Last Name:________________First Name_________________Network-ID__________

Discussion Section:________Discussion TA Name:______________________________

Turn off your cell phone and put it out of sight.
Keep your calculator on your own desk. Calculators cannot be shared.
This is a closed book exam. You have ninety (90) minutes to complete it.

1. Use a #2 pencil. Do not use a mechanical pencil or pen. Darken each circle completely, but stay within the boundary. If you decide to change an answer, erase vigorously; the scanner sometimes registers incompletely erased marks as intended answers; this can adversely affect your grade. Light marks or marks extending outside the circle may be read improperly by the scanner. Be especially careful that your mark covers the **center** of its circle.

2. You may find the version of **this Exam Booklet at the top of page 2**. Mark the version circle in the TEST FORM box near the middle of your answer sheet. **DO THIS NOW!**

3. Print your **NETWORK ID** in the designated spaces at the *right* side of the answer sheet, starting in the left most column, then **mark the corresponding circle** below each character. If there is a letter "o" in your NetID, be sure to mark the "o" circle and not the circle for the digit zero. If and only if there is a hyphen "-" in your NetID, mark the hyphen circle at the bottom of the column. When you have finished marking the circles corresponding to your NetID, check particularly that you have not marked two circles in any one of the columns.

4. Print **YOUR LAST NAME** in the designated spaces at the *left* side of the answer sheet, then mark the corresponding circle below each letter. Do the same for your **FIRST NAME INITIAL**.

5. Print your UIN# in the STUDENT NUMBER designated spaces and mark the corresponding circles. You need not write in or mark the circles in the SECTION box.

6. Sign your name **(DO NOT PRINT)** on the **STUDENT SIGNATURE** *line*.

7. On the **SECTION** *line*, print your **DISCUSSION SECTION**. You need not fill in the COURSE or INSTRUCTOR lines.

Before starting work, check to make sure that your test booklet is complete. You should have 10 ***numbered pages*** *plus three (3) Formula Sheets following these instructions.*

Academic Integrity—**Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including dismissal from the University.**

This Exam Booklet is Version A. Mark the **A** circle in the **TEST FORM** box near the middle of your answer sheet. **DO THIS NOW!**

Exam Grading Policy—

The exam is worth a total of **110** points, composed of three types of questions.

MC5: *multiple-choice-five-answer questions, each worth 6 points.*
Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer,
you earn **6** points.
(b) If you mark *two* answers, one of which is the correct answer,
you earn **3** points.
(c) If you mark *three* answers, one of which is the correct answer,
you earn **2** points.
(d) If you mark no answers, or more than *three*, you earn 0 points.

MC3: *multiple-choice-three-answer questions, each worth 3 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **3** points.
(b) If you mark a wrong answer or no answers, you earn **0** points.

MC2: *multiple-choice-two-answer questions, each worth 2 points.*
No partial credit.

(a) If you mark only one answer and it is the correct answer,
you earn **2** points.
(b) If you mark the wrong answer or neither answer, you earn **0** points.

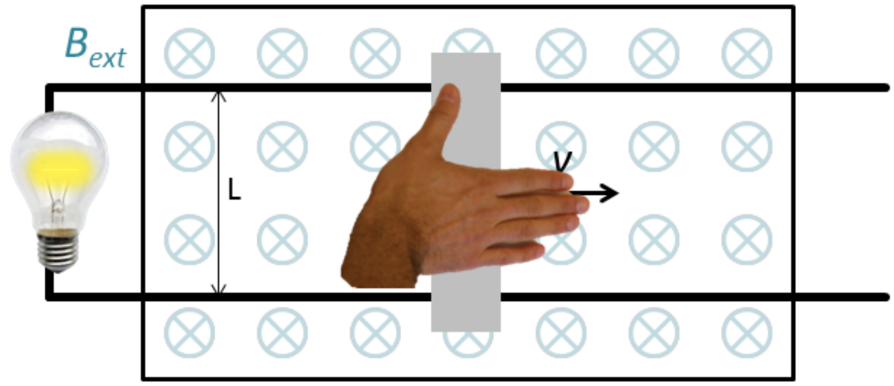
Some helpful information:

- A reminder about prefixes: p (pico) = 10^{-12}; n (nano) = 10^{-9}; μ (micro) = 10^{-6}; m (milli) = 10^{-3}; k (kilo) = 10^{+3}; M or Meg (mega) = 10^{+6}; G or Gig (giga) = 10^{+9}.

