Your Name____

Discussion Instructor's Name:_________________________ Discussion Section #:_______

Physics 2213 **Final Exam** **May 17, 2011**

7 - 9:30 PM

PLEASE BE SURE THIS PACKET HAS 20 PAGES!

(This includes this cover sheet.)

This packet contains 7 **Short Answer Questions**, 5 **Problems**, 2 pages of **Scratch Paper**, and 2 pages of **Possibly Useful Information**. You may use any relevant information from the **Possibly Useful Information** pages without derivation.

Write your answers ON THESE QUESTION SHEETS in the spaces provided.

For Short Answer Questions #1-7, ONLY ANSWERS WILL BE GRADED, unless calculations or constructions are explicitly requested.

For Problems #8-12, where algebra or computations are required, BE SURE YOUR METHOD OF SOLUTION IS CLEAR, and SHOW ALL YOUR WORK in the spaces provided. If you need more space, use the backs of the question sheets and indicate the whereabouts of your work for each question. ANSWERS WITHOUT WORK WILL NOT RECEIVE CREDIT (except for short answer questions). WORK ON SCRATCH PAPER WILL NOT BE GRADED.

Point values for questions are given by each problem and below. BUDGET YOUR TIME. Don't spend too much time on any one question or part of a question. Answer those questions you can do easily first, and then return to the more difficult ones. It is valuable use of your time to READ THE ENTIRE EXAM before starting to work on it.

This is a CLOSED BOOK and CLOSED NOTES exam. You may NOT use any other references or personal assistance. You may use a non-graphing, non-programmable calculator.

GRAPHING and PROGRAMMABLE CALCULATORS are NOT allowed.

For Grading Only:

1-2	________ / 7	8	________ / 15
3	________ / 5	9	________ / 16
4-5	________ / 8	10	________ / 10
6	________ / 6	11	________ / 15
7	________ / 9	12	________ / 14

Graded out of 100 points with 5 "extra" points: TOTAL ________ / 105

I. Mostly SHORT ANSWER [34 points] Write your answers in the spaces provided.

1. [5 points] Consider these five equations:

(A) $\oint \vec{\mathbf{E}} \bullet d\vec{\mathbf{A}} = \frac{Q}{\varepsilon_o}$ **(B)** $\oint \vec{\mathbf{B}} \bullet d\vec{\mathbf{A}} = 0$ **(C)** $\oint \vec{\mathbf{E}} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

(D) $\oint \vec{\mathbf{B}} \bullet d\vec{\ell} = \mu_o I + \mu_o \varepsilon_o \frac{d\Phi_E}{dt}$ **(E)** $\vec{\mathbf{F}} = q\,(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}})$

Which of these equations implies (or imply) each of the following statements? If two or more equations together imply a statement, please list all those equations.

(a) A magnet moving through a coil of wire produces an emf. __________________

(b) Electric charges can move in circular paths in magnetic fields. __________________

(c) Electric charges of like signs repel each other. __________________

(d) Electromagnetic waves travel at speed 3.0×10^8 m/s in vacuum. __________________

2. [2 points] If the intensity of a beam of light were doubled without changing its size or shape, then . . .

(a) . . . the *amplitude* of the *electric field* oscillations in the light would:

(A) Not change. answer:___________

(B) Increase by $\times\sqrt{2}$.

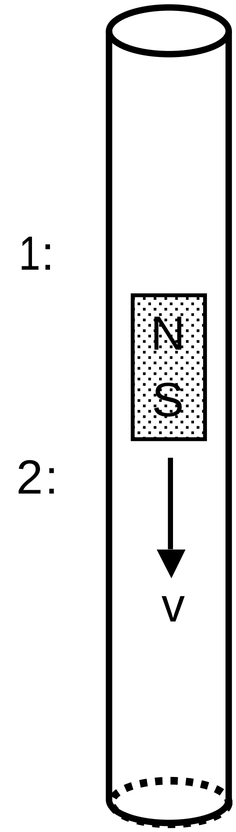
(C) Increase by $\times 2$.

(D) Increase by $\times 4$.

(b) . . . and the *force* that the light applies to any object it strikes would:

[Same choices as in (a)] answer:___________

3. [5 points] Based on lecture demos. A magnet falls down through the inside of a hollow metal pipe made from a non-magnetic metal, i.e., one that experiences no magnetic force due to a stationary magnet.)



(a) As seen from above the pipe, what is the *direction* of the *induced electric current* in the pipe in region #1 just above the magnet?

(A) ↻ (B) ↺

(C) Induced current is 0 there. answer:___________

(b) As seen from above the pipe, what is the *direction* of the *induced electric current* in the pipe in region #2 just below the magnet?

(A) ↻ (B) ↺

(C) Induced current is 0 there. answer:___________

(c) What is the *direction* of the *magnetic force* acting on the magnet due to induced current in region #1 just above the magnet?

(A) ↓ (B) ↑

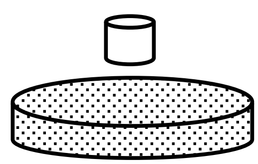
(C) other (D) This force is 0. answer:___________

(d) What is the *direction* of the *magnetic force* acting on the magnet due to induced current in region #2 just below the magnet?

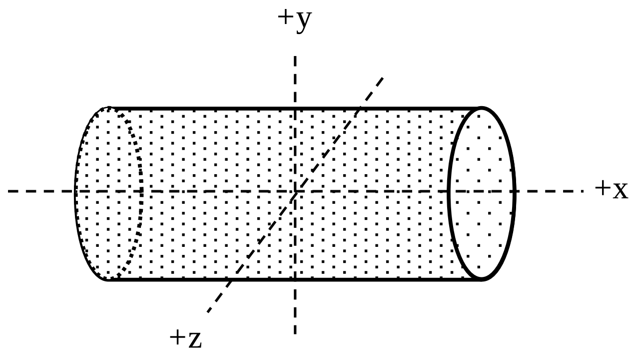
(A) ↓ (B) ↑

(C) other (D) This force is 0. answer:___________

(e) When a small but strong magnet is lowered down above a superconductor, the magnet eventually levitates at rest above the superconductor. Why can this magnet levitate *at rest* rather than continually falling as in the metal pipe above?



4. [5 points] A thin hollow cylindrical insulating shell of uniformly distributed electric charge +Q with radius R and length L is centered at the origin of an xyz coordinate system. The shell's ends are open.

