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 **128** 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}.

1) A concave mirror has a radius of
   curvature with absolute value
$|R| = 24\ cm$. If you put an object at a
distance of $s = 29\ cm$ away from the
mirror, what is the image distance s'?

object distance s
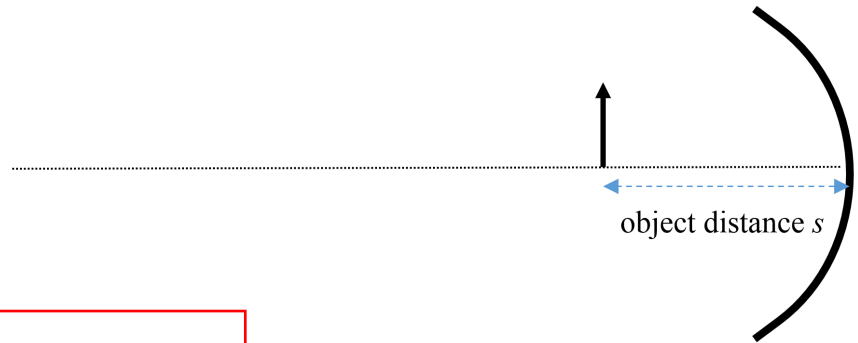
| $|R| = 2|f|$ |
| $1/f = 1/do + 1/di$ |

a. $s' = 8.5\ cm$
b. $s' = 20\ cm$
c. $s' = 140\ cm$

```
Concave mirror -> convergin -> f = 12
cm
Object is real -> do = s = 29 cm
1/s' = 1/f - 1/s
     = 1/12 - 1/29 = 1/20.47
```

2) Select the **incorrect** statement.

   a. When light passes from vacuum into glass, its frequency stays the same.
   b. The vectors that represent the electric and magnetic fields of an electromagnetic wave in a vacuum
      are perpendicular to one another and to the direction in which the wave is propagating.
   c. Light, radio waves, and X-rays are all electromagnetic waves.
   d. When electromagnetic waves are absorbed by a large object, energy is transferred to the object.
   e. Light has a greater speed in matter than in a vacuum.

```
       Nothing can be faster than light in vacuum.
```

3) Which of the following rays for light from an object onto a converging lens is drawn **incorrectly**?

Object

1

f

2

3

4

f
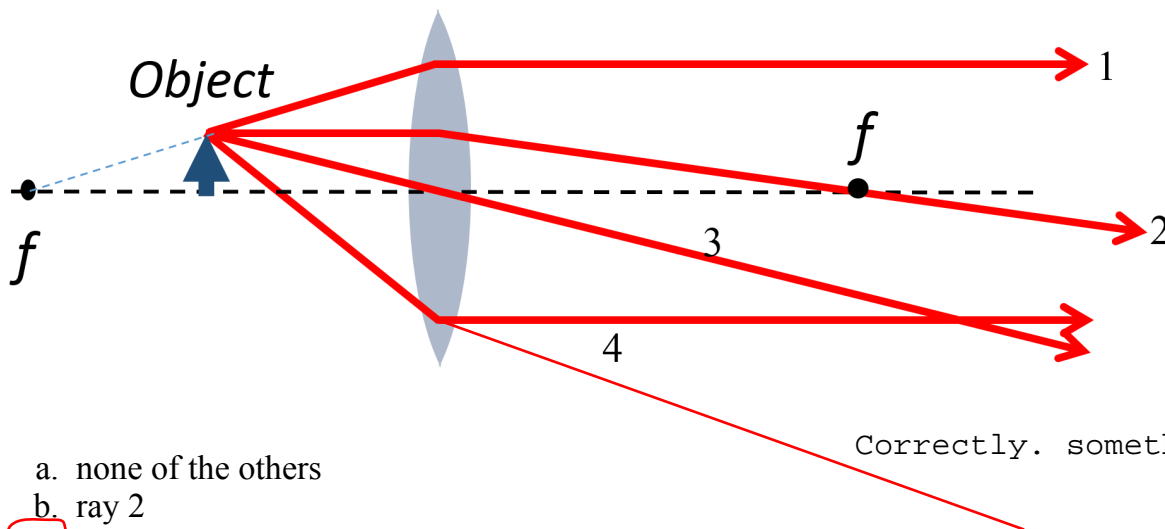
```
Correctly. something like this
```

   a. none of the others
   b. ray 2
   c. ray 4
   d. ray 3
   e. ray 1

4) A beam consisting of red and blue light is incident from air onto a flat rectangular slab of glass, for which the index of refraction n depends on frequency in the usual way (n is smaller for larger wavelengths). When the light emerges at the bottom of the slab, we can say that...
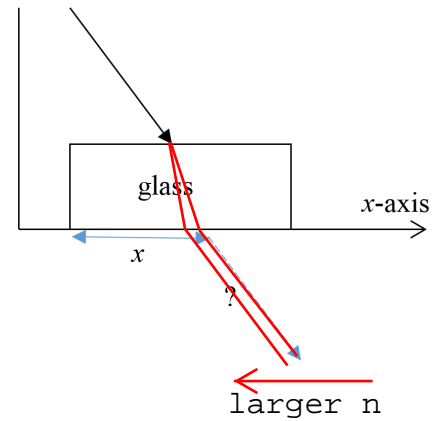
`larger n bends rays more.`

glass

x-axis

x

`larger n`

a. the blue light emerges at a larger value of x along the x-axis than does the red. `blue`   `red`
b. the red and the blue light emerge at the same point.
c. the red light will not emerge because of total internal reflection.
d. the blue light will not emerge because of total internal reflection.
e. the red light emerges at a larger value of x along the x-axis than does the blue.