The next two questions pertain to the situation described below.

A light bulb is attached to a frictionless, conducting track as shown in the figure. The tracks run through an area containing a magnetic field, $B_{ext} = 4\ T$, pointing into the page. The tracks are $L = 0.45\ m$ apart.

The lightbulb produces *60 W* when attached to a *115 V* power source. A conducting bar is attached to the track. You push the bar with constant velocity *v* to the right as shown.



1) With what speed must the bar travel for the light bulb to dissipate *60 W* of power?

motional emf = vBL

115/(4 x 0.45) = 63.88 m/s

a. $v = 13\ m/s$
b. $v = 64\ m/s$
c. $v = 200\ m/s$

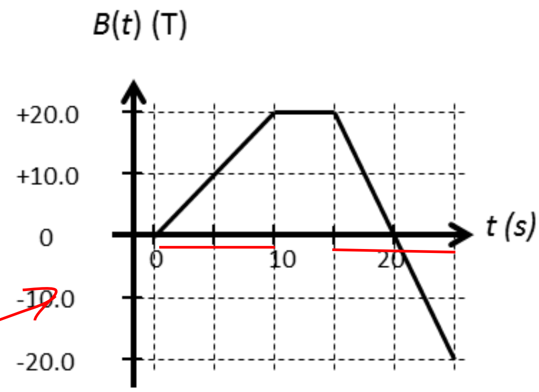
2) Once the bar is pushed outside of the magnetic field area, the light bulb will continue to produce light.

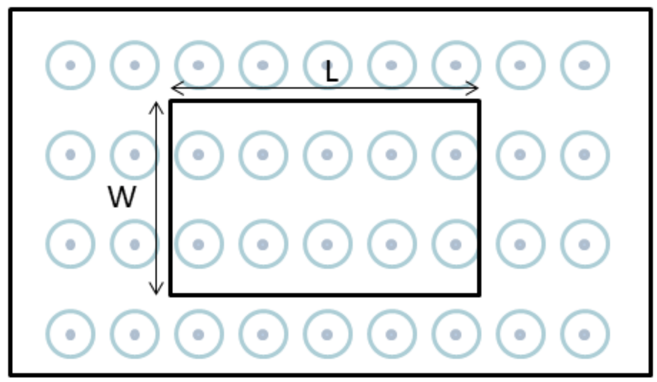
Only when the metal bar cuts through the B field vectors can there be any emf.

a. *True*
b. *False*

The next three questions pertain to the situation described below.

A loop of wire length $L = 90\ cm$ and width $W=40\ cm$ sits in a magnetic field which varies with time, as shown in the graph. The magnetic field points out of the page.





Faraday's law,
Only when ¥Phi changes can
there be any emf.

3) During which times does current flow through the loop?

a. $0\ s < t < 10\ s$ and $15\ s < t < 25\ s$
b. $10\ s < t < 15\ s$ and $15\ s < t < 25\ s$
c. $0\ s < t < 10\ s$ and $10\ s < t < 15\ s$
d. $0\ s < t < 10\ s$ only
e. $15\ s < t < 25\ s$ only

but, precisely speaking, actually we cannot say
for sure that t< 25 s. No information is given.

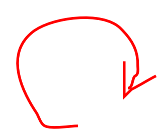
4) In what direction does current flow between $0\ s < t < 10\ s$?

a. *current does not flow*
b. *clockwise*
c. *counter-clockwise*

Lenz

RH screw rule

```
B out of the page is increasing
-> The loop `wishes to oppose this' by
   creating the B into the page.
```



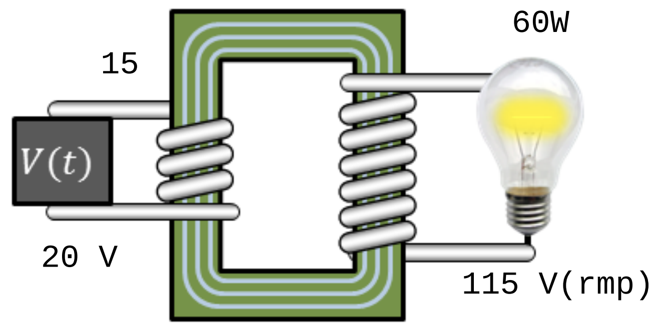
5) What is the magnitude of the EMF, $|\varepsilon|$, between $0\ s < t < 10\ s$?

a. $|\varepsilon| = 0.72\ V$
b. $|\varepsilon| = 0.32\ V$
c. $|\varepsilon| = 0\ V$

```
|emf| = |d Phi/dt| = A dB/dt
  = 0.9x0.4 x 20/10 = 0.72 V
```

A light bulb is attached to a "step-up" transformer as shown in the figure. The light bulb produces *60 W* when attached to a *115 V* power source.

