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 14 **numbered pages** plus three (3) Formula Sheets.*

*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 **125** 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.
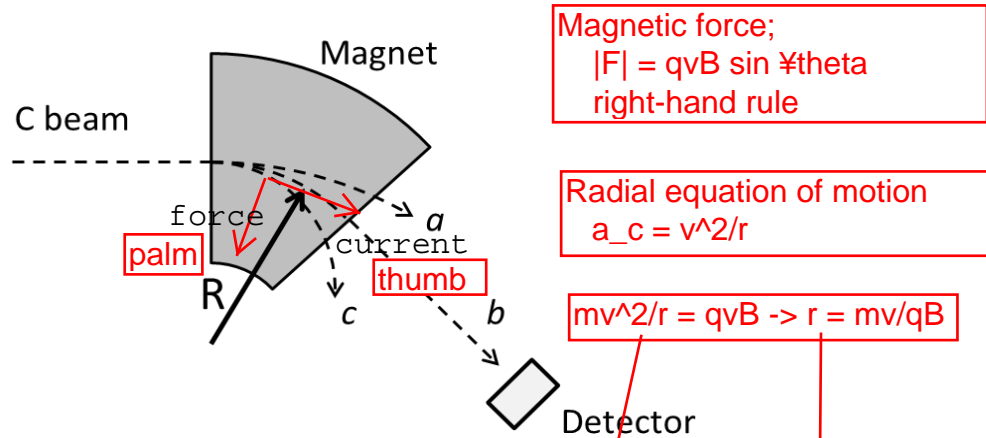(b) If you mark the wrong answer or neither answer, you earn **0** points.

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 three questions pertain to the following situation:***

A mass spectrometer is used to separate different isotopes of carbon.  A beam of carbon ions is accelerated to a speed $v = 10^5$ m/s into a magnet that generates a field $B = 0.2$ T. The carbon ions all have the same positive charge $q = +1e = 1.6 \times 10^{-19}$ C.

As shown in the figure below, the beam separates into three ($a$, $b$, $c$) inside the magnetic field.  Only particles of type $b$ travel around a radius of curvature $R = 6.7$ cm and into a detector.



Magnetic force;
|F| = qvB sin ¥theta
right-hand rule

Radial equation of motion
a_c = v^2/r

mv^2/r = qvB -> r = mv/qB

1.  In which direction does the magnetic field $B$ point inside the magnet?

a.  Out of the page
b.  Into the page
c.  Along the dotted path of particle $b$
d.  To the right
e.  To the left

Your fingers must be out of this page.

2.  What is the mass of the particles of type $b$?

a.  $m_b = 1.3 \times 10^{-28}$ kg
b.  $m_b = 3.7 \times 10^{-27}$ kg
c.  $m_b = 5.1 \times 10^{-27}$ kg
d.  $m_b = 9.8 \times 10^{-27}$ kg
e.  $m_b = 2.1 \times 10^{-26}$ kg

R = 0.067 m

m = rqB/v
  = 0.067 x (1.6 x 10^{-19}) x 0.2/10^5
  = 0.0211 x 10^{-19 - 5} kg

assuming m/q is identical.