5) A candle is placed at a distance $d_o = 7\ cm$ in front of a certain lens (marked by the textured rectangle in the figure) with focal length f. It is unknown whether the lens is converging or diverging. An experiment shows that the lens produces a well-focused image of the flame on a screen a distance $d_i = 3$ cm away.

$1/f = 1/do + 1/di$

p.a.

f

d_i

d_o

f

Screen

?
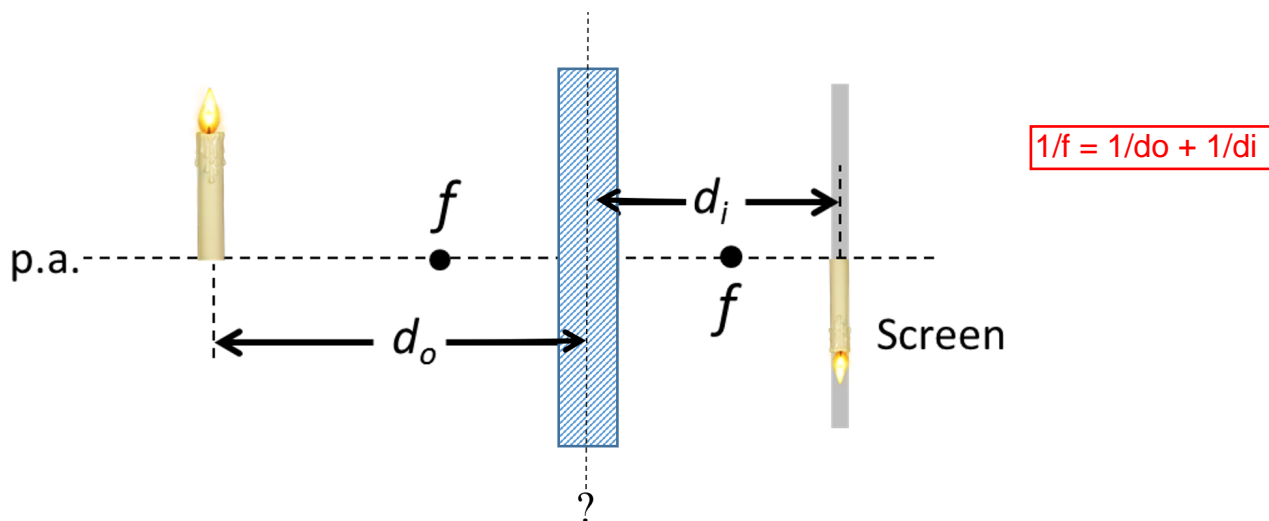
What is the focal length of the lens?

`An image you can see on a screen is real.`

a. $f = -5.2\ cm$
b. $f = -2.1\ cm$
c. $f = 5.2\ cm$
d. $f = 2.1\ cm$
e. $f = 10\ cm$

`do = 7, di = 3`
`1/f = 1/7 + 1/3 = 1/2.1`

The next three questions pertain to the situation described below.

A candle of height $h_o = 3\ cm$ is placed a distance $d_o = 6\ cm$ in front of a diverging lens, creating a virtual image $1\ cm$ away from the lens.

p.a. - - - - - - - - - - - - - - - - - - ● - - - - - - - - - - ● - - - -

f f

$1/f = 1/do + 1/di$
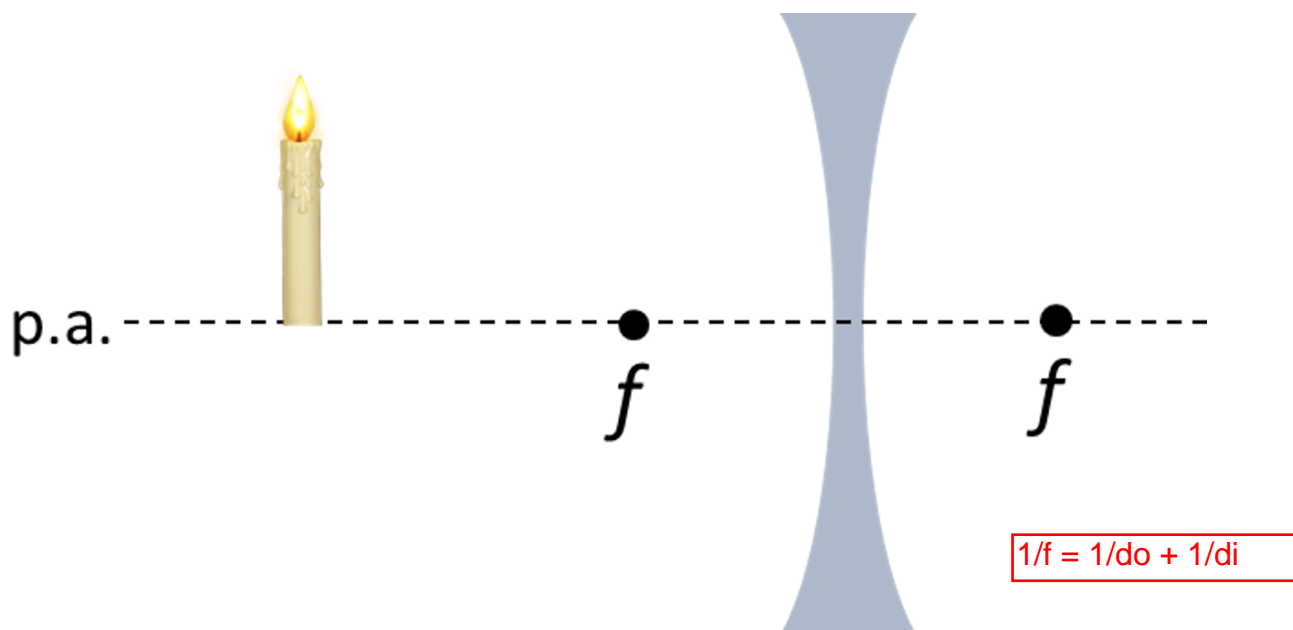
6) What is the absolute value of the height h_i of the image?