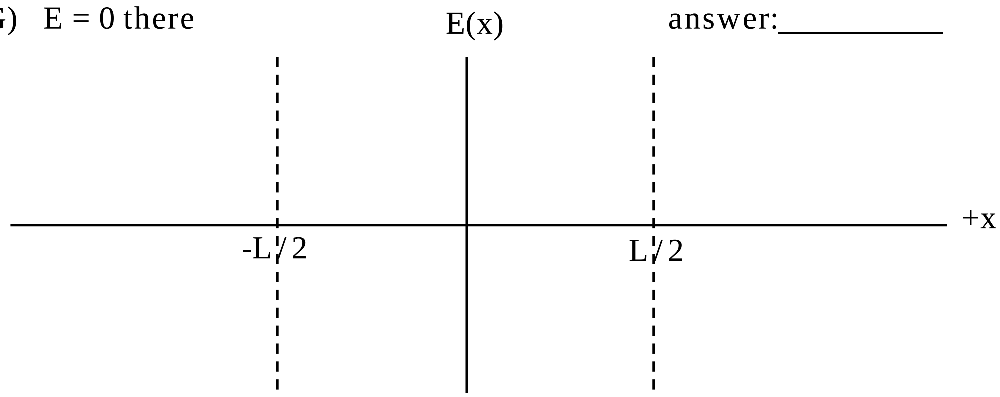


(a) (1 point) The direction of the *electric field* at the origin is:

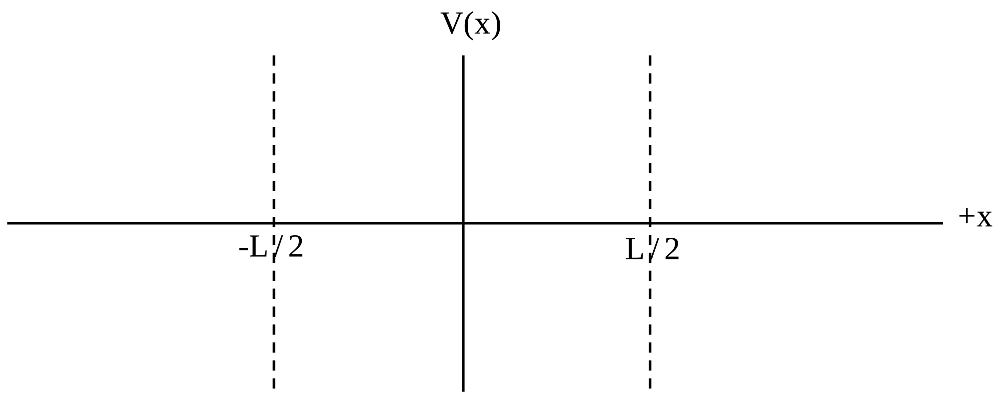
(A) +x (D) -x (G) E = 0 there
(B) +y (E) -y
(C) +z (F) -z

answer:__________

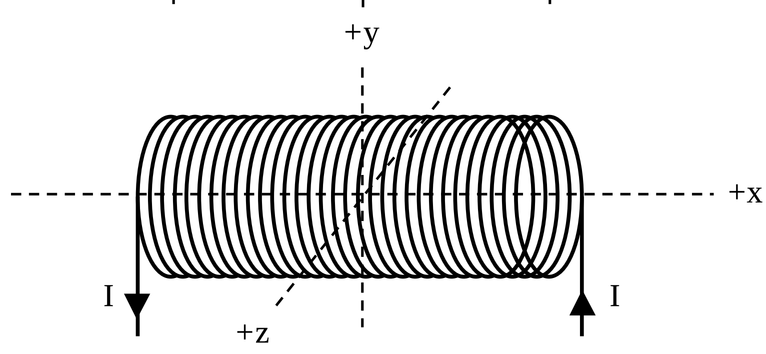
(b) (2 points) For points on the x-axis, graph the *electric field* E(x) vs. position x. Let changes in sign of E(x) show changes in direction of the field.



(c) (2 points) For points on the x-axis, graph the *electric potential* V(x) vs. position x. Let V = 0 very far away from the origin.



5. [3 points] A cylindrical solenoid of radius R and length L centered at the origin carries steady electric current I, as shown.

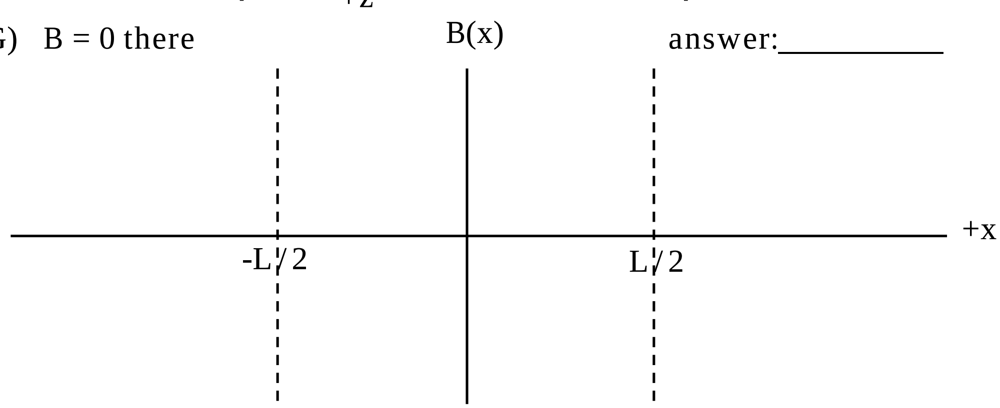


(a) (1 point) The direction of the *magnetic field* at the origin is:

(A) +x (D) -x (G) B = 0 there
(B) +y (E) -y
(C) +z (F) -z

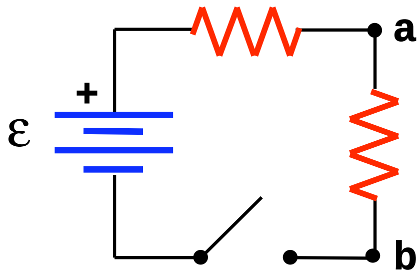
answer:__________

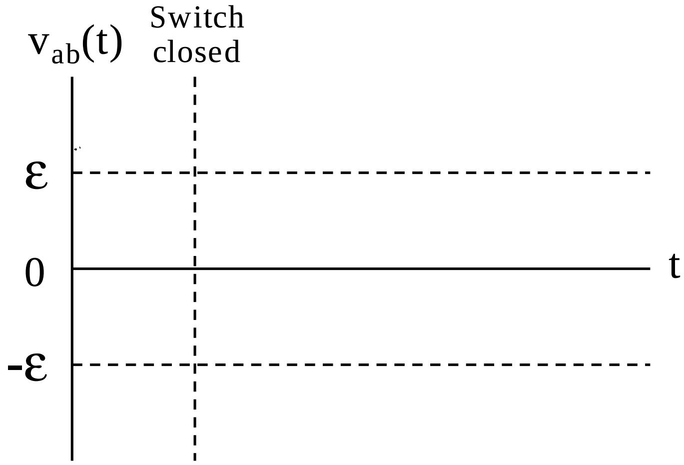
(b) (2 points) For points on the x-axis, graph the *magnetic field* B(x) vs. position x. Let changes in sign of B(x) show changes in direction of the field.



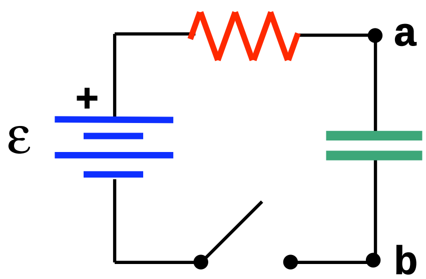
6. [6 points] In the circuits below, all the resistors are identical, the capacitors are initially uncharged, the DC power supplies are ideal (no resistance), and the switches are initially open. On the axes, sketch *graphs* showing the *voltage* $v_{ab}(t)$ as a function of time t from $t < 0$ to $t > 0$. Please show important physical behavior if the circuit has a characteristic time constant or period.

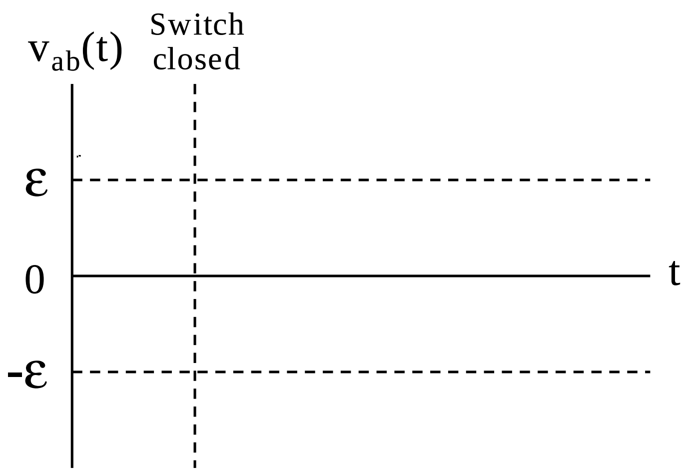
(a)



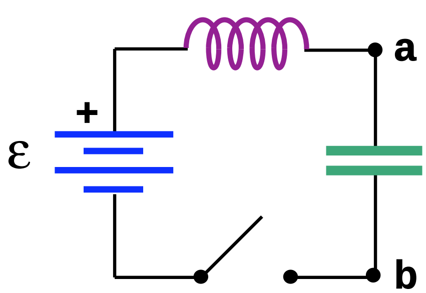


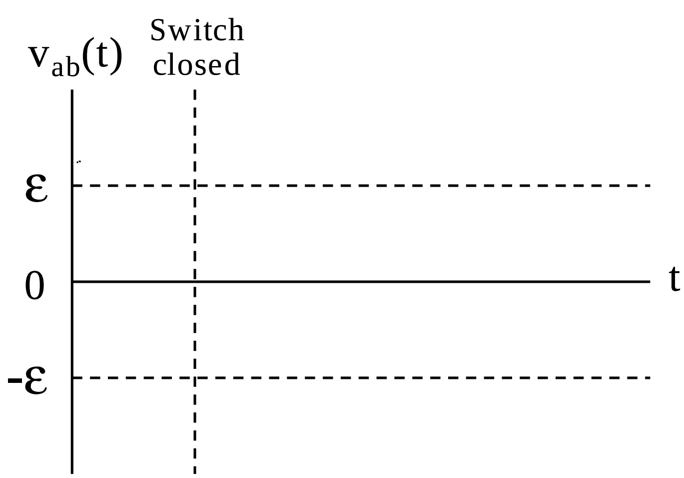
(b)



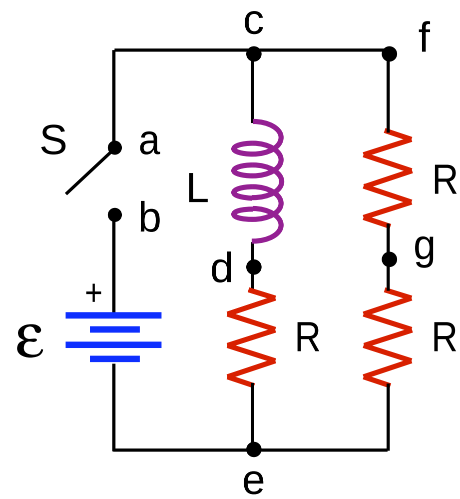


(c)





7. **[9 points]** The inductor and DC power supply are ideal (no internal resistance), and all the resistors are identical. Switch S has been open for a long time.

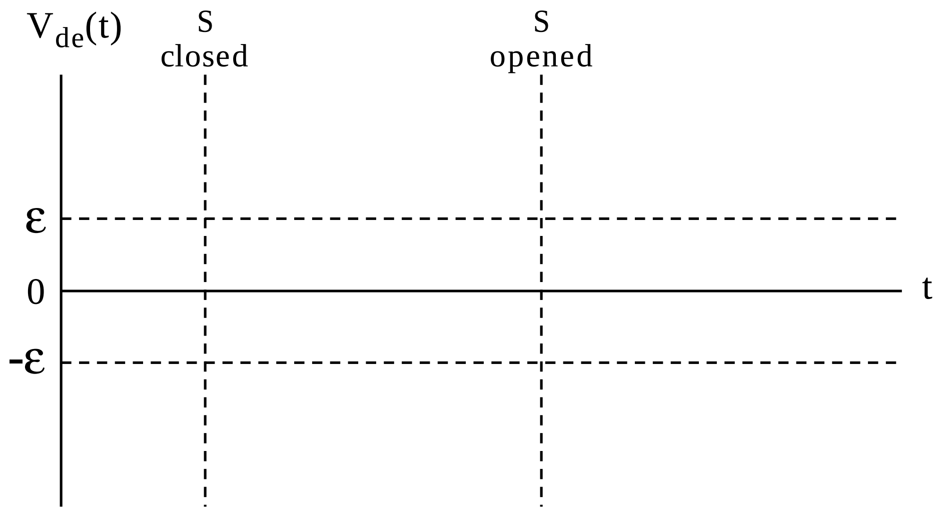


First, switch S is closed, the circuit approaches near to a steady state, and then switch S is opened and kept open.