3.  The speed of particle $b$ after leaving the magnet is higher than that of particle $c$.

a.  True
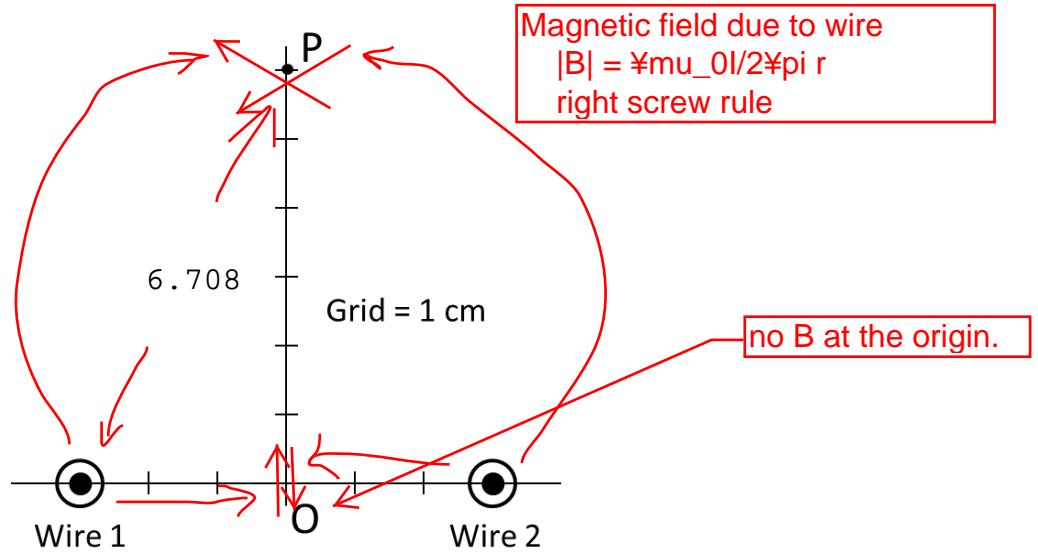b.  False

smaller r means smaller v

rb > rc -> vb > vc

*The next three questions pertain to the following situation:*

Consider two parallel, infinitely long wires 1 and 2 at (–3 cm, 0 cm) and (3 cm, 0 cm), as shown below.  Both wires carry the same current $I = 0.2$ A, out of the page.

Magnetic field due to wire
|B| = ¥mu_0I/2¥pi r
right screw rule

6.708

Grid = 1 cm

no B at the origin.

P

O

Wire 1                              Wire 2

4.  What is the direction of the net magnetic field $B$ from both wires at point **P** (0 cm, 6 cm) in the figure?

a.  Into the page
b.  Down
c.  Right
d.  Left
e.  Out of the page

As seen from the figure above, add the two Bs due to wires.

5.  Calculate the magnitude of the field $B$ at point **P**.

a.  $B = 0.32$ μT
b.  $B = 1.07$ μT
c.  $B = 4.45$ μT
d.  $B = 9.82$ μT
e.  $B = 12.3$ μT

To be quantitative, we have only to compute the B due to one wire and double its x-component.

|B|  = 4¥pi x 10^{-7}x 0.2/(2¥pi x 0.06708)
     = 5.96 x 10^{-7} T
Its x-component is -|B|(6/6.708) = -5.33 x 10^{-7} T.
The answer is 2 times this.

Not kindly worded.

*(Problem continues from previous page)*     Sketch the B fields.

6.  Suppose that we place a third long wire at the origin **O**, parallel to wires 1 and 2. What must be the magnitude and direction of the current $I_3$ in the 3$^{rd}$ wire such that there is no net force on wire 1 or 2?

These must be the
B due to 3

a.  $I_3 = 0$ A
b.  $I_3 = 4.2$ A, into the page
c.  $I_3 = 4.2$ A, out of the page
d.  $I_3 = 0.1$ A, into the page
e.  $I_3 = 0.1$ A, out of the page

```
                1          3          2
                          ⊗
      B due to 2  ←——— 6cm ———→  B due to 1
```
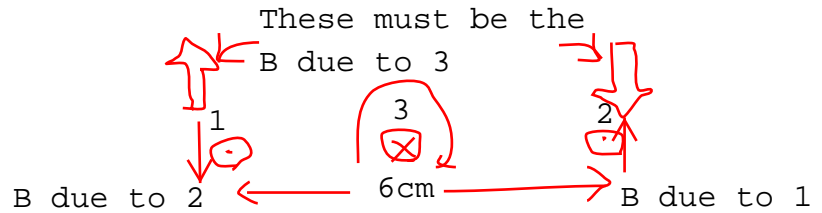
In order not to have any net force on each wire the B at
each wire must vanish.  This requires the B indicated
in the figure (`bold arrows').  Hence, the current must
be into the page.

B is proportional to 1/r, and 3 is closer to 1 than 2 is,
so we need 1/2 the current = 0.1 A.

***The next two questions pertain to the following situation:***

A single circular loop of wire of radius $r_{loop}$ = 11 cm is placed around a very long solenoid. The solenoid has a radius $r_{sol}$ = 4.8 cm and $n$ = 10,000 turns/m of wire. A current $I$ runs through the solenoid, generating a magnetic field $B_{sol}$ in the direction shown below. The current <u>increases</u> at a rate of 1.5 A/s.