The transformer is attached to a power source with a voltage that varies with time. The primary coil has $N_p = 15$ turns of wire.



6) What is the maximum number of turns on the secondary coil for the output voltage not to exceed *115 V* when the voltage on the primary coil is $V = 20\ V$?

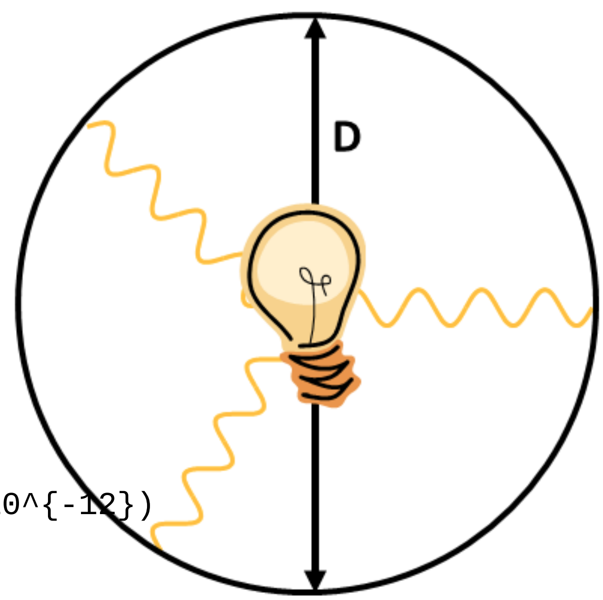
a. $N_s = 430$
b. $N_s = 29$
c. $N_s = 86$

V/N is the same.

```
115/Ns = 20/Np
Ns = (115/20)x15 = 86
If Ns is less than 86 it is OK, but the
question asks the max allowed.
```

7) As shown in the figure, a small light bulb that emits an average power of *40 W* is placed inside of a sphere of diameter $D = 20\ m$. What is the root mean square (rms) electric field strength at a point on the inner surface of the sphere?

Remember: The surface area of a sphere is $4\pi r^2$



P= A u c
u = epsilon0 Erms^2

```
u = 40/(4 pi 10^2 x 3 x 10^8)
  = 10/9.4248x10^{10}
Erms = sqrt(10/9.4248x10^{10} x 8.85 x 10^{-12})
     = sqrt(10/83.41x10{-2}) = 3.463 V/m
```

a. $E_{rms} = 0.29\ V/m$
b. $E_{rms} = 3.5\ V/m$
c. $E_{rms} = 1.7\ V/m$
d. $E_{rms} = 6.9\ V/m$
e. $E_{rms} = 4.9\ V/m$

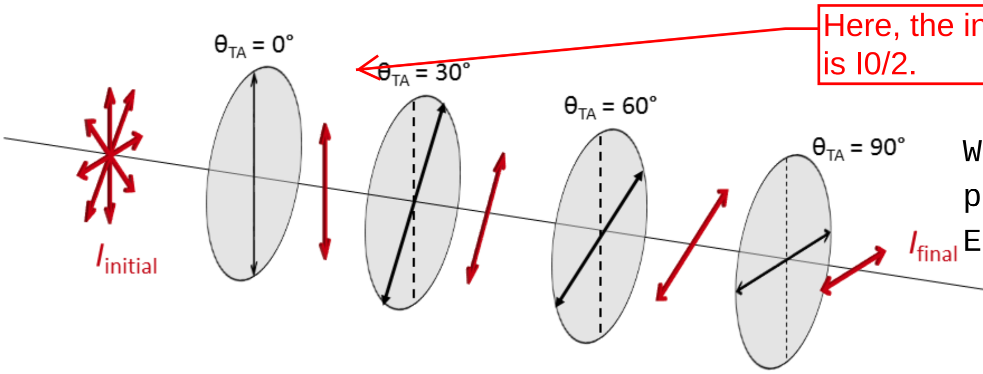
`Unpolarized' is the appropriate expression

8) This question refers to the figure.

