

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.

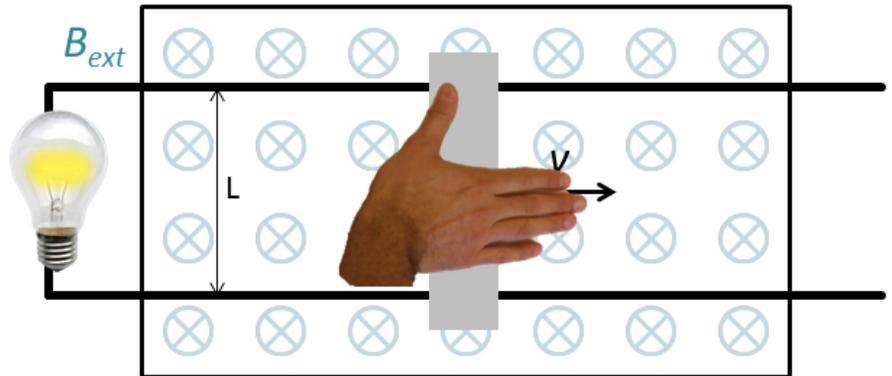
Some helpful information:

- 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, $B_{ext} = 4\text{ T}$, pointing into the page. The tracks are $L = 0.45\text{ m}$ 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?

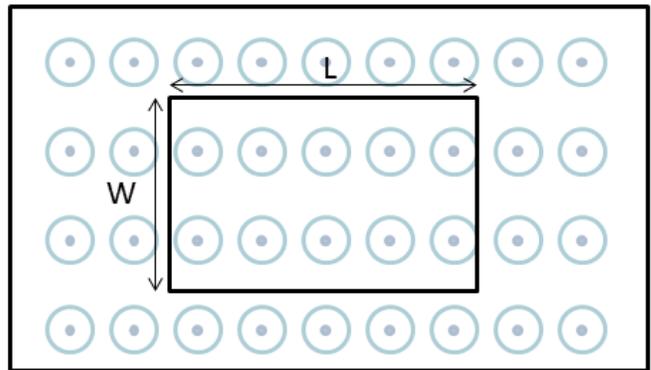
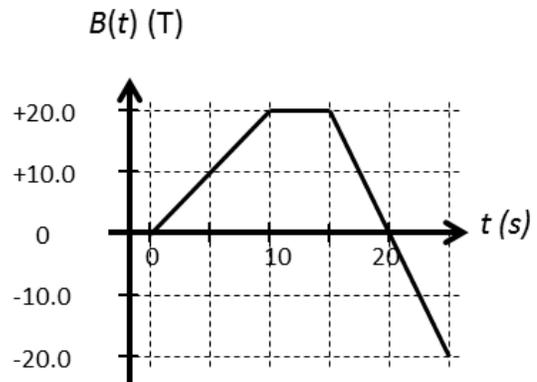
- a. $v = 13\text{ m/s}$
- b. $v = 64\text{ m/s}$
- c. $v = 200\text{ m/s}$

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

- a. *True*
- b. *False*

The next three questions pertain to the situation described below.

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



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

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

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

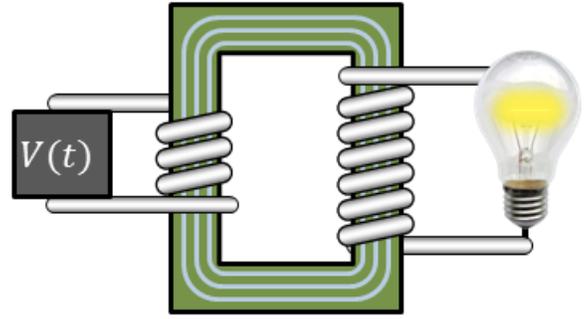
- a. *current does not flow*
- b. *clockwise*
- c. *counter-clockwise*

5) What is the magnitude of the EMF, $|\mathcal{E}|$, between $0 \text{ s} < t < 10 \text{ s}$?

- a. $|\mathcal{E}| = 0.72 \text{ V}$
- b. $|\mathcal{E}| = 0.32 \text{ V}$
- c. $|\mathcal{E}| = 0 \text{ V}$

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.