Bsol = ¥mu_0 nI

Faraday's law

loop

loop

$B_{sol}$

$B_{sol}$

Lenz's B

solenoid

Side view

End view
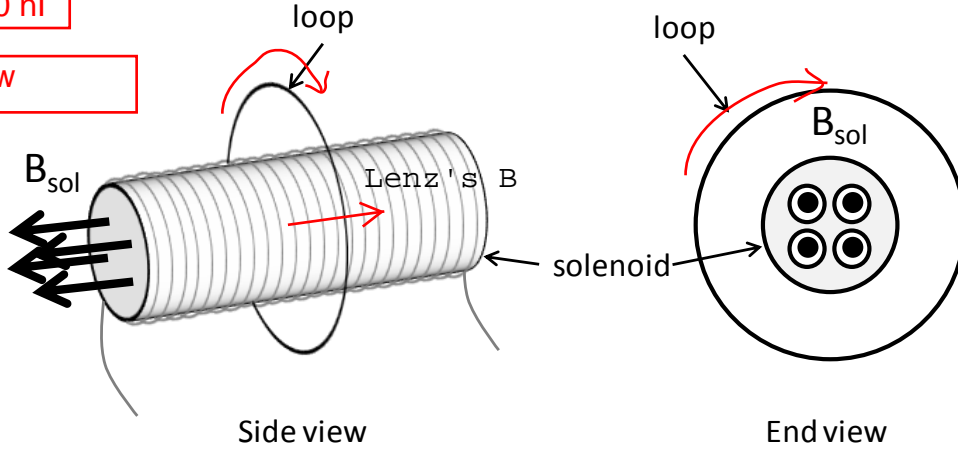
7.  In which direction does the induced current flow around the loop?

a.  Clockwise
b.  Counterclockwise
c.  There is no induced current

```
I increases -> B increases -> mag flux
increases
Then, Lenz tells us that the Loop should
create B to compensate this increase.
```

8.  What is the magnitude of the induced EMF $|\varepsilon|$ in the loop?

Faraday's law
|emf| = N changing rate of B flux

a.  $|\varepsilon|$ = 0.136 mV
b.  $|\varepsilon|$ = 0.527 mV
c.  $|\varepsilon|$ = 1.63 mV
d.  $|\varepsilon|$ = 3.72 mV
e.  $|\varepsilon|$ = 7.91 mV

```
N = 1

flux = (¥mu_0 n I) x (¥pi r_sol)^2.
Therefore, changing rate of flux
     = (¥mu_0 n dI/dt) x (¥pi r_sol^2)
     = (4¥pix10^{-7} x 10^4 x 1.5)x(¥pi x 0.048^2)
     = 0.136 x 10^{-3} V
```

***The next two questions pertain to the following situation:***

A single rectangular loop of wire of resistance $R = 1.3\ \Omega$, width $w = 3$ cm, and height $h = 5$ cm is traveling at a speed $v = 3$ m/s to the right. At the instant shown, the loop enters a region with a uniform magnetic field $B = 2$ T into the page.

Faraday
Lenz

R = 1.3 Ω     h = 5 cm     B = 2 T    v = 3m/s

← w = 3 cm →
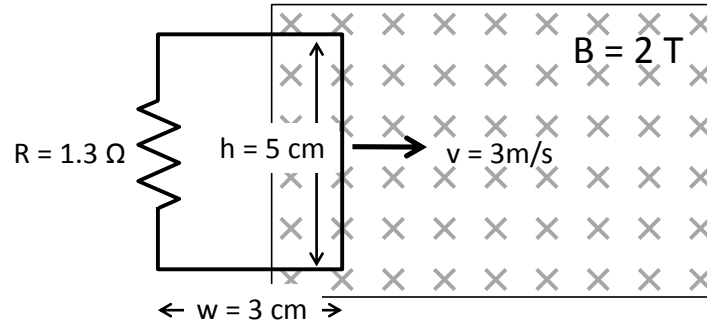
9. In which direction does the induced current flow around the loop?

   a. Clockwise
   b. Counterclockwise
   c. There is no induced current

Flux into the page increases
-> Lenz tells us that the loop wishes to
diminish this effect: B out of the page
-> right-screw rule implies counterclockwise.