~~Randomly polarized light~~ of intensity $I_{initial}$ is incident on 4 linear polarizers. The initial polarizer's transmission axis is aligned vertically, at $\theta_{TA} = 0^{\circ}$. The final polarizer is aligned horizontally at $\theta_{TA} = 90^{\circ}$. The angles of the intermediary polarizers are evenly spaced, rotating from vertical to horizontal, as shown.

What is the intensity of light after the final polarizer?

Here, the intensity is I0/2.



We have three more polarizers. Each contribute (cos 30)^2.

Therefore,
I0x (1/2) x (cos 30)^6
= I0x(1/2)x(3/4)^3 = 0.2109 I0

a. $I_{final} = 0.42\ I_{initial}$
b. $I_{final} = 1.2\ I_{initial}$
c. $I_{final} = 0.75\ I_{initial}$
d. $I_{final} = 0.21\ I_{initial}$
e. $I_{final} = 0.32\ I_{initial}$

9) From the choices below, which option properly orders different types of electromagnetic radiation from highest to lowest frequency?

a. *ultraviolet, visible light, infra-red radiation, radio waves*
b. *X-rays, infra-red radiation, visible light, radio waves*
c. *radio waves, X-rays, ultraviolet, visible light*

10) Laser light with a frequency $f_{air} = 400\ THz$ is sent from vacuum to a medium with index of refraction $n = 1.6$. What is the radiation's frequency in this material?

Frequency does not change.

a. $f_{material} = 250\ THz$
b. $f_{material} = 400\ THz$
c. $f_{material} = 640\ THz$

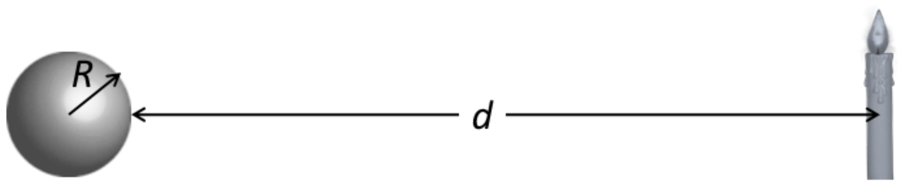
11) A microwave horn antenna is driven at a frequency $f = 1.3\ GHz$. What is the wavelength in air of the electromagnetic radiation emitted from the horn?

c = lambda x f

a. $\lambda = 4.3\ cm$
b. $\lambda = 12\ cm$
c. $\lambda = 23\ cm$

lambda = c/f = 3x10^8/1.3x10^9 = 2.3 x10^{-1} m

The next two questions pertain to the situation described below.



A silvered sphere has a radius $R = 5\ cm$. A candle of height $h_o = 7\ cm$ is placed at a distance of $d = 23\ cm$ from the surface the sphere, as shown.

12) Which of the following statements on the image formed by the sphere is TRUE?

f= -R/2
1/f = 1/do + 1/di   m = -di/do

a. *The image is virtual and inverted*
b. *The image is virtual and upright*
c. *The image is real and upright*

1/di = -1/2.5 -1/23 = -1/2.2548<0 -> virtual
m = 2.2348/23 = 0.09717>0 -> upright

13) What is the height $|h_i|$ of the candle's image?

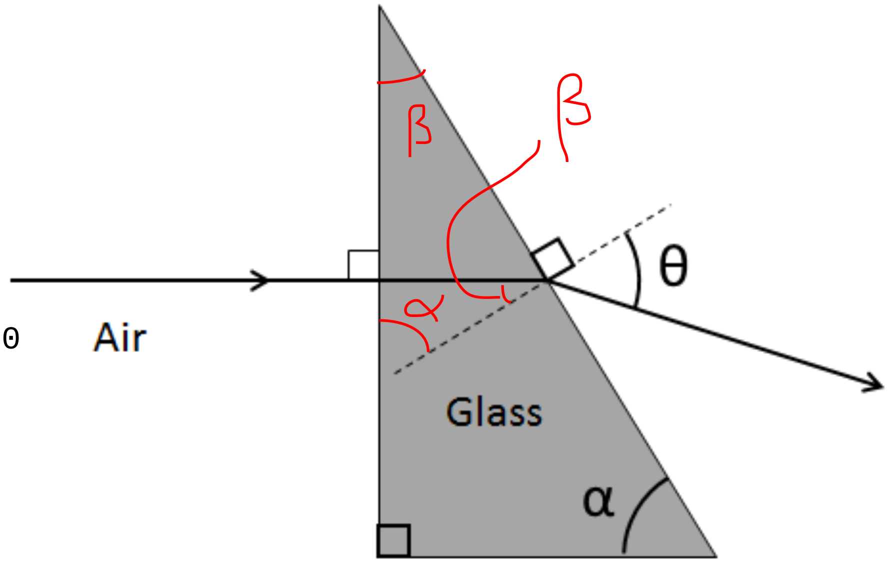
a. $h_i = 0.85\ cm$
b. $h_i = 1.3\ cm$
c. $h_i = 0.69\ cm$

hi = mx ho = 0.6802 cm

The next three questions pertain to the situation described below.

