°) = 0.828$$
$$\Rightarrow \theta_t = 55.9°$$

27. What angle of incidence θ_i relative to the surface normal on the transmission side would correspond to the critical angle for total internal reflection?

a. $\theta_t = 43.6°$
b. $\theta_t = 24.4°$
c. $\theta_t = 31.2°$

$$\sin\theta_c = \frac{n_{outside}}{n_{inside}} = \frac{1}{2.42}$$
$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{1}{2.42}\right)$$

**Check to make sure you bubbled in all your answers.
Did you bubble in your name, exam version and network-ID?**

The next two questions pertain to the following situation.

Unpolarized light with intensity I_0 is incident on a series of three polarizers, as shown in the picture below.

Unpolarized light

I_0

$30°$ $35°$ $82°$

$\frac{I_0}{2}$

$\frac{I_0}{2}\cos^2(5°)$

$\frac{I_0}{2}\cos^2(5°)\cos^2(47°)$
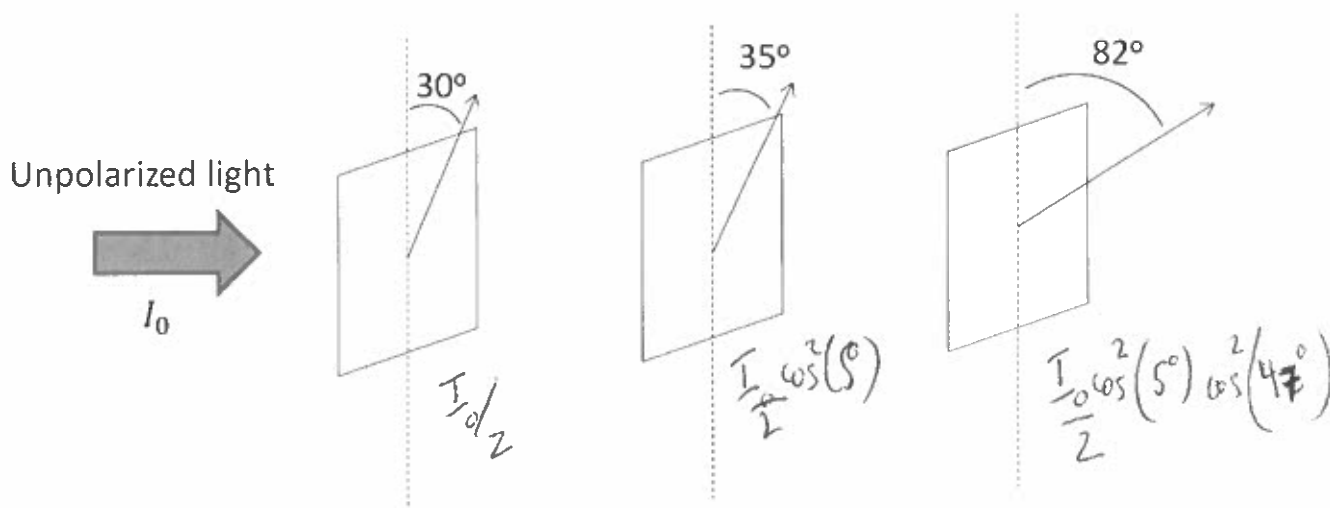
9. The intensity after the first polarizer is

a. $0.75\,I_0$
b. $0.87\,I_0$
c. independent of the angle of the first polarizer.

10. The intensity of the light after the third polarizer is

a. $0.05\,I_0$
b. $0.34\,I_0$
c. $0.23\,I_0$

$I \rightarrow \frac{I_0}{2} \rightarrow \left(\frac{I_0}{2}\right)\left[\cos(5°)\right]^2 \rightarrow \frac{I_0}{2}\left[\cos(5°)\right]^2\left[\cos(47°)\right]^2$

The next three questions pertain to the following situation:

Consider the figure below which shows a snapshot of an electromagnetic wave propagating in vacuum along the x axis. The wave is linearly polarized along the y axis and oscillates at a frequency $f = 1.25 \times 10^{12}$ Hz. The light has an average intensity $I = 0.5$ W/m^2.
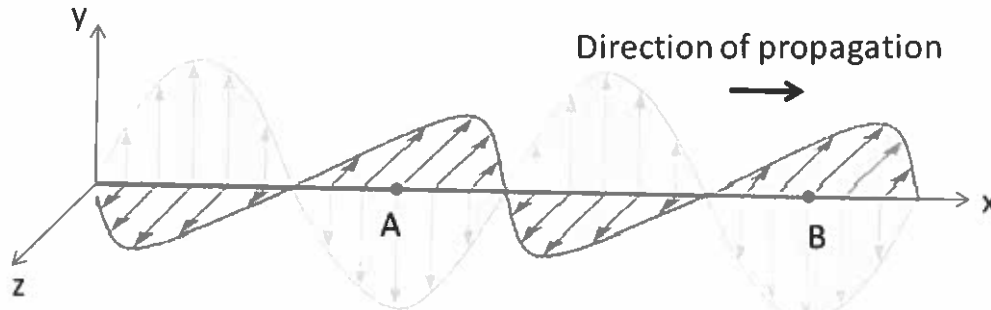
9. What is the magnitude of the electric field E at point A on the x axis at the instant shown?

a. $E = 0$ N/C
b. $E = 7.9$ N/C
c. $E = 19.4$ N/C

E is at a maximum

$$I = \bar{u}c = \varepsilon_c E_{rms}^2 C = \varepsilon_c \frac{E_{max}^2}{2} C$$

$$\Rightarrow E_{max} = \sqrt{\frac{2I}{\varepsilon_c C}}$$

10. Along which direction does the magnetic field oscillate?

a. x axis
b. y axis
c. z axis

E is along y [says above]
propagates along x $\Rightarrow$ B must be along z

11. What is the distance between points A and B?

a. 2.4×10^{-4} m
b. 3.1×10^{-2} m
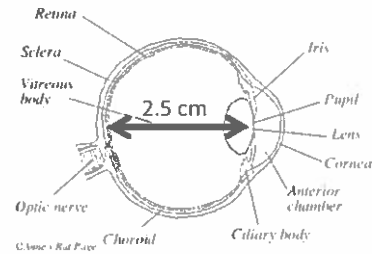c. 7.8×10^{-3} m

from A $\rightarrow$ B is exactly 1 wavelength.

$c = \lambda f$

$$\Rightarrow \lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{1.25 \times 10^{12} \frac{1}{s}} = \left(\frac{3}{1.25}\right) \times 10^{-4} \text{ m}$$

$= \frac{3}{(5/4)} = \frac{12}{5} = 2 + \frac{2}{5}$

$= 2.4$

23. The diameter of the human eye is about 2.5 cm. One college student can focus on objects that are 10 cm in front of her face. What is the focal length, f, of her eye's lens when she is doing that?

a. $f = -5.00$ cm
b. $f = -3.33$ cm
c. $f = +1.25$ cm
d. $f = +2.00$ cm
e. $f = +2.50$ cm

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$= \frac{1}{2.5 cm} + \frac{1}{10 cm}$$

$$= \frac{4}{10 cm} + \frac{1}{10 cm}$$

$$\frac{1}{f} = \frac{5}{10 cm}$$

$$\Rightarrow f = 2 \text{ cm}$$

24. When you are young, your near point is 25 cm. Suppose an older person's near point has increased to 60 cm. What strength reading glasses, in diopters, must this person buy to regain the original 25 cm near point?

a. 0.42 diopters
b. 1.40 diopters
c. 2.33 diopters
d. 3.33 diopters
e. 5.67 diopter

$$\text{strength} = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$25 cm \qquad -60 cm$$

$$\Rightarrow \left(\frac{1}{f}\right) = \frac{1}{0.25} - \frac{1}{0.6} = 2.33 \text{ m}^{-1}$$

Check to make sure you bubbled in all your answers.
Did you bubble in your name, exam version and network-ID?