10. Calculate the force $F_{loop}$ on the loop due to the magnetic field.

   a. $1.1 \times 10^{-3}$ N
   b. $5.9 \times 10^{-2}$ N
   c. $2.3 \times 10^{-2}$ N

F = ILB = IhB (in our case)
I = emf/R
emf = dA/dt B = vhB

Combining all, we get
     F = vh^2B^2/R
       = 3 (0.05)^2 x 4/1.3 = 0.02308 N

***The next two questions pertain to the following situation:***

A 4-turn square coil of wire of side $L = 0.2$ m is spinning with angular velocity $\omega = 6$ rad/s in a uniform magnetic field $B = 0.8$ T, as shown in the figure below. (The plane of the loop is perpendicular to the plane of the page.)

## Top view



¥Phi = B A sin(¥omega t)
d¥Phi/dt
= B A ¥omega cos(¥omega t)
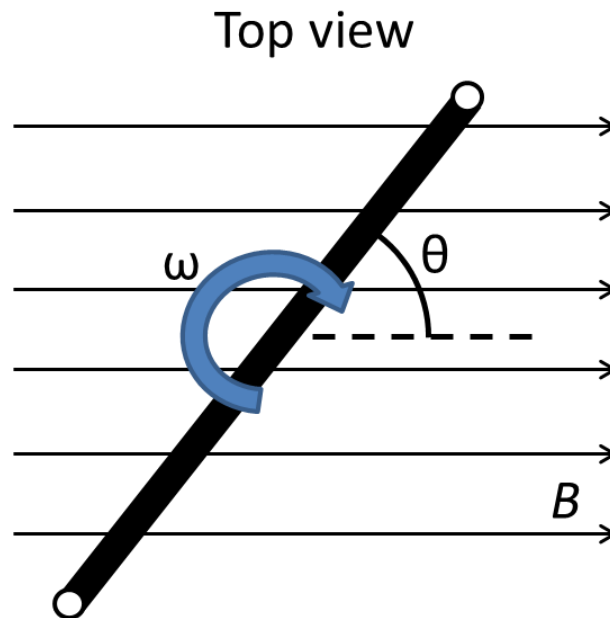
11. What value of the angle $\theta$ will make the induced EMF a <u>maximum</u>?

    a.) $\theta = 0°$
    b. $\theta = 45°$
    c. $\theta = 90°$

12. If the coil has a total resistance $R = 11$ Ω, what is the maximum current $I_{max}$ through the coil?

emf = N B A ¥omega cos(¥omega t)

    a. $I_{max} = 181$ mA
    b. $I_{max} = 97.2$ mA
    c. $I_{max} = 15.5$ mA
    d.) $I_{max} = 69.8$ mA
    e. $I_{max} = 12.0$ mA
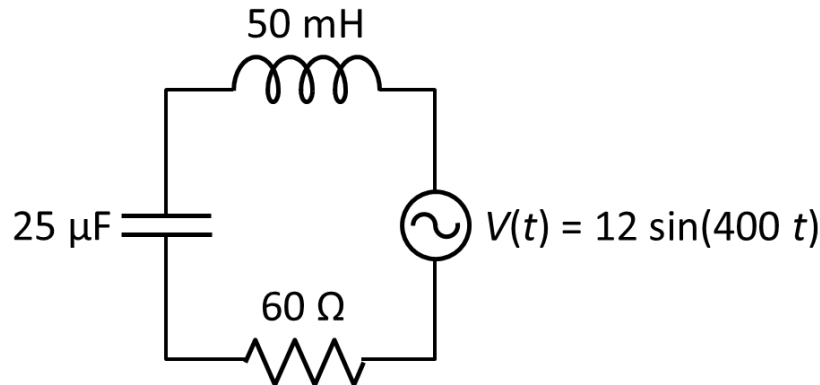
```
V_max = 4x0.8 x (0.2)^2 x 6 = 0.768 V.
i_max = 0.768/11 = 0.069818 = 69.8 mA
```

***The next three questions pertain to the following situation:***

We skip this.

A circuit consists of a 60 Ω resistor, a 50 mH inductor and a 2
series and driven by an AC generator with $V_{max}$ = 12 V and ω = 400 rad/s.