(a) (2 points) What is *voltage* v_{ab} *before* switch S is closed (including sign)?

answer:____________________

(b) (4 points) Draw a *graph* showing *voltage* $v_{de}(t)$ as a function of time t over the entire time span indicated.



(c) (1 point) What is the *direction* of the *electric current* between points f and g shortly *after* switch S is opened?

(A) ↑ (B) ↓

(C) This current is zero at that time.

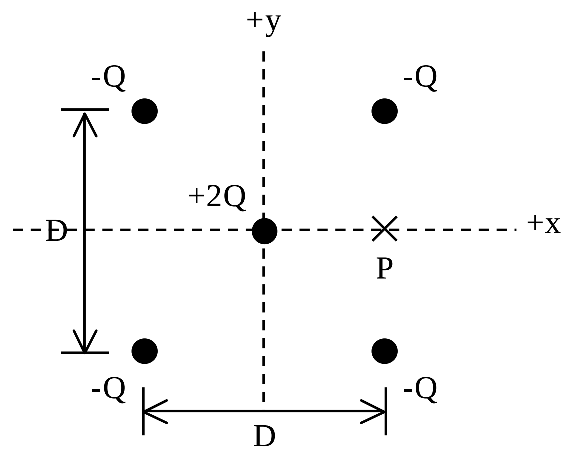
answer:________________

(d) (2 points) What is *voltage* v_{cd} just *after* switch S is opened (including sign)?

answer:______________________

II. Mostly PROBLEMS [66 points] Be sure your method is clear. Show ALL your WORK.

8. [15 points] Four identical (-) point electric charges -Q are at the corners of a square of side D that is centered on the origin of an xy-coordinate system where a (+) point charge +2Q is located.



(a) (1 point) What is the *direction* of the *net electric force* on the -Q charge in the upper right corner? Draw an arrow in this box:

(b) (6 points) What is the *magnitude* of the *net electric force* on the -Q charge in the upper right corner? Please show your work.

answer:____

[Problem CONTINUES on next page]

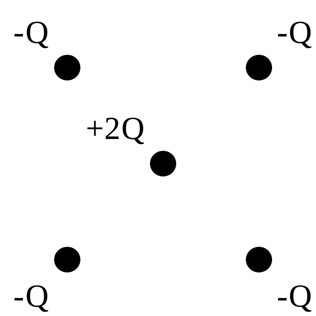
(c) (1 point) What is the direction of the net electric field at point P on the diagram on the previous page? Draw an arrow in this box:

(d) (1 point) What is the direction of the net electric field at points on the +x-axis very far from the origin (x >> D)? Draw an arrow in this box:

(e) (2 points) Write an approximate simplified *power law expression* of the form $1/x^n$ (with all relevant constants) for the *net electric field* E(x) at points on the +x-axis for x >> D.

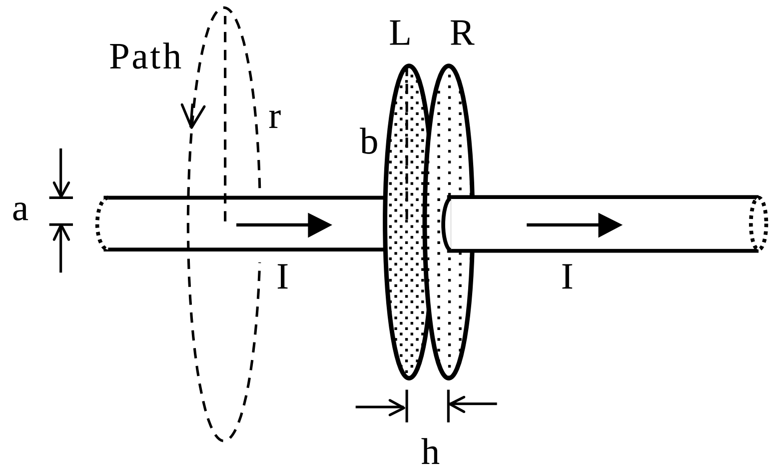
answer:____________________________________

(f) (3 points) On the diagram below, draw *electric field lines* (with arrows) for this charge configuration. Let 4 field lines be associated with each amount of charge of magnitude Q.

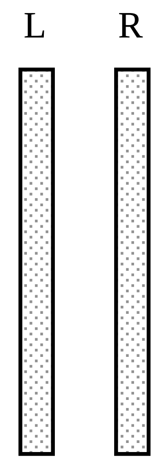


(g) (1 point) Are there any *points* where the electric field = 0?
If so, please mark the approximate location of one such point (o) on your field line diagram. If not, then write NONE here:

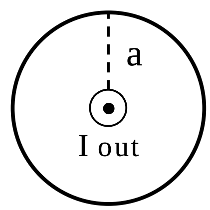
9. **[16 points]** An initially uncharged parallel plate capacitor consists of two circular plates (L & R) of radius "b" separated by distance h (<< b). The capacitor is being charged by constant electric current I through two long cylindrical wires of radius "a" and resistivity ρ, as shown. The current is uniformly distributed over the cross section of each wire. These wires extend far to the left and right.