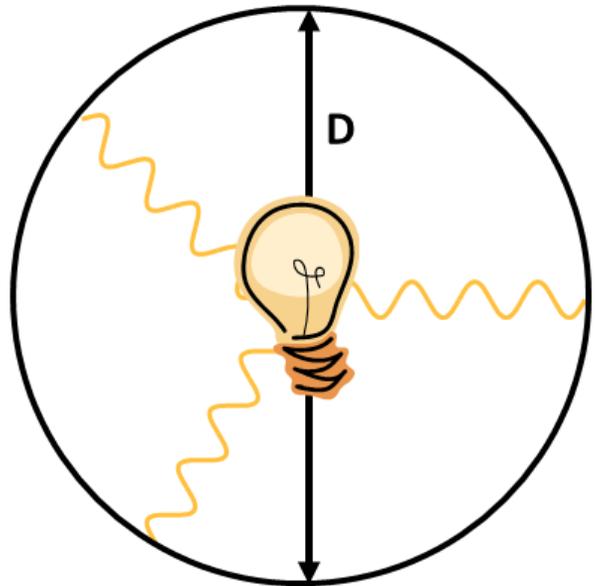


6) What is the maximum number of turns on the secondary coil for the output voltage not to exceed 115 V when the voltage on the primary coil is $V = 20\text{ V}$?

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

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 $D = 20\text{ m}$. What is the root mean square (rms) electric field strength at a point on the inner surface of the sphere?

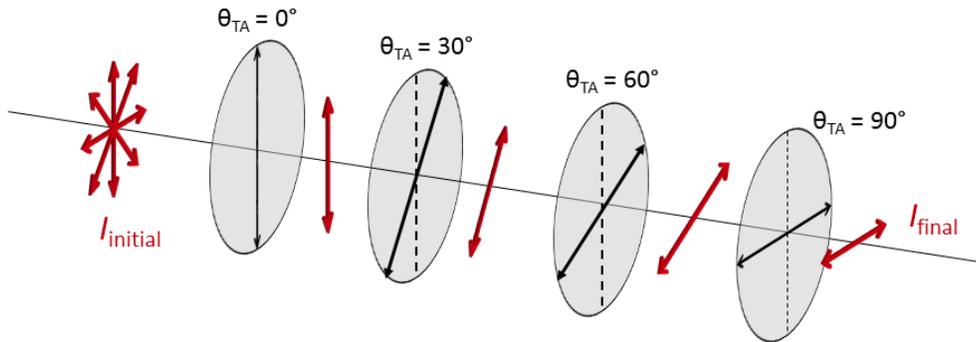
Remember: The surface area of a sphere is $4\pi r^2$



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

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?



- 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*

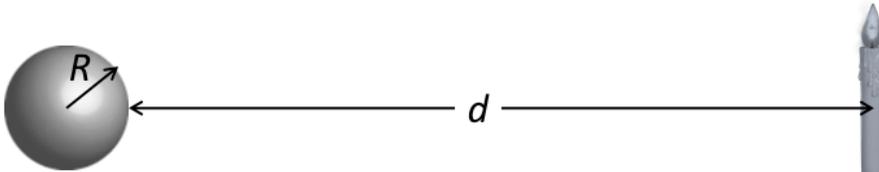
10) Laser light with a frequency $f_{air} = 400 \text{ THz}$ is sent from vacuum to a medium with index of refraction $n = 1.6$. What is the radiation's frequency in this material?

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

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

- a. $\lambda = 4.3 \text{ cm}$
- b. $\lambda = 12 \text{ cm}$
- c. $\lambda = 23 \text{ cm}$

The next two questions pertain to the situation described below.