Consider a glass prism in the shape of a right triangle that makes an angle $\alpha = 70^{o}$, as shown. The glass has index of refraction $n_{red} = 1.5$ and $n_{blue} = 1.53$ for red and blue light, respectively.

Notice that beta = 90 - 70
= 20 deg



14) A ray of red, monochromatic light travelling in air to the right hits the surface of the prism at 90°, as shown in the figure. What is the angle θ at which the light emerges?

Snell's law n sin theta is constant.

a. $\theta = 20°$
b. $\theta = 46°$
c. $\theta = 70°$
d. $\theta = 31°$
e. $\theta = 59°$

1.5 sin 20 = 1 sin theta -> theta = 30.865 deg

15) Now, the prism is immersed in water. What happens to the angle θ from the previous question?

1.5 sin 20 = n sin theta, and n>1, so theta must be less than 30.865 deg.

a. θ *increases*
b. θ *decreases*
c. θ *remains the same*

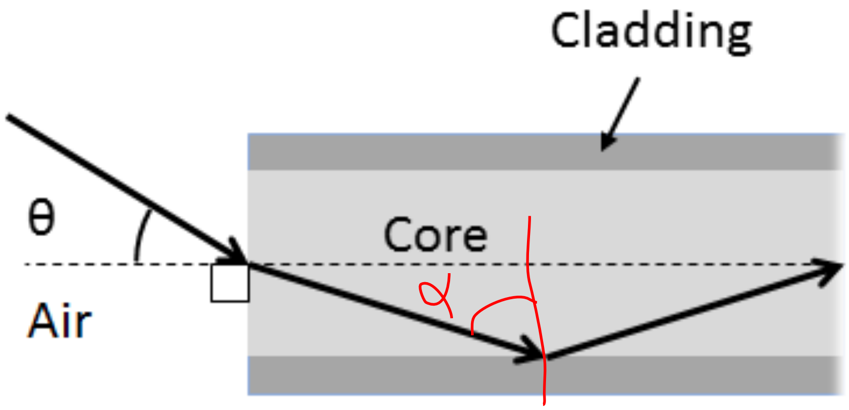
16) Now, a ray of white light hits the surface of the prism at 90°. In what order, from top to bottom do the different colored rays emerge?

Larger n bends more.

a. *Red ray on top, blue ray on the bottom*
b. *Red and blue rays at the same angle*
c. *Blue ray on top, red ray on the bottom*

The next two questions pertain to the situation described below.

A beam of monochromatic green light of wavelength $\lambda = 532\ nm$ (measured in air) is incident on the core of an optical fiber with refractive index $n_{core} = 1.48$, as shown. The core is surrounded by a cladding of refractive index $n_{cladding} = 1.39$.



Total internal reflection occurs if alpha is larger than given by ncore sin alpha = nclad

17) What must be the maximum incident angle θ of the beam at the air-core interface, as shown in the figure, such that light cannot escape through the cladding of the optical fiber?

a. $\theta_{max} = 43.4°$
b. $\theta_{max} = 39.4°$
c. *There is no such angle*
d. $\theta_{max} = 13.4°$
e. $\theta_{max} = 30.5°$

alpha must not be smaller than 69.91 deg.

sin theta = 1.48 sin(90 - 69.91)

theta = 30.55 or smaller.