real object -> do = 6
virtual image -> di = -1

   a. $|h_i| = 0.056\ cm$
   b. $|h_i| = 0.5\ cm$ $m = -di/do$ m = 1/6 -> hi = 3/6 = 0.5
   c. $|h_i| = 18\ cm$

7) Is the image upright or inverted?

m > 0 -> upright

   a. inverted
   b. upright

8) What is the focal length of the lens f?

   a. $f = 7\ cm$ 1/f = 1/6 - 1/1 = -1/1.2
   b. $f = 0.86\ cm$
   c. $f = -1.2\ cm$
   d. $f = -0.86\ cm$
   e. $f = 1.2\ cm$

The next two questions pertain to the situation described below.

A resistor $R = 3.9\ \Omega$ is attached to a frictionless conducting track. The right end of the track is inside a uniform magnetic field $B_{ext} = 0.3\ T$ that points out of the page; the field is zero everywhere else. A sliding metal bar of length $L = 5.5\ cm$ moves to the right along the track at a speed $v = 0.4\ m/s$. The bar initially starts outside the B field.

B_{ext}
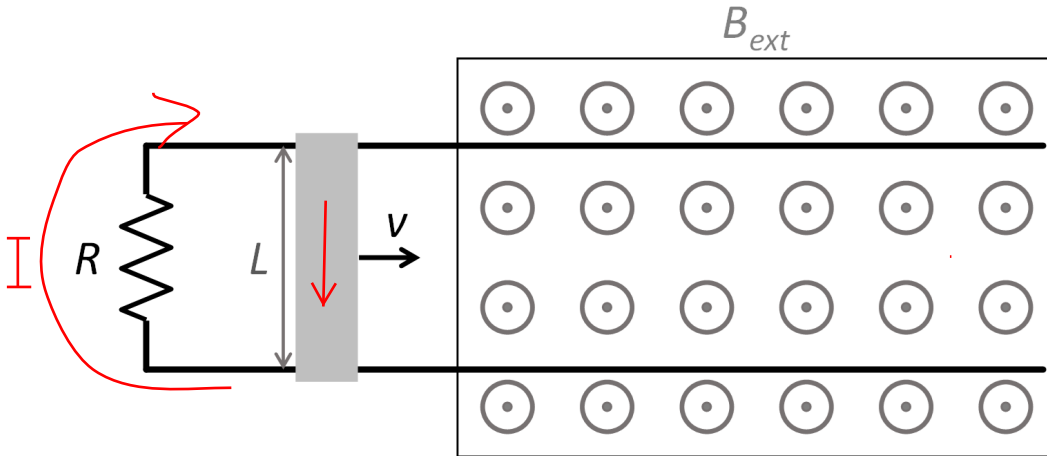
9) Which diagram below best represents the current I through the resistor R vs. time? Use the sign convention that $I > 0$ when flowing _up_ through R, $I < 0$ _down_ through R.

(1) (2) (3) (4) (5)
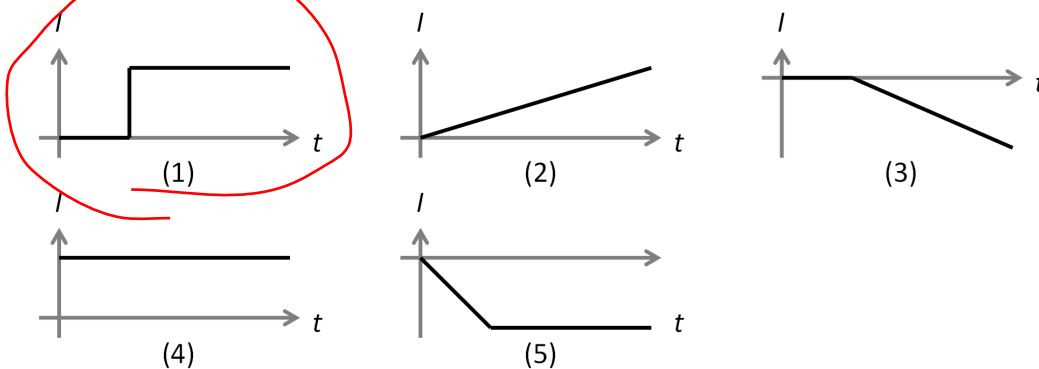
a. 4
b. 2
c. 1
d. 3
e. 5

10) What is the magnitude of the current $|I|$ at its highest value?

motional emf = vBL
I = emf/R

a. $|I| = 0.85\ mA$
b. $|I| = 0.056\ mA$
c. $|I| = 11\ mA$
d. $|I| = 5.3\ mA$
e. $|I| = 1.7\ mA$

I = vBL/R = 0.4 x 0.3 x 0.055/3.9 = 0.001692 A

The next two questions pertain to the situation described below.