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

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

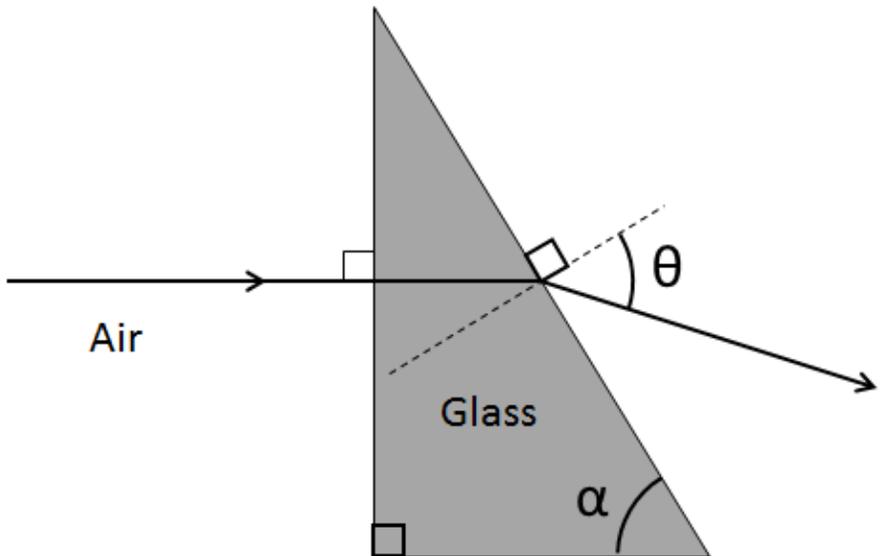
- a. *The image is virtual and inverted*
- b. *The image is virtual and upright*
- c. *The image is real and upright*

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

- a. $h_i = 0.85 \text{ cm}$
- b. $h_i = 1.3 \text{ cm}$
- c. $h_i = 0.69 \text{ cm}$

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 $\alpha = 70^\circ$, as shown. The glass has index of refraction $n_{red} = 1.5$ and $n_{blue} = 1.53$ for red and blue light, respectively.



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?

- a. $\theta = 20^\circ$
- b. $\theta = 46^\circ$
- c. $\theta = 70^\circ$
- d. $\theta = 31^\circ$
- e. $\theta = 59^\circ$

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

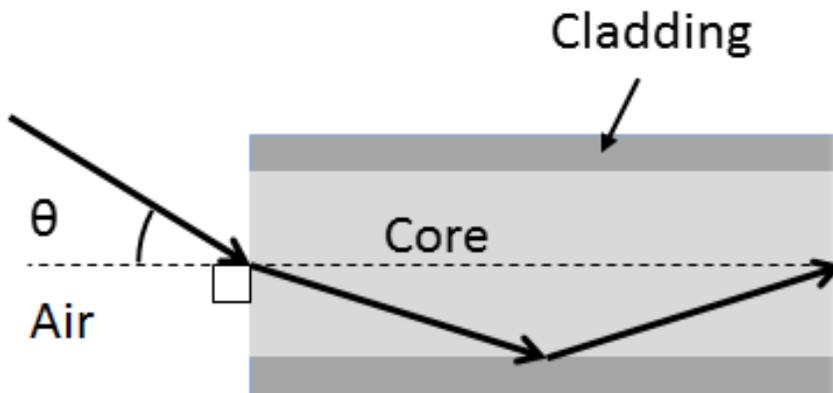
- a. θ increases
- b. θ decreases
- c. θ remains the same

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?

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



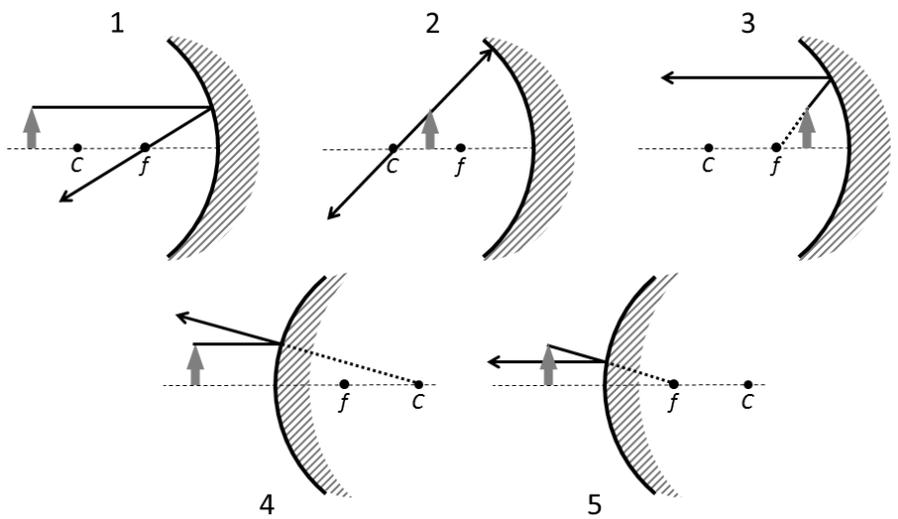
17) What must be the maximum incident angle θ of the beam at the air-core interface, as shown in the figure, such that light cannot escape through the cladding of the optical fiber?