**50 mH**

**25 μF**                $V(t)$ = 12 sin(400 $t$)

**60 Ω**

13. What is the impedance $Z$ of the circuit?

a. $Z = 75\ \Omega$
b. $Z = 100\ \Omega$
c. $Z = 125\ \Omega$

14. Now the frequency of the generator is changed such that the generator voltage is in phase with the current in the circuit. What is the new value of the frequency $f$?

a. $f = 1.80 \times 10^{-3}$ Hz
b. $f = 94.8$ Hz
c. $f = 0.0383$ Hz
d. $f = 4.89$ Hz
e. $f = 142.4$ Hz

15. If the frequency is <u>increased</u> from the value you found in the previous question, the average power delivered to the resistor will:

a. Decrease
b. Stay the same
c. Increase

*The next two questions pertain to the following situation:*

A transformer used to deliver electricity to a house takes a maximum input voltage $V_{P,max} = 5$ kV across its primary coil and outputs a maximum voltage $V_{S,max} = 170$ V across its secondary coil.
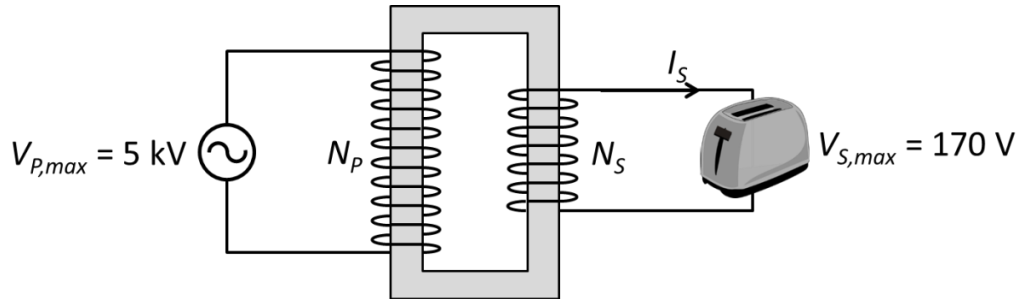


16.  What is the ratio $N_P/N_S$ between the number of turns in the primary ($N_P$) and the number of turns in the secondary ($N_S$)?

V/N = const

a.  $N_P/N_S = 0.054$
b.  $N_P/N_S = 29.4$
c.  $N_P/N_S = 2.04$
d.  $N_P/N_S = 6.28$
e.  $N_P/N_S = 15.0$

5000/N_p = 170/N_s -> N_p/N_s = 5000/170 = 29.41

17.  A toaster connected to the secondary dissipates an average power of 900 W. What is the rms current $I_{S,rms}$ delivered to the toaster?

a.  $I_{S,rms} = 7.49$ A
b.  $I_{S,rms} = 4.18$ A
c.  $I_{S,rms} = 15.7$ A
d.  $I_{S,rms} = 10.5$ A
e.  $I_{S,rms} = 22.5$ A

P = I_rms V_rms
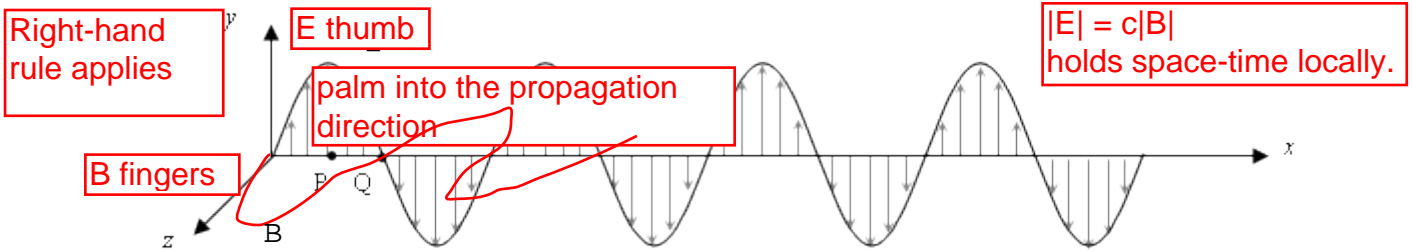
V_Max/¥sqrt{2} = V_rmp

900/(V_max/¥sqrt{2}) = I_rmp
   = 7.487 A

*The next three questions pertain to the following situation:*

A plane electromagnetic wave propagating in the +x direction in a vacuum has an intensity of 1.6 kW/m². The figure below represents a snapshot of the electric field associated with this wave.