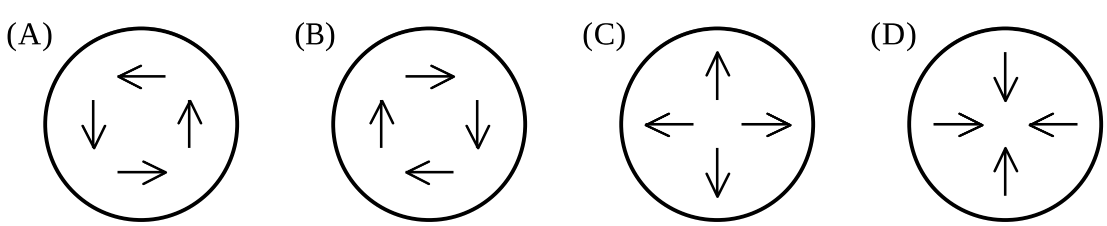
(a) (4 points) Use *Gauss' Law* to derive the expression $E = q/\pi\varepsilon_o b^2$ for the *electric field* between the capacitor plates in terms of the magnitude q of the charge on each of them. Be sure your reasoning is clear. Draw and label any geometric constructions you use in the space below.



(b) (2 points) On this magnified view of the right wire as seen from the right end of the diagram on the previous page, draw *magnetic field lines* for the magnetic field outside and inside the wire.



(c) (1 point) Which diagram below best shows the *magnetic forces* acting on the electric current carriers inside this wire? answer:___________

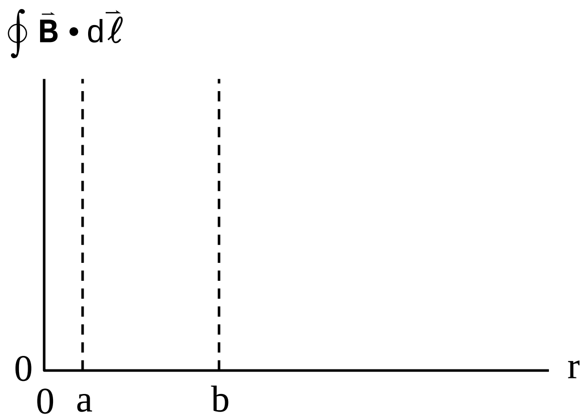


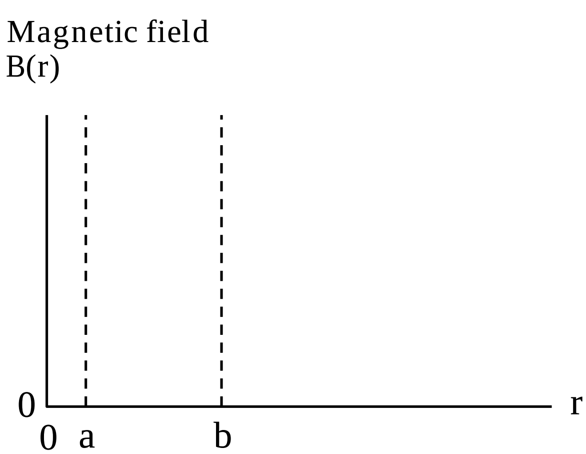
(E) None of the electric current carriers in this wire experience a magnetic force.

[Problem CONTINUES on next page]

(d) (4 points) For the imaginary circular Path of variable radius r surrounding the left wire coming into the capacitor, draw graphs below showing how each of the specified quantities depends on distance r from the central axis of the wire.

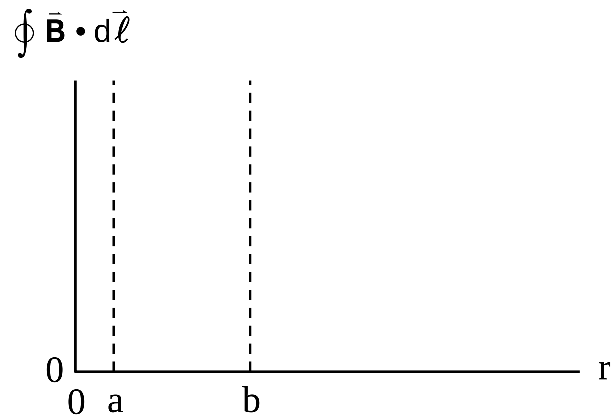
<u>Path around left wire</u>

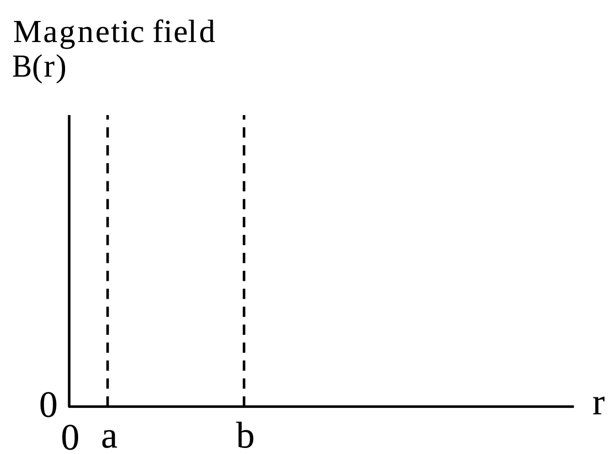




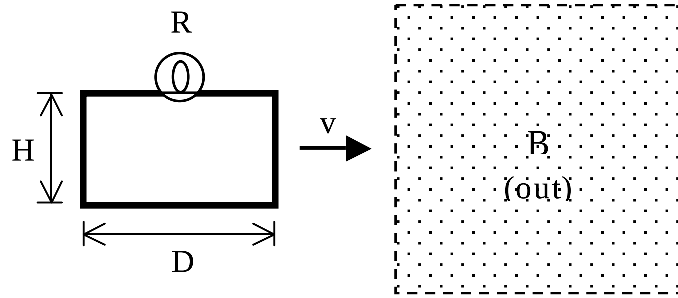
(e) (4 points) For a similar imaginary circular Path of variable radius r surrounding or in the gap between the capacitor plates, draw graphs below showing how each of the specified quantities depends on distance r from the wire's axis. Be sure your graphs are drawn to scale with those for the Path in (d).

<u>Path around or in gap</u>





10. [10 points] A 100-turn rectangular wire with sides D = 12.0 cm and H = 8.0 cm moves with constant speed v towards, into, through, and out of a region of uniform constant magnetic field B = 0.060 T, as shown. A light bulb rated at "0.50 W @ 2.5 V" is connected into the loop. The wire loop's electrical resistance is negligible compared to the bulb's resistance.



(a) (2 points) *When* does an electric current flow through the light bulb? List all that apply.