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

18) Now suppose $n_{\text{cladding}} = 1.53$. 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?

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

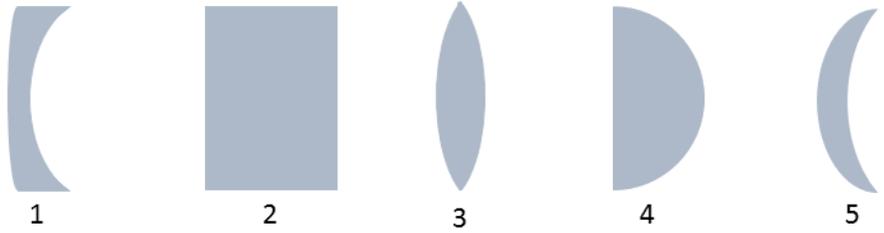
19) Which of the ray tracing diagrams is INCORRECT?



- 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 $|f|$?

- 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.

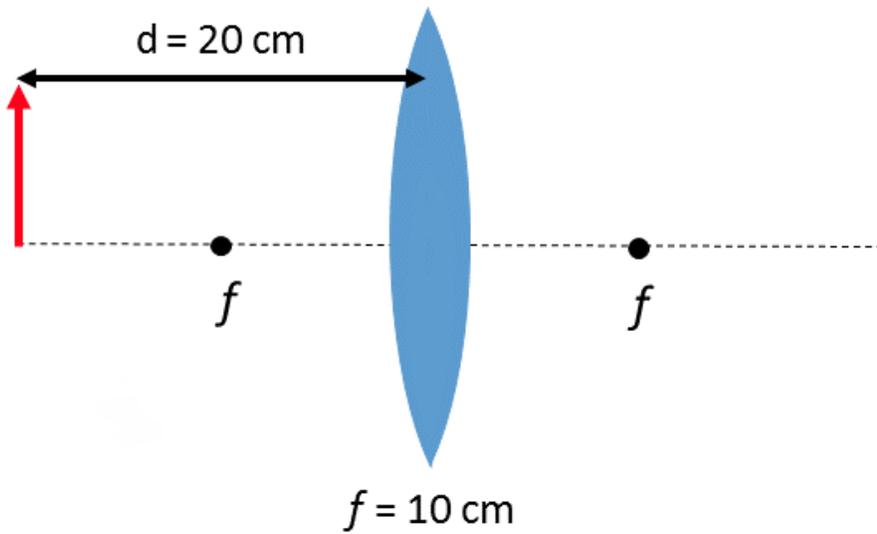
22) Jane is

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

23) Jane's near-point is $d_{near} = 4.5 \text{ m}$. 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 $d_o = 25 \text{ cm}$ from her eye clearly?

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

The next two questions pertain to the situation described below.



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

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?

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

25) What is the magnification of the image?

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

Kinematics and mechanics:

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

$$v = v_0 + at$$

$$v^2 = v_0^2 + 2a\Delta x$$

$$F = ma$$

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

$$E_{tot} = K.E. + P.E.$$

$$K.E. = \frac{1}{2} m v^2 = \frac{p^2}{2m}$$

$$p = mv$$

$$W_F = Fd \cos \theta$$

Electrostatics:

$$F_{12} = \frac{kq_1 q_2}{r^2}$$

$$E \equiv \frac{F}{q_0}$$

$$U_{12} = \frac{kq_1 q_2}{r}$$

$$V \equiv \frac{U}{q_0}$$

$$W_E = -\Delta U = -W_{you}$$

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: $R = \rho \frac{L}{A}$

$$P = IV = I^2 R = \frac{V^2}{R}$$

$$R_S = R_1 + R_2 + \dots$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

Capacitance:

$$C \equiv \frac{Q}{V}$$

Parallel plate capacitor: $C = \frac{\kappa \epsilon_0 A}{d}$, $E = \frac{Q}{\epsilon_0 A}$, $V = Ed$