A generator is made from a loop of $N = 20$ turns of wire wound into a rectangle of sides $w = 2.2$ cm and $L = 4$ cm. The loop rotates inside a uniform magnetic field $B = 0.4$ T pointing up and completes each full rotation cycle in $T = 2$ s.

B

Phi = AB, A = wL sin (omega t)
|emf| = N d Phi/d t = N omega wLB cos(omega t)
omega = 2 pi/T
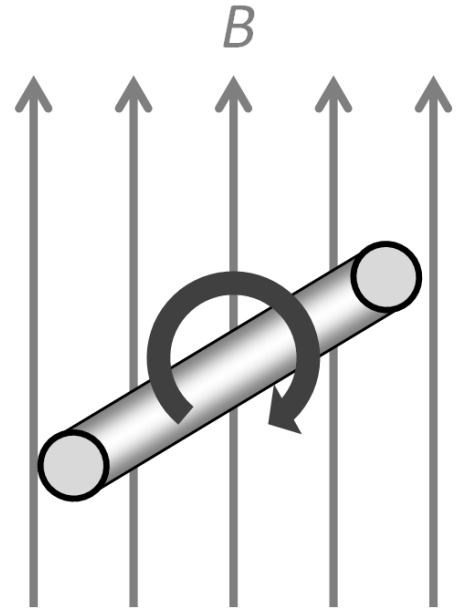
11) What is the maximum emf ε_{max} generated in the loop?

1 for max

a. $\varepsilon_{max} = 22$ mV
b. $\varepsilon_{max} = 14$ mV
c. $\varepsilon_{max} = 3.5$ mV
d. $\varepsilon_{max} = 0.091$ mV
e. $\varepsilon_{max} = 140$ mV

|emf| = N (2 pi/T) wLB cos(omega t)
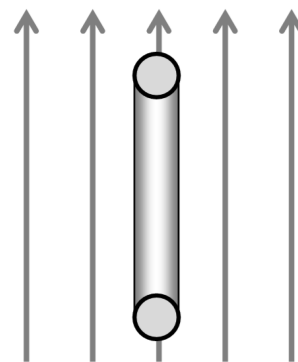   = 20 x pi x 0.022 x 0.04 x 0.4
     = 0.0221 A

12) The diagrams below show the loop at different time points. For which of the following diagrams is the magnitude of the current in the loop maximum?
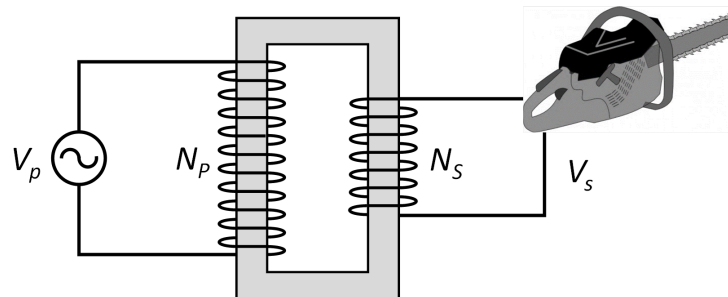
(1)   (2)   (3)
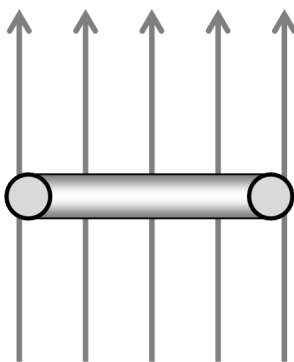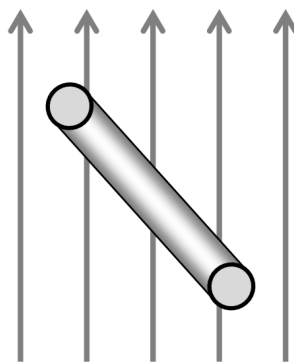
most cutting of B vectors by the loop wire -> max emf

a. 1
b. 3
c. 2

13) A gasoline-powered AC generator produces a maximum power of $P = 5\ kW$. The peak voltage of its output is $V = 120\ V$. You need to use this generator to drive a power tool that cannot take current larger than $I_{max} = 6\ A$, so you build a transformer with $N_p = 300$ and N_s turns for the primary and secondary coils, respectively. What must be the minimum number of turns in the secondary coil N_s such that the maximum current I_{max} is not exceeded?

V/N = constant
P = VI = constant
IN = constant

a. $N_s = 2100$
b. $N_s = 3400$
c. $N_s = 2900$
d. $N_s = 4800$
e. $N_s = 1600$

Since IN is constant, to make I smaller, we must make N larger. An upper bound of I implies a lower bound of N.
From P Ip = 5000/120 = 41.667 (max primary current).
41.67x300 = 6xNs -> Ns = 12500/6 = 2083.

The next two questions pertain to the situation described below.