(A) While the loop is entirely outside the magnetic field region.
(B) While the loop is entering the magnetic field region.
(C) While the loop is entirely inside the magnetic field region.
(D) While the loop is leaving the magnetic field region.
(E) None of the above.

answer(s):_______________

(b) (4 points) At what constant *speed* v must the loop move in order for the bulb to be able to light as specified above in the appropriate place(s)? Please show your work.

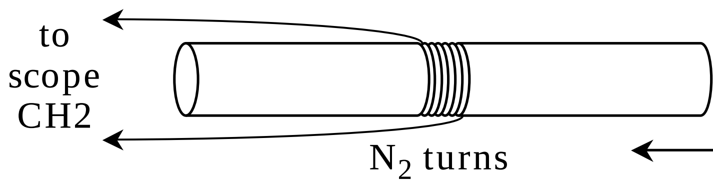
answer:____

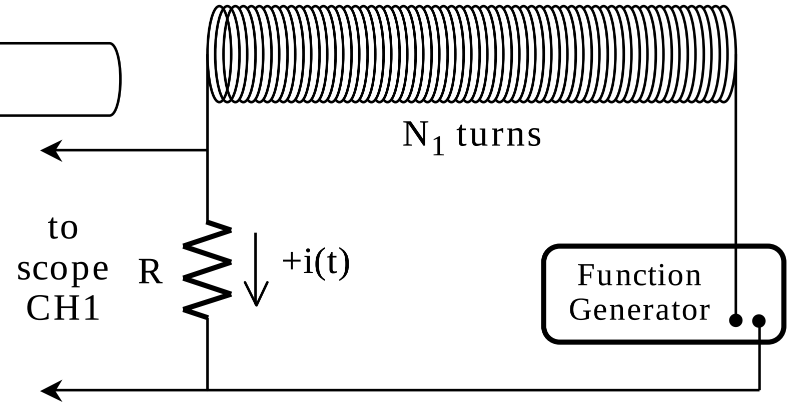
(c) (4 points) When the bulb is lit, what *mechanical force* (magnitude & direction) must be applied to the loop in order to keep it moving at its constant speed in part (a).

direction: ☐

magnitude:____________________________________

11. [15 points] A long hollow cylindrical solenoid is connected to a resistor $R = 20\ \Omega$ and a function generator delivering a sinusoidal signal at frequency $f = 2000$ Hz. A probe coil wrapped on a hollow plastic cylinder fits neatly inside the solenoid. The resistor and probe coil are connected to the two channels of an oscilloscope, as shown.



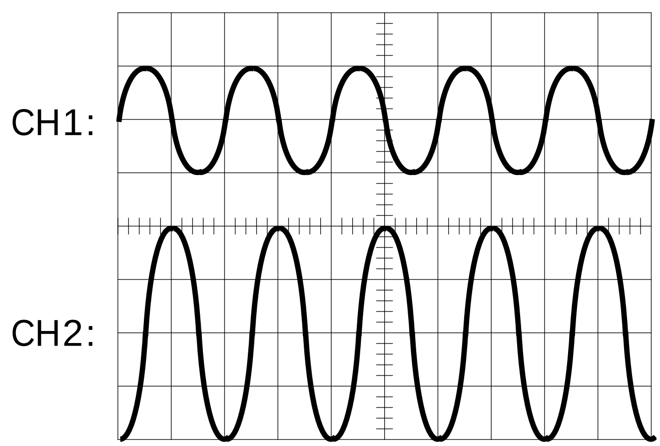


The two coils have negligible resistance and these physical properties:

Probe Coil: radius $r_2 = 1.0$ cm
$N_2 = 160$ turns
length $\ell_2 = 2.0$ cm

Solenoid: radius $r_1 = 1.5$ cm
$N_1 = 1000$ turns
length $\ell_1 = 20.0$ cm

When the Probe Coil is inserted inside the Solenoid at its middle, the signals shown here are displayed on the oscilloscope with these settings:



CH1 VOLTS / DIV (↕) = 0.5 V

CH2 VOLTS / DIV (↕) = 0.05 V

(a) (4 points) Use the signal displayed on CH1 to calculate the *amplitude* B_{max} of the *magnetic field* oscillations inside the Solenoid. For simplicity, treat the Solenoid as very long and ideal. Be sure your work is clear.

answer:____

[Problem CONTINUES on next page]

(b) (3 points) Derive an *algebraic expression* for the *voltage signal* $v_2(t)$ on oscilloscope CH2 in terms of the magnetic field B(t) inside the Solenoid as a function of time t. Your answer may contain algebraic quantities specified on the previous page, but don't evaluate numbers yet.

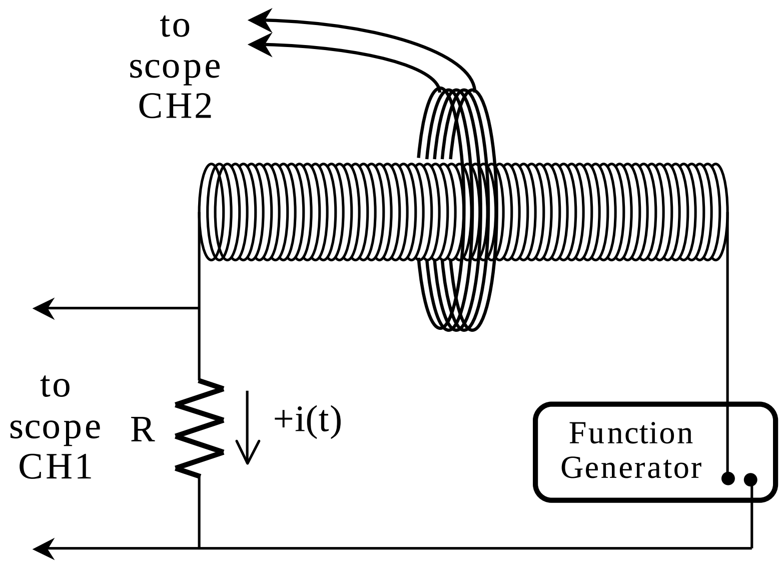
answer:____

(c) (4 points) Now use your result from part (b) along with the signal displayed on CH2 of the oscilloscope to calculate the *amplitude* B_{max} of the *magnetic field* oscillations inside the Solenoid. Be sure your work is clear. [HINT: Write B(t) in terms of B_{max} and an oscillatory function such as $\sin(2\pi ft)$ or $\cos(2\pi ft)$.]

answer:____

[Problem CONTINUES on next page]

Student A proposes using this modified arrangement to detect the effects of the oscillating magnetic field inside the Solenoid — a Probe Coil placed *around* the Solenoid instead of inside it. Again, for simplicity, the Solenoid may be treated as very long and ideal.