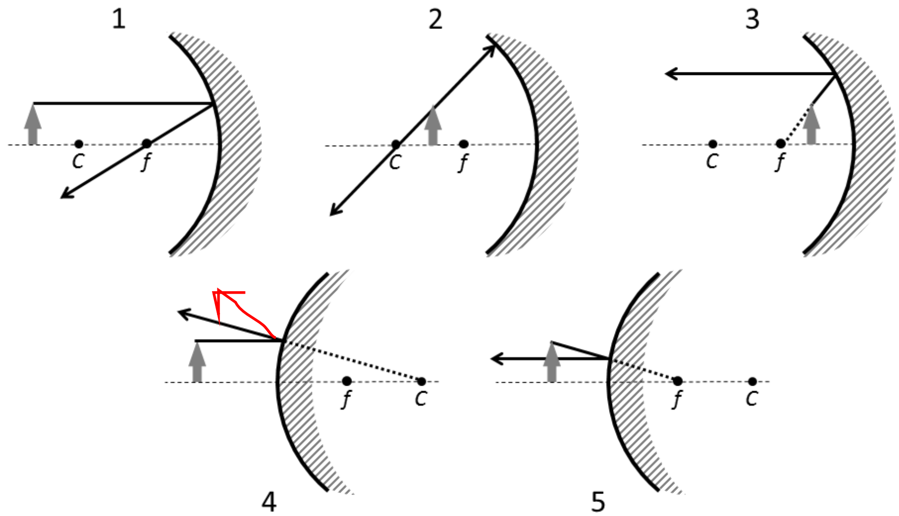
18) Now suppose $n_{cladding} = 1.53$. What must be the maximum incident angle θ of the beam at the air-core interface such that light cannot escape through the cladding of the optical fiber?

no total internal reflection is possible.

a. *There is no such angle*
b. $\theta_{max} = 30.5°$
c. $\theta_{max} = 13.4°$
d. $\theta_{max} = 39.4°$
e. $\theta_{max} = 43.4°$

19) Which of the ray tracing diagrams is INCORRECT?

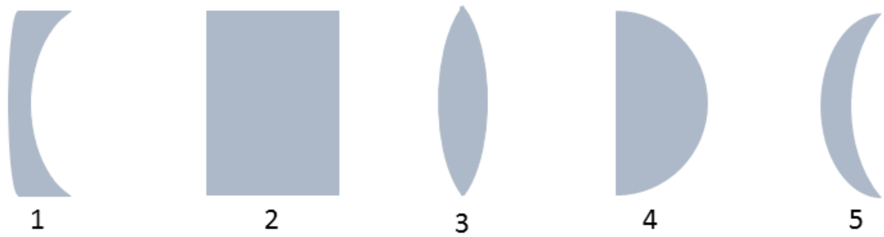
You can unambiguously draw only the following
1) going through c
2) going through f
3) retracing the above.



a. *Diagram 1*
b. *Diagram 5*
c. *Diagram 4*
d. *Diagram 3*
e. *Diagram 2*

The next two questions pertain to the situation described below.

The optical components shown are all made of the same material.



20) Which of the above is a diverging lens?

a. *Figure 2*
b. *Figure 4*
c. *Figure 3*
d. *Figure 1*
e. *Figure 5*

21) Which of the above has the largest magnitude of focal length $|f|$?

flat -> f = infinity

a. *Figure 1*
b. *Figure 3*
c. *Figure 2*
d. *Figure 4*
e. *Figure 5*

The next two questions pertain to the situation described below.

Jane is having trouble seeing through her glasses. Close objects are blurry. Her corrective lenses sit 2 cm from her eyes as shown in the figure.

22) Jane is

If the corrective lens is very poor, anything can happen, although here a may be expected.

BAD question

a. *far-sighted.*
b. *neither.*
c. *near-sighted.*

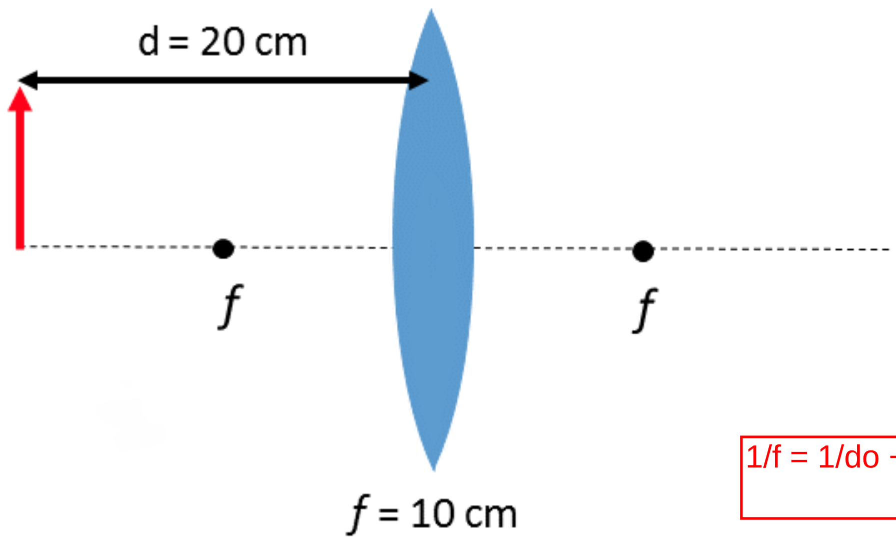
23) Jane's near-point is $d_{near} = 4.5\ m$. Remembering that a diopter is $P = 1/f$, where f is measured in meters, what should her corrective lens prescription be to see an object $d_o = 25\ cm$ from her eye clearly?