A rectangular loop is placed next to a long straight wire as shown. The loop and wire lie in the same plane. A current is flowing through the wire to the right and *increasing*.

increasing
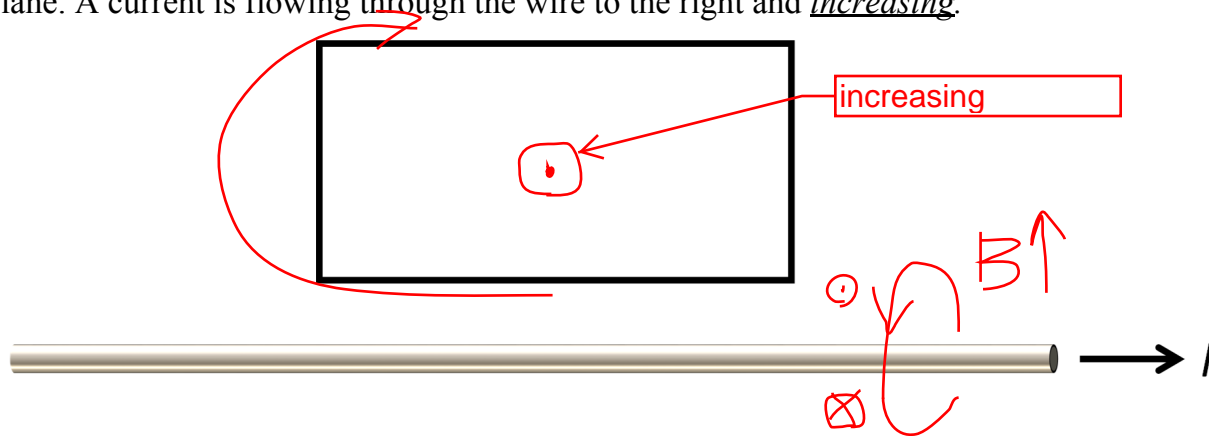
14) In which direction does the induced current through the loop flow?

a. no current flows
b. clockwise
c. counterclockwise

Lenz tells us that the loop current wishes to reduce the change of the B-flux through the loop.

15) If the loop is now allowed to move in the plane, in which direction does it go?

a. The loop moves toward the wire.
b. The loop moves parallel to the wire.
c. The loop moves away from the wire.

Lenz, again. To reduce the flux through the loop, it wishes to run away from the wire.

The next two questions pertain to the situation described below.

A square loop of side *L = 6.9 cm* is placed around a long
solenoid of radius *r = 1.3 cm* that generates a magnetic
field *B = 1.5 mT* pointing to the left.

loop

B_{sol}

solenoid

I_{ind}
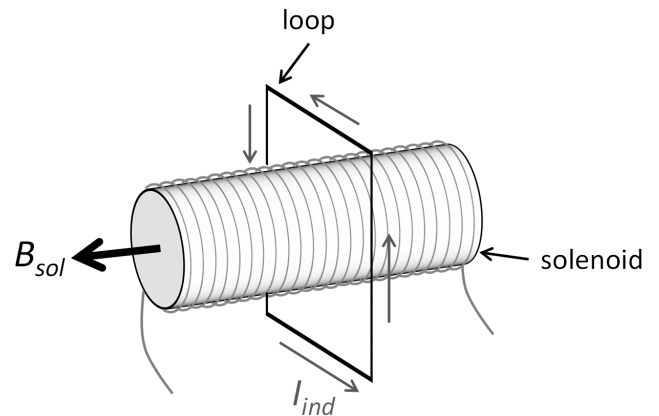
16) What is the magnetic flux Φ_{loop} through the loop?

Note that B exists only inside the solenoid.
Phi = AB = pi r^2 B

a. $\Phi_{loop} = 1.2 \times 10^{-4} \ T \cdot m^2$

b. $\Phi_{loop} = 2.5 \times 10^{-7} \ T \cdot m^2$

c. $\Phi_{loop} = 2.2 \times 10^{-5} \ T \cdot m^2$

d. $\Phi_{loop} = 8 \times 10^{-7} \ T \cdot m^2$

e. $\Phi_{loop} = 6.1 \times 10^{-5} \ T \cdot m^2$

```
Phi = pi(0.013)^2 x 1.5x10^{-3}
    = 0.000796 x 10^{-3} Wb
    = 7.96 x 10^{-7} Wb
```

17) At the instant shown, you find that an induced current is flowing around the square loop in the
    counterclockwise direction. Which of the following statements must be true?

a. The current in the solenoid is decreasing. Lenz

b. The flux through the loop is constant.

c. The magnitude of the magnetic field from the solenoid is increasing.

```
Loop makes the B field in
the Bsolenoid
direction. Hence,
the solenoid B must be
decreasing.
```

18) A person is standing a distance *D = 5.8 m* in
    front of a flat, vertical mirror. The distance from
the ground to his eyes is *H = 1.6 m*. An object is
placed on the ground a distance *d = D/2 = 2.9 m* in
front of the mirror. At what height *h* should the
bottom of the mirror be so that the person can see
the bottom of the object?

Mirror

Object

H

h

d = D/2

D
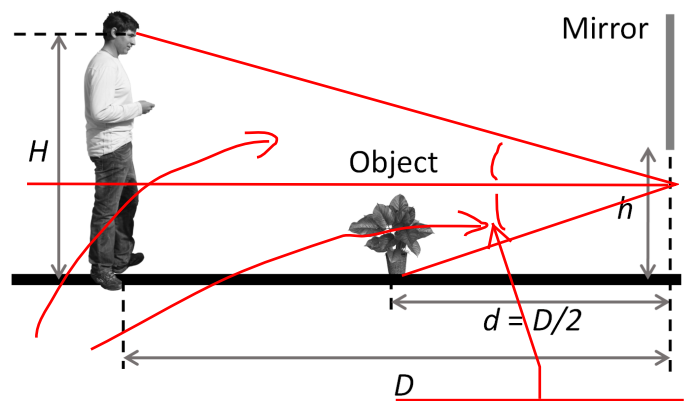
The same angles

a. *h = 3.62 m*

b. *h = 0.533 m*

c. *h = 0.267 m*

```
H - h : D = h : D/2
-> Dh = (D/2)(H - h) or 3Dh = DH -> h = H/3.

h = 1.6/3 = 0.533 m.
```

The next five questions pertain to the situation described below.