Student B poses this objection: "Since there is no (or very little) magnetic field outside the Solenoid, no voltage signal will be detected in the Probe Coil if it is outside the Solenoid."

(d) (2 points) How should you respond to Student B, using physics principles?

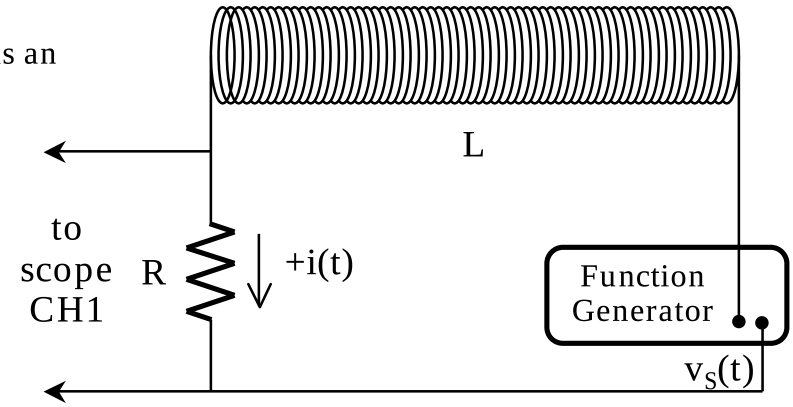
Student C poses this objection: "Since the Probe Coil is outside the Solenoid's magnetic field, there is nothing out there to push electric charges around the Probe Coil and produce an emf and voltage reading."

(e) (2 points) How should you respond to Student C, using physics principles?

[Exam CONTINUES on next page]

12. [13 points] Now the probe coils are removed, and a similar Solenoid is used as an inductor with these properties:

radius = 1.5 cm
length = 20.0 cm
inductance = 3.2 mH = 0.0032 H
negligible internal resistance



Resistor R = 20 Ω. The Function Generator delivers a sinusoidal signal of amplitude 2.0 Vat frequency 2000 Hz, and its internal resistance is negligible.

(a) (3 points) In the space at the right, draw a carefully-labeled *phasor diagram* showing the *voltages* for the resistor, Solenoid, and Function Generator, and the *electric current* i(t):

(b) (4 points) What is the *amplitude* of the *voltage* oscillations across the resistor R? Please show your work

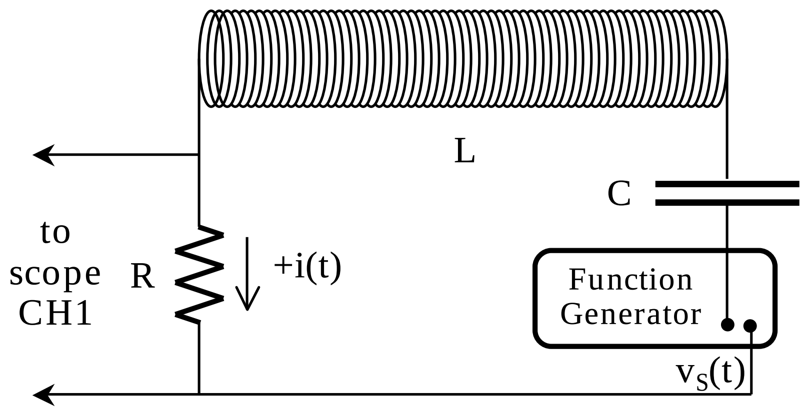
answer:____

[Problem CONTINUES on next page]

(c) (2 points) How many *coils* (turns of wire) are in this Solenoid? For simplicity, treat the Solenoid as very long and ideal. Please show your work.

answer:________________________________

Now a capacitor C is added into the circuit as shown.



(d) (3 points) What should be the *capacitance* C in order for the amplitude of the voltage oscillations across the resistor to be as large as possible? Be sure your work is clear.

answer________________________________

(e) (2 points) What is the *amplitude* of the *electric current* oscillations through the resistor? Be sure your work is clear.

answer________________________________

[END of Exam Questions and Problems]

Possibly Useful Information:

$F_e = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_o r^2}$ $\quad \vec{F} = q\vec{E}$ $\quad E \propto \frac{N}{A_\perp}$ $\quad B \propto \frac{N}{A_\perp}$

$E = \frac{kQ}{r^2} = \frac{Q}{4\pi\varepsilon_o r^2}$ $\quad E = \frac{2k\lambda}{r} = \frac{\lambda}{2\pi\varepsilon_o r}$ $\quad \Phi_E = \int \vec{E} \bullet d\vec{A}$

$\oint \vec{E} \bullet d\vec{A} = 4\pi k Q_{encl} = \frac{Q_{encl}}{\varepsilon_o}$ $\quad E = 2\pi k\sigma = \frac{\sigma}{2\varepsilon_o}$ $\quad E = 4\pi k\sigma = \frac{\sigma}{\varepsilon_o}$

$V_{ba} = V(b) - V(a) = -\int_a^b \vec{E} \bullet d\vec{\ell}$ $\quad U_e(\vec{r}) = qV(\vec{r})$ $\quad V = \frac{kQ}{r} = \frac{Q}{4\pi\varepsilon_o r}$

$E_x(x) = -\frac{dV(x)}{dx}$ $\quad \vec{E}(\vec{r}) = -\vec{\nabla} V(\vec{r})$ $\quad U_e = \frac{kq_1q_2}{r} = \frac{q_1q_2}{4\pi\varepsilon_o r}$

$\vec{J} = nq\vec{v}_d = \frac{1}{\rho}\vec{E}$ $\quad I = \frac{dQ}{dt} = JA_\perp$ $\quad R = \frac{V}{I} = \rho\frac{L}{A}$

$\rho(T) = \rho(T_o)[1 + \alpha(T - T_o)]$ $\quad R_{eq} = R_1 + R_2$ $\quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$P = IV = \frac{V^2}{R} = I^2R$ $\quad C = \frac{Q}{V} = K\varepsilon_o\frac{A}{d}$ $\quad K = E_{out}/E_{in}$

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$ $\quad U_C = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2$ $\quad u_E = \frac{1}{2}K\varepsilon_o E^2$