$$U_C = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$$

$$C_P = C_1 + C_2 + \dots$$

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$$

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:

$$F = qvB \sin \theta$$

$$r = \frac{mv}{qB}$$

$$F_{wire} = ILB \sin \theta$$

$$\tau_{loop} = NIAB \sin \phi$$

Magnetic dipole:

$$\mu \equiv NIA$$

$$\tau_{dip} = \mu B \sin \phi$$

$$U_{dip} = -\mu B \cos \phi$$

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

$$B_{sol} = \mu_0 nI$$

Electromagnetic induction:

$$\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$$

$$|\varepsilon_{bar}| = BLv$$

$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

$$\Phi = BA \cos \varphi$$

$$\varepsilon_{gen} = \varepsilon_{max} \sin \omega t = \omega NAB \sin \omega t$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

$$\omega = 2\pi f$$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Electromagnetic waves:

$$\lambda = \frac{c}{f}$$

$$E = cB$$

$$u_E = \frac{1}{2} \varepsilon_0 E^2$$

$$u_B = \frac{1}{2\mu_0} B^2$$

$$\bar{u} = \frac{1}{2} \varepsilon_0 E_{rms}^2 + \frac{1}{2\mu_0} B_{rms}^2 = \varepsilon_0 E_{rms}^2 = \frac{B_{rms}^2}{\mu_0}$$

$$S = I = \bar{u}c = \frac{P}{A}$$

$$f' = f \left(1 \pm \frac{u}{c} \right)$$

$$I = I_0 \cos^2 \theta$$

Reflection and refraction:

$$\theta_r = \theta_i$$

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

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

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$v = \frac{c}{n}$$

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$M = \frac{\theta'}{\theta} \approx \frac{d_{near}}{f}$$

Compound microscope:

$$m_{obj} = -\frac{L_{tube}}{f_{obj}}$$

$$M_{eye} = \frac{d_{near}}{f_{eye}}$$

$$M_{tot} = M_{eye} m_{obj}$$

Interference and diffraction:

Double slit interference:

$$d \sin \theta = m\lambda$$

$$d \sin \theta = (m + \frac{1}{2})\lambda$$

$$m = 0, \pm 1, \pm 2 \dots$$

Single-slit diffraction:

$$a \sin \theta = m\lambda$$

$$m = \pm 1, \pm 2 \dots$$

Circular aperture:

$$a \sin \theta \approx 1.22\lambda$$

Quantum mechanics:

$$E = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{h}{p}$$

$$\Delta p_x \Delta x \geq \frac{\hbar}{2}$$

$$\hbar \equiv \frac{h}{2\pi}$$

$$\text{Bohr atom: } 2\pi r_n = n\lambda \quad n = 1, 2, 3 \dots$$

$$L_n = mv_n r_n = n\hbar$$

$$r_n = \left(\frac{\hbar^2}{mke^2} \right) \frac{n^2}{Z} \approx (5.29 \times 10^{-11} \text{ m}) \frac{n^2}{Z}$$

$$E_n = - \left(\frac{mk^2 e^4}{2\hbar^2} \right) \frac{Z^2}{n^2} \approx -(13.6 \text{ eV}) \frac{Z^2}{n^2}$$

$$\frac{1}{\lambda} \approx (1.097 \times 10^7 \text{ m}^{-1}) Z^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

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

$$L_z = m_\ell \hbar$$

Nuclear physics and radioactive decay:

$$A = Z + N$$

$$r \approx (1.2 \times 10^{-15} \text{ m}) A^{1/3}$$

$$E_0 = mc^2$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$N(t) = N_0 e^{-\lambda t} = N_0 2^{-t/T_{1/2}}$$

$$T_{1/2} \equiv \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda}$$

Constants and unit conversions:

$$g = 9.8 \text{ m/s}^2$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 / \text{Nm}^2$$

$$k \equiv \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ Nm}^2 / \text{C}^2$$

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

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8 \text{ m/s}$$

$$h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$$

$$hc = 1240 \text{ nm} \cdot \text{eV}$$

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$$

$$m_{\text{proton}} = 1.67 \times 10^{-27} \text{ kg} = 938 \text{ MeV}$$

$$m_{\text{electron}} = 9.11 \times 10^{-31} \text{ kg} = 511 \text{ keV}$$

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