Right-hand rule applies

E thumb

palm into the propagation direction

B fingers

B

|E| = c|B| holds space-time locally.

18. Identify the direction of the magnetic field *B* of this wave at point **P**.

a. +x
b. +y
c. +z

E and B are perpendicular. Screw rotation E to B should point the propagation direction.

19. Which of the options below correctly relates the <u>magnitudes</u> of the magnetic fields $B_P$ and $B_Q$, at points **P** and **Q** respectively?

As illustrated above

a. $B_P = B_Q$
b. $B_P > B_Q$
c. $B_P < B_Q$

20. Calculate the maximum value of the electric field $E_{max}$ of this wave.

a. $E_{max} = 0.86$ V/m
b. $E_{max} = 6.2 \times 10^{-3}$ V/m
c. $E_{max} = 42$ V/m
d. $E_{max} = 1100$ V/m
e. $E_{max} = 5600$ V/m

S = P/A = c u
u = ¥epsilon_0 E_rms^2
E_rms = E_max/¥sqrt{2}

We get

S = c¥epsilon_0 E_max^2/2

or

E_max^2 = 2S/c¥epsilon_0
        = 2x1.6x10^3/(3x10^8 x8.85 x10^{-12})
        = 0.1205 x 10^{3+4} = 1.205 x10^6

That is, Emax = 1.097 x 10^3 V/m

we skip

21.  An inductor in a computer motherboard is formed by wrapping a wire around a cylinder of radius equal to 3 mm and length equal to 1.2 cm. In order to obtain an inductance of 20.4 µH, how many turns of wire are needed?

a.  83300
b.  8330
c.  833
d.  83
e.  8

22.  You observe a star in a distant galaxy through your telescope. Based on information you have found, you know the entire galaxy is moving relative to the earth such that the wavelength of light you observe is 1.004 times greater than the wavelength of the light emitted by the star. What is the speed of the star relative to the earth?

a.  $v_{rel} = 6.5 \times 10^7$ m/s toward the earth
b.  $v_{rel} = 1.2 \times 10^6$ m/s away from the earth
c.  $v_{rel} = 8.5 \times 10^5$ m/s away from the earth
d.  $v_{rel} = 4.9 \times 10^4$ m/s toward the earth
e.  $v_{rel} = 7.5 \times 10^8$ m/s away from earth

0.004C common sense!

***The next three questions pertain to the following situation:***

A green laser of wavelength 528 nm is used to emit pulses of light. Each pulse lasts 2.00 ns and delivers 1.50 J of energy. The radius of the beam $r_{beam}$ is 2.50 mm. Assume the laser is being operated in deep space, which is a vacuum.

$L_{pulse}$

$r_{beam}$

$c = ¥lambda \times f$
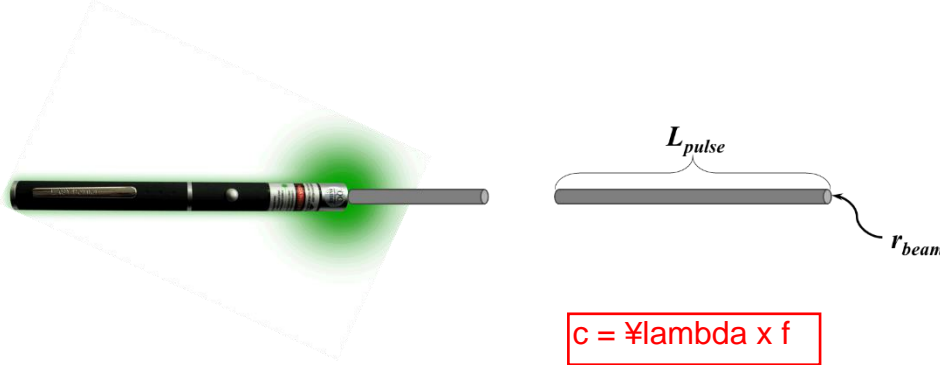
23. What is the frequency $f$ of the green light?