a. *0.22 diopters*
b. *4.1 diopters*
c. *4.6 diopters*
d. *-0.22 diopters*
e. *-4.1 diopters*

We wish to make the virtual image 448 cm from the lens for the object at 23 cm from the lens.

1/f = 1/23 -1/448 = 1/24.24 or D = 1/0.2424 = 4.1 D

The next two questions pertain to the situation described below.



1/f = 1/do + 1/di

An arrow is located a distance $d = 20\ cm$ to the left of a convex lens, which has a focal length of $f = 10\ cm$.

24) At what position relative to the lens (positive being to the right, negative to the left) will the image of the arrow be formed?

1/di = 1/f - 1/do = 1/10-1/20 = 1/20

a. $x = 20\ cm$
b. $x = -10\ cm$
c. $x = 10\ cm$
d. $x = 30\ cm$
e. $x = +\infty$

25) What is the magnification of the image?

m = -di/do

a. $m = 1$
b. $m = -1$
c. $m = 0.5$
d. $m = -0.5$
e. $m = 0$

m = -20/20 = -1

Kinematics and mechanics:

$x = x_0 + v_0 t + \frac{1}{2}at^2$ $v = v_0 + at$ $v^2 = v_0^2 + 2a\Delta x$

$F = ma$ $a_c = \frac{v^2}{r}$

$E_{tot} = K.E. + P.E.$ $K.E. = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ $p = mv$ $W_F = Fd\cos\theta$

Electrostatics:

$F_{12} = \frac{kq_1q_2}{r^2}$ $E \equiv \frac{F}{q_0}$ $U_{12} = \frac{kq_1q_2}{r}$ $V \equiv \frac{U}{q_0}$ $W_E = -\Delta U = -W_{you}$

Point charge: $E = \frac{kq}{r^2}$ $V = \frac{kq}{r}$

Electric dipole: $p \equiv qd$ $\tau_{dip} = pE\sin\theta$ $U_{dip} = -pE\cos\theta$

Resistance:

$R \equiv \frac{V}{I}$ $I = \frac{\Delta q}{\Delta t}$ Physical resistance: $R = \rho\frac{L}{A}$

$P = IV = I^2R = \frac{V^2}{R}$ $R_S = R_1 + R_2 + \cdots$ $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

Capacitance:

$C \equiv \frac{Q}{V}$ Parallel plate capacitor: $C = \frac{\kappa\varepsilon_0 A}{d}$, $E = \frac{Q}{\varepsilon_0 A}$, $V = Ed$

$U_C = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$ $C_P = C_1 + C_2 + \cdots$ $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$

Circuits:

$\sum \Delta V = 0$ $\sum I_{in} = \sum I_{out}$

$q(t) = q_\infty(1 - e^{-t/\tau})$ $q(t) = q_0 e^{-t/\tau}$ $I(t) = I_0 e^{-t/\tau}$ $\tau = RC$

Magnetism:

$F = qvB\sin\theta$ $r = \frac{mv}{qB}$ $F_{wire} = ILB\sin\theta$ $\tau_{loop} = NIAB\sin\varphi$

Magnetic dipole: $\mu \equiv NIA$ $\tau_{dip} = \mu B\sin\varphi$ $U_{dip} = -\mu B\cos\varphi$

$B_{wire} = \frac{\mu_0 I}{2\pi r}$ $B_{sol} = \mu_0 nI$

Electromagnetic induction:

$\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$ $\Phi = BA\cos\varphi$

$|\varepsilon_{bar}| = BLv$ $\varepsilon_{gen} = \varepsilon_{max}\sin\omega t = \omega NAB\sin\omega t$ $\omega = 2\pi f$