A plane electromagnetic wave is propagating in the +*x* direction in vacuum, whose electric field **E** is parallel to the *y*-axis. The sine wave in the following figure describes the electric field along the *x*-axis at a certain instant.
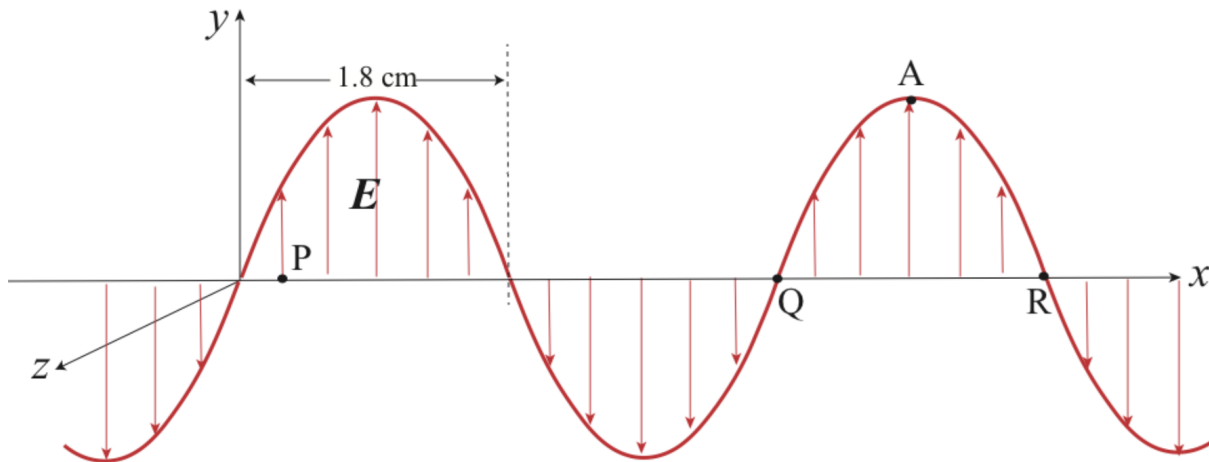
19) At point P at this instant the electric field is in the positive *y* direction. What is the direction of the magnetic field vector at the same point and time? Pay due attention to the positive *z* direction in the figure.

   a. -*y* direction
   b. -*z* direction
   c. +*z* direction
   d. +*x* direction
   e. -*x* direction

E to B right-handed screw rule.

20) What is the frequency of this electromagnetic wave?

   a. *8.33 MHz*
   b. *4.17 MHz*
   c. *4.17 GHz*
   d. *6.42 MHz*
   e. *8.33 GHz*

f = c/lambda

lambda = 0.018 x 2 m.
f = 3x10^8/0.036 = 83.33 x 10^8 Hz

21) What is the polarization of this electromagnetic wave?

Polarization direction = E vector direction

   a. unpolarized
   b. linearly polarized in the y-direction
   c. linearly polarized in the z-direction

22) **This question and the next one follow from the previous set.**
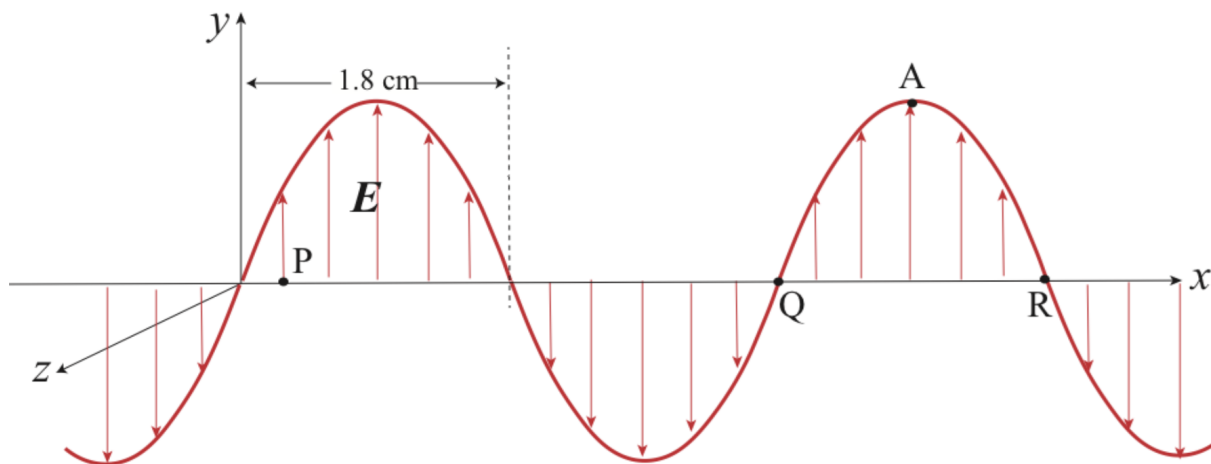
This wave goes through a thick slab of a material with index of refraction $n = 1.7$. What is the distance between the adjacent nodes (where the electric field vanishes, corresponding to the distance between Q and R in the figure)?