a. $f = 3.00 \times 10^8$ Hz
b. $f = 5.68 \times 10^{14}$ Hz
c. $f = 1.76 \times 10^{-15}$ Hz

```
f = 3 x 10^8/(528 x 10^{-9})
  = 0.005682 x 10^{17} Hz
```

24. What is the length $L_{pulse}$ of each pulse of light?

a. $L_{pulse} = 0.60$ m
b. $L_{pulse} = 106$ m
c. $L_{pulse} = 1.25 \times 10^{-3}$ m
d. $L_{pulse} = 2.15$ m
e. $L_{pulse} = 0.03$ m

```
2 x 10^{-9} x c
= 2x10^{-9}x(3x10^8) = 0.6 m
```

25. What is the intensity $I_{beam}$ of this beam of laser light?

Common sense question

a. $I_{beam} = 8.3 \times 10^9$ W/m²
b. $I_{beam} = 4.2 \times 10^3$ W/m²
c. $I_{beam} = 9.6 \times 10^{-17}$ W/m²
d. $I_{beam} = 5.1 \times 10^{-5}$ W/m²
e. $I_{beam} = 3.8 \times 10^{13}$ W/m²

```
Beam cross section = ¥pi (2.5 x 10^{-3})^2
   = 19.63 x10^{-6} m^2
The beam total energy transported is
   1.5/(2x 10^{-9}) = 7.5 x 10^8 W

Per unit area
 7.5 x 10^8/19.63 x10^{-6} = 0.382 x 10^14 W/
m^2
```

***The next two questions pertain to the following situation.***

Two polarizers are arranged as in the diagram above. In between the polarizers is a perfectly transparent crystal that rotates the polarization of light that passes through it by 45° in the direction indicated on the diagram by the large arrow. Unpolarized light with intensity $I_0$ is sent from the origin at point **O** in the +$z$ direction (toward point **Q**).
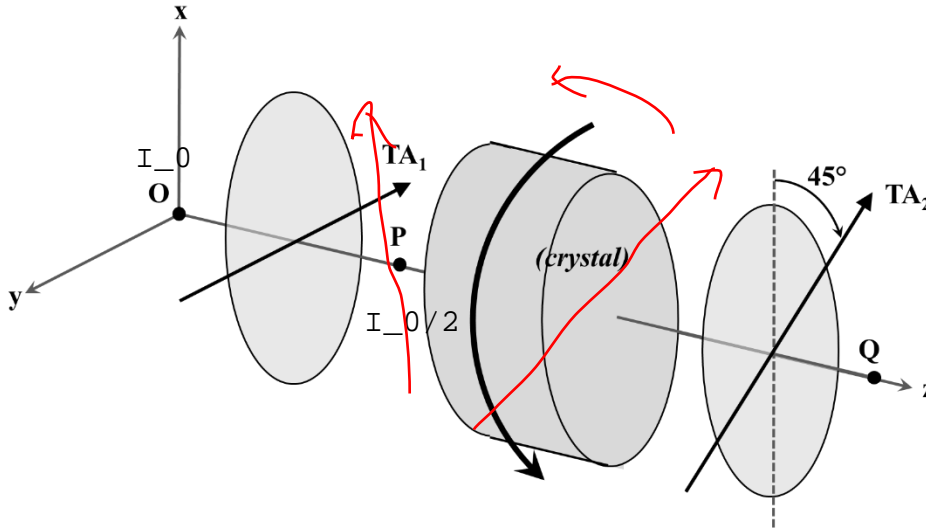


26. What is the intensity $I_Q$ at point **Q**?

    Since the polarization direction of light just
    a. $I_Q = 0$                           before the last polarizer agree with TA2, so
    b. $I_Q = I_0 / 2$                      I_Q = I at P.
    c. $I_Q = I_0 / \sqrt{2}$

27. Now light polarized along the $x$ direction is sent from point **Q** in the $-z$ direction (toward point **O**). What is the intensity $I_{origin}$ at the origin, point **O**?

    a. $I_{origin} = 0$                    See  the figure.
    b. $I_{origin} = I_0$
    c. $I_{origin} = I_0 / \sqrt{2}$

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

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