$V_{rms} = \dfrac{V_{max}}{\sqrt{2}}$ $I_{rms} = \dfrac{I_{max}}{\sqrt{2}}$ $\dfrac{V_p}{V_s} = \dfrac{I_s}{I_p} = \dfrac{N_p}{N_s}$

Electromagnetic waves:

$\lambda = \dfrac{c}{f}$ $E = cB$

$u_E = \dfrac{1}{2}\varepsilon_0 E^2$ $u_B = \dfrac{1}{2\mu_0}B^2$ $\bar{u} = \dfrac{1}{2}\varepsilon_0 E_{rms}^2 + \dfrac{1}{2\mu_0}B_{rms}^2 = \varepsilon_0 E_{rms}^2 = \dfrac{B_{rms}^2}{\mu_0}$ $S = I = \bar{u}c = \dfrac{P}{A}$

$f' = f\left(1 \pm \dfrac{u}{c}\right)$ $I = I_0\cos^2\theta$

Reflection and refraction:

$\theta_r = \theta_i$ $\dfrac{1}{d_o} + \dfrac{1}{d_i} = \dfrac{1}{f}$ $f = \pm\dfrac{R}{2}$ $m = \dfrac{h_i}{h_o} = -\dfrac{d_i}{d_o}$

$n_1\sin\theta_1 = n_2\sin\theta_2$ $v = \dfrac{c}{n}$ $\sin\theta_c = \dfrac{n_2}{n_1}$ $M = \dfrac{\theta'}{\theta} \approx \dfrac{d_{near}}{f}$

Compound microscope: $m_{obj} = -\dfrac{L_{tube}}{f_{obj}}$ $M_{eye} = \dfrac{d_{near}}{f_{eye}}$ $M_{tot} = M_{eye}m_{obj}$

Interference and diffraction:

Double slit interference: $d\sin\theta = m\lambda$ $d\sin\theta = (m+\tfrac{1}{2})\lambda$ $m = 0, \pm 1, \pm 2\ldots$

Single-slit diffraction: $a\sin\theta = m\lambda$ $m = \pm 1, \pm 2\ldots$

Circular aperture: $a\sin\theta \approx 1.22\lambda$

Quantum mechanics:

$E = hf = \dfrac{hc}{\lambda}$ $\lambda = \dfrac{h}{p}$ $\Delta p_x \Delta x \ge \dfrac{\hbar}{2}$ $\hbar \equiv \dfrac{h}{2\pi}$

Bohr atom: $2\pi r_n = n\lambda$ $n = 1, 2, 3\ldots$ $L_n = mv_n r_n = n\hbar$

$r_n = \left(\dfrac{\hbar^2}{mke^2}\right)\dfrac{n^2}{Z} \approx (5.29\times10^{-11}m)\dfrac{n^2}{Z}$ $E_n = -\left(\dfrac{mk^2e^4}{2\hbar^2}\right)\dfrac{Z^2}{n^2} \approx -(13.6\,eV)\dfrac{Z^2}{n^2}$

$\dfrac{1}{\lambda} \approx (1.097\times10^7 m^{-1})Z^2\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$

Quantum atom: $L = \sqrt{\ell(\ell+1)}\hbar$ $L_z = m_\ell \hbar$

Nuclear physics and radioactive decay:

$A = Z + N$ $r \approx (1.2\times10^{-15} m)A^{1/3}$ $E_0 = mc^2$

$\frac{\Delta N}{\Delta t} = -\lambda N$ $N(t) = N_0 e^{-\lambda t} = N_0 2^{-t/T_{1/2}}$ $T_{1/2} \equiv \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda}$

Constants and unit conversions:

$g = 9.8\, m/s^2$ $e = 1.60\times10^{-19}\, C$

$\varepsilon_0 = 8.85\times10^{-12}\, C^2/Nm^2$ $k \equiv \frac{1}{4\pi\varepsilon_0} = 8.99\times10^9\, Nm^2/C^2$ $\mu_0 = 4\pi\times10^{-7}\, T\cdot m/A$

$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 3\times10^8\, m/s$ $h = 6.626\times10^{-34}\, J\cdot s$ $hc = 1240\, nm\cdot eV$

$1eV = 1.60\times10^{-19}\, J$ $m_{proton} = 1.67\times10^{-27}\, kg = 938\, MeV$ $m_{electron} = 9.11\times10^{-31}\, kg = 511\, keV$

SI Prefixes

Power	**Prefix**	**Symbol**
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^0	—	—
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p