a. $d = 1.06\ cm$

b. $d = 1.8\ cm$

c. $d = 2.12\ cm$

d. $d = 3.06\ cm$

e. $d = 1.53\ cm$

v = c/n, f does not change.

d is one half of the wavelength. lambda -> lambda/n
so d = 1.8/n = 1.8/1.7 = 1.0588 cm

23) A perfect absorber of the electromagnetic wave of area $A = 15\ m^2$ is placed parallel to the yz-plane. What is the energy this absorber receives from the source of the electromagnetic wave in 1 minute? The peak value of the electric field is $E = 1.2\ V/m$.

a. $Energy = 0.00764\ J$

b. $Energy = 3.44\ J$

c. $Energy = 1.72\ J$

d. $Energy = 0.0287\ J$

e. $Energy = 0.115\ J$

P = IA. This times time is the energy.
I = c u
u = epsilon_0 Emax^2/2

E = 60 x 3x10^8 x (8.85x10^{-12} x 1.2^2/2)
        x 15
  = 17203.8 x 10{-4} J

24) A 100 W light bulb emits a total of 100 W of electromagnetic waves of various frequencies isotropically (i.e., evenly in all directions in space). What is the total average magnetic energy density u_B at a point $d = 14\ m$ away from the bulb?

a. $u_B = 1.9 \times 10^{-9}\ J/m^3$

b. $u_B = 1.5 \times 10^{-11}\ J/m^3$

c. $u_B = 6.8 \times 10^{-11}\ J/m^3$

d. $u_B = 1.4 \times 10^{-10}\ J/m^3$

e. $u_B = 9.5 \times 10^{-10}\ J/m^3$

P/4 pi d^2 = cu
u_B = u/2

u_B = 100/2[(4 pi 14^2) 3x10^8]
    = 0.00677 x 10^{-8} J/m^3

The next two questions pertain to the situation described below.

Initially, there are two polarizers as exhibited in the following figure. Unpolarized light of intensity I_0 is incident from left. The transmission axis of the second polarizer makes an angle of 30° with the first transmission axis, as shown in the figure.
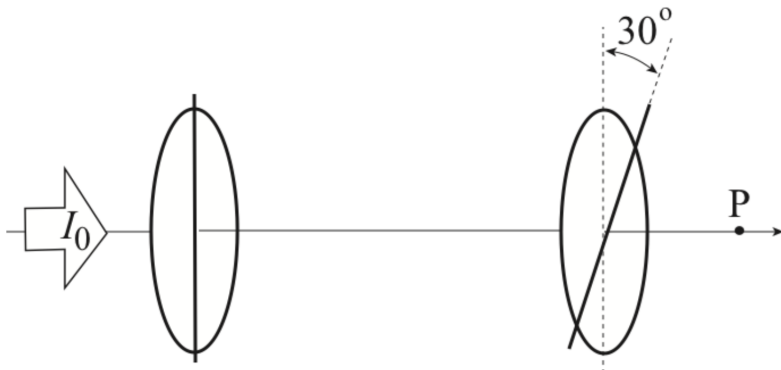
Malus's law
I = I0 cos^2 theta

25) What is the intensity I_P of the light at P?

a. $I_P = I_0$
b. None of the other solutions.
c. $I_P = I_0 / 2$
d. $I_P = 3 I_0 / 4$
e. $I_P = 3 I_0 / 8$

```
IP  =  (I0/2) cos^2(30)
    =  (I0/2) (¥sqrt{3}/2)^2 = 3I_0/8.
```

26) Now, a third polarizer is placed between the two existing polarizers so that its transmission axis makes an angle of 15° with that of the first polarizer as illustrated below.
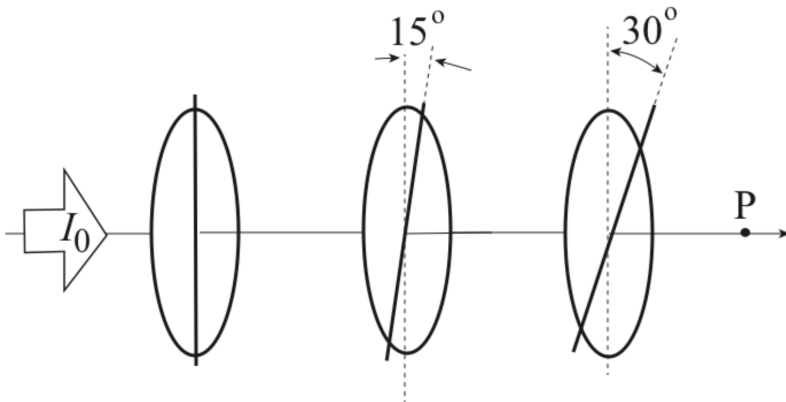
What is the intensity I_P of the light at P now?

a. $I_P = 0.351 I_0$
b. $I_P = 0.435 I_0$
c. $I_P = 0.282 I_0$
d. $I_P = 0.725 I_0$
e. $I_P = 0.871 I_0$

```
IP  =  (I0/2) (cos 15)^4
    =  0.435 I
```

Physic 102 formula sheet (SP2015)

Kinematics and mechanics

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

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

$$E_{\text{tot}} = K + U \qquad K = \frac{1}{2}mv^2 = \frac{p^2}{2m} \qquad p = mv \qquad W_F = Fd\cos\theta$$