$C_{eq} = C_1 + C_2$ $\quad Q(t) = Q_f(1 - e^{-t/\tau})$ $\quad Q(t) = Q_o e^{-t/\tau}$

$\vec{F}_B = q\,\vec{v} \times \vec{B}$ $\quad \tau = RC$ $\quad I(t) = I_o e^{-t/\tau}$

$\vec{F}_B = I\,\vec{\ell} \times \vec{B}$ $\quad d\vec{B} = \frac{\mu_o}{4\pi}\frac{I\,d\vec{\ell} \times \hat{r}}{r^2}$ $\quad \oint \vec{B} \bullet d\vec{\ell} = \mu_o I_{enclosed}$

$B = \frac{\mu_o I}{4\pi r}(\sin\theta_1 + \sin\theta_2)$ $\quad B = \frac{\mu_o I R^2}{2(x^2 + R^2)^{3/2}}$ $\quad B = \frac{\mu_o nI}{2}(\sin\theta_1 + \sin\theta_2)$

$B = \frac{\mu_o I}{2\pi r}$ $\quad B = \frac{\mu_o I}{2R}$ $\quad B = \mu_o nI$

$\vec{\mu} = I\vec{A}$ $\quad \vec{\tau} = \vec{\mu} \times \vec{B}$ $\quad \mu_o = 4\pi \times 10^{-7}$ T-m/A

$k = \frac{1}{4\pi\varepsilon_o} = 9.0 \times 10^9$ N-m^2/C^2 $\quad \varepsilon_o = 8.85 \times 10^{-12}$ C^2/N-m^2 (or F/m)

$E_{breakdown\ air} \sim 3 \times 10^6$ V/m

$\Phi_B = \int \vec{B} \bullet d\vec{A}$ $\quad \mathcal{E} = -N\frac{d\Phi_B}{dt} = -\frac{d\Phi_{B\ total}}{dt}$ $\quad \mathcal{E} = \oint (\vec{E}_{ne} + \vec{v} \times \vec{B}) \bullet d\vec{\ell}$

$\mathcal{E}_2(t) = -M\frac{di_1(t)}{dt}$ $\quad \mathcal{E}(t) = -L\frac{di(t)}{dt}$ $\quad L = \mu_o n^2 \ell A = \frac{\mu_o N^2 A}{\ell}$

$M = \frac{N_2\Phi_{B2}(t)}{i_1(t)} = \frac{\Phi_{B2\ total}(t)}{i_1(t)}$ $\quad L = \frac{N\Phi_B(t)}{i(t)} = \frac{\Phi_{B\ total}(t)}{i(t)}$ $\quad U_L = \frac{1}{2}Li^2$

$i(t) = I_f\,(1 - e^{-t/\tau})$

$\tau = \dfrac{L}{R}$

$u_B = \dfrac{B^2}{2\mu_o}$

$\text{rms} = \dfrac{\text{max}}{\sqrt{2}}$

$P_{avg} = I_{rms}^{\ 2}\,R$

$P_{avg} = I_{rms}\,V_{rms}\cos\phi$

$V = I\,Z$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

$\omega = 2\pi f$

$V = IX$

$X_L = \omega L$

$X_C = 1/\omega C$

$\dfrac{V_2}{V_1} = \dfrac{N_2}{N_1}$

$\omega_o = \dfrac{1}{\sqrt{LC}}$

$\tan\phi = \dfrac{X_L - X_C}{R}$

$\oint \vec{\mathbf{B}} \bullet d\vec{\ell} = \mu_o(I_{enclosed} + \varepsilon_o \dfrac{d\Phi_E}{dt})$

$\Phi_E = \int \vec{\mathbf{E}} \bullet d\vec{\mathbf{A}} = \int E\,dA_\perp$

$\oint \vec{\mathbf{E}} \bullet d\vec{\mathbf{A}} = \dfrac{Q_{enclosed}}{\varepsilon_o}$

$c = \dfrac{1}{\sqrt{\mu_o \varepsilon_o}} = 3.0 \times 10^8\ \text{m/s}$

$\oint \vec{\mathbf{E}} \bullet d\vec{\ell} = -\dfrac{d\Phi_B}{dt}$

$\oint \vec{\mathbf{B}} \bullet d\vec{\mathbf{A}} = 0$

$E = cB$ $\qquad c = f\lambda$

$\vec{\mathbf{S}} = \dfrac{1}{\mu_o}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$

$u = u_E + u_B$

$p = U/c$

$\vartheta = P/A_\perp = S_{avg} = \dfrac{1}{2\mu_o}E_{max}B_{max} = \dfrac{1}{\mu_o}E_{rms}B_{rms}$

$C = 2\pi r \qquad A = \pi r^2$

$A = 4\pi r^2 \qquad V = \frac{4}{3}\pi r^3$

$A = 2\pi rh \qquad V = \pi r^2 h$

For $|z| < 1$: $\quad (1 + z)^p = 1 + pz + \dfrac{p(p-1)}{2!}z^2 + \dfrac{p(p-1)(p-2)}{3!}z^3 + \ldots$

For $p \neq -1$: $\quad \int x^p\,dx = \dfrac{x^{p+1}}{p+1}$

$\int \dfrac{dx}{x} = \ln x$

$\int e^{ax}\,dx = \dfrac{e^{ax}}{a}$

$\ln(ab) = \ln(a) + \ln(b)$

$\ln(a/b) = \ln(a) - \ln(b)$

$(e^a)^b = e^{ab}$

$d(uv)/dx = v\,du/dx + u\,dv/dx$

$d(u/v)/dx = (v\,du/dx - u\,dv/dx)/v^2$

$\dfrac{d(\sin u)}{du} = \cos u$

$\dfrac{d(\tan u)}{du} = \sec^2 u$

$\dfrac{d(\sec u)}{du} = \sec u \tan u$

$\dfrac{d(\cos u)}{du} = -\sin u$

$\dfrac{d(\cot u)}{du} = -\csc^2 u$

$\dfrac{d(\csc u)}{du} = -\csc u \cot u$

$\cot u = 1/\tan u$

$\sec u = 1/\cos u$

$\csc u = 1/\sin u$

$\sin^2 u = \dfrac{1 - \cos 2u}{2}$

$\cos^2 u = \dfrac{1 + \cos 2u}{2}$

$2\,(\sin u)(\cos u) = \sin 2u$