Electrostatics

$$F_{12} = k\frac{q_1 q_2}{r^2} \qquad E = \frac{F}{q_0} \qquad U_{12} = k\frac{q_1 q_2}{r} \qquad V \equiv \frac{U}{q_0} \qquad W_E = -\Delta U = -W_{\text{you}}$$

Point charge $\qquad E = k\dfrac{q}{r^2} \qquad V = k\dfrac{q}{r}$

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

Resistance

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

$$P = IV = I^2 R = \frac{V^2}{R} \qquad R_{\text{S}} = R_1 + R_2 + \cdots \qquad \frac{1}{R_{\text{P}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

Capacitance

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

$$U_C = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C} \qquad C_{\text{P}} = C_1 + C_2 + \cdots \qquad \frac{1}{C_{\text{S}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$$

Circuits

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

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

Magnetism

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

Magentic dipole: $\qquad \mu = NIA \qquad \tau_{\text{dip}} = \mu B\sin\varphi \qquad U_{\text{dip}} = -\mu B\cos\varphi$

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

Electromagnetic induction

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} \qquad \Phi = BA\cos\varphi$$

$$|\mathcal{E}_{\text{bar}}| = BLv \qquad \mathcal{E}_{\text{gen}} = \mathcal{E}_{\text{max}}\sin\omega t = \omega NAB\sin\omega t \qquad \omega = 2\pi f$$

$$V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}} \qquad I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}} \qquad \frac{V_{\text{p}}}{V_{\text{s}}} = \frac{I_{\text{s}}}{I_{\text{p}}} = \frac{N_{\text{p}}}{N_{\text{s}}}$$

Electromagnetic waves

$$\lambda = \frac{c}{f} \qquad E = cB$$

$$u_E = \frac{1}{2}\epsilon_0 E^2 \qquad u_B = \frac{1}{2\mu_0}B^2 \qquad \bar{u} = \frac{1}{2}\epsilon_0 E_{\text{rms}}^2 + \frac{1}{2\mu_0}B_{\text{rms}}^2 = \epsilon_0 E_{\text{rms}}^2 = \frac{B_{\text{rms}}^2}{\mu_0} \qquad S = I = \bar{u}c = \frac{P}{A}$$

$$f_0 = f_e\sqrt{\frac{1 + v_{\text{rel}}/c}{1 - v_{\text{rel}}/c}} \approx f_e\left(1 + \frac{v_{\text{rel}}}{c}\right) \qquad I = I_0\cos^2\theta$$

Reflection and refraction

$$\theta_r = \theta_i$$

$$\frac{1}{d_o} + \frac{1}{d_1} = \frac{1}{f}$$

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

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

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

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

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

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

Compound microscope:

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

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

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

Interference and diffraction

Double-slit interference:

$$d\sin\theta = m\lambda \qquad d\sin\theta = \left(m + \frac{1}{2}\right)\lambda \qquad m = 0, \pm 1, \pm 2, \cdots$$

Single-slit diffraction: $\quad a\sin\theta = m\lambda \qquad m = 0, \pm 1, \pm 2, \cdots$

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

Quantum mechanics

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

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

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

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

Bohr atom: $\qquad 2\pi r_n = n\lambda \qquad n = 1, 2, 3, \cdots \qquad L_n = m_e v_n r_n = n\hbar$

$$r_n = \left(\frac{\hbar^2}{m_e k e^2}\right)\frac{n^2}{Z} \approx (5.29 \times 10^{-11} \text{ m})\frac{n^2}{Z} \qquad E_n = -\left(\frac{m_e k^2 e^4}{2\hbar^2}\right)\frac{Z^2}{n^2} \approx -(13.6 \text{ eV})\frac{Z^2}{n^2}$$

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

Quantum atom: $\qquad L = \sqrt{\ell(\ell+1)}\hbar \qquad L_Z = m_{\epsilon,}\hbar \qquad S_z = ms\hbar$

Atomic magnetism: $\qquad \mu_{e,z} = -\frac{e}{2m_e}L_z \qquad \mu_{s,z} = -\frac{ge}{2m_e}S_z, g \approx 2 \qquad \mu_B \equiv \frac{e\hbar}{2m_e} \approx 5.8 \times 10^{-5} \text{ eV/T}$

Nuclear physics and radioactive decay

$$A = Z + N \qquad\qquad r \approx (1.2 \times 10^{-15} \text{ m})A^{1/3} \qquad\qquad E_0 = mc^2$$

$$m_{\text{nucleus}} = Z m_{\text{proton}} + N m_{\text{neutron}} - \frac{|E_{\text{bind}}|}{c^2}$$

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

Constants and unit conversion

$$g = 9.8 \text{ m/s}^2 \qquad\qquad e = 1.60 \times 10^{-19} \text{ C}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2 \qquad k \equiv \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2 \qquad \mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$$

$$c = \frac{1}{\sqrt{\epsilon_0\mu_0}} = 3 \times 10^8 \text{ m/s} \qquad h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \qquad hc = 1240 \text{ eV}\cdot\text{nm}$$

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J} \qquad\qquad m_{\text{electron}} = 9.11 \times 10^{-31} \text{ kg} = 511 \text{ keV}/c^2$$

$$m_{\text{proton}} = 1.673 \times 10^{-27} \text{ kg} = 938 \text{ MeV}/c^2 \qquad m_{\text{neutron}} = 1.675 \times 10^{-27} \text{ kg} = 939.5 \text{ MeV}/c^2$$

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