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MIDTERM #2
Version H
Physics 1C, Prof. David Saltzberg
May 22, 2017

Time: 50 minutes. Closed Notes. Closed Book. Two 3”x5” sheets (one from last exam). Calculators are allowed. Show your work.

If a problem is confusing or ambiguous, notify the professor. Clarifications will be written on the blackboard. Check the board.

Extra paper is at the front of the room.

You may use the small-circle approximation: $\pi = 3$ so you don’t need a calculator.

Problem	Points
1	16 /16
2	16 /16
3	16 /16
4	20 /20
5	16 /16
6	16 /16
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TOTAL	100 /100

1) Short answers: (Hint: You don't need a full page for these but I am giving you room.)

a) (8 pts) Express the units of inductance in terms of the fundamental units of the SI system (kg, m, s, A).

$V = L\frac{dI}{dt}$

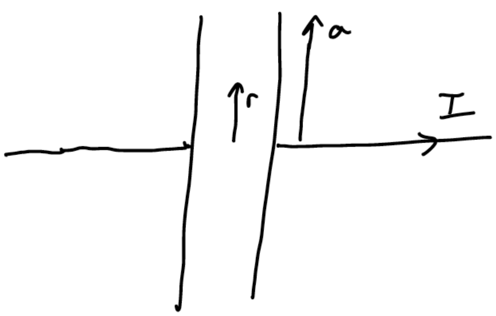
inductance

$$[L] = \frac{V}{A/s} = \frac{J/C}{A/s} = \frac{J\cdot\frac{1}{A\cdot s}}{A/s}$$

$$= \frac{J}{A^2}$$

$$= \frac{kg\, m^2}{A^2\, s^2}$$

b) (8 pts) A capacitor has circular plates of radius *a*=4.0 cm, with a uniform electric field between them. It is discharged with a constant current, *I*=2.0A. After it discharges completely, the constant current continues so that the capacitor charges up again, but with opposite charges on each plate. At the moment the capacitor is discharged completely, what is the magnetic field between the plates at a distance r=2.0 cm from the central axis.



$E = 0$ but $\frac{d\Phi_E}{dt} \neq 0$

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_D$$

$$(B)(2\pi r) = \mu_0 I \left(\frac{r}{a}\right)^2$$

$$B = \frac{\mu_0}{2\pi} I \frac{r}{a^2}$$

$$B = (2\times10^{-7})(2)\left(\frac{.02}{(.04)^2}\right)$$

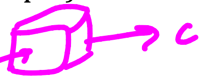
$$= 10^{-7}(4)\left(\tfrac{1}{2}\right)\frac{100}{4}$$

$$= 0.5\times10^{-5}$$

$$= \boxed{5\times10^{-6}\,T}$$

2) Solar panels convert sunlight into electrical power. On a sunny day, sunlight at the surface of the earth is 1kiloWatt per square meter, which determines the maximum output of a solar panel. You may treat air as vacuum for this problem.

a) (8 pts) What is the RMS magnetic field of the sunlight just before hitting your panels?



$u = U/V$

$uc = I$

$$\cancel{2}\left(\frac{1}{\cancel{2}\mu_0}B_{Rms}^2\right)c = (1000\,W/m^2)$$

since E field carries equal energy

$$B_{Rms} = \sqrt{\frac{\mu_0}{c}1000}$$

$$= \sqrt{(4\cancel{\pi}\times10^{-7})\frac{1000}{\cancel{3}\times10^{8}}}$$

$$= 2\times\sqrt{10^{-12}} = \boxed{2\times10^{-6}\,T}$$

(exact value using π is 2.05×10^{-6})

b) (8 pts) Assume in part *a,* the sunlight is absorbed 100% by your black solar panels which are each 1.0m×1.0m in area. What is the force of the sunlight on the panels in Newtons? (Hint: you do not need any answers from part *a* to solve this part.)

$$F = (P_{rad})(1m^2) = I/c\,(1)$$

absorbs

$$= \frac{1000}{3\times10^{8}}$$

$$= \frac{1}{3}\times10^{-5}$$

$$\boxed{= 3\times10^{-6}\,N}$$

Much less than gravity!

3) In class we used a large concave mirror (focal length, f =0.75 m) to produce a real image of a light bulb on the wall. In this problem we move the object to make a virtual image instead.

a) (8 pts) You move the object to make a virtual image at a position "inside" the mirror of lateral magnification +3.0. Where do you place the object and where is the image?

$$m = +3 = -s'/s$$

$$s' = -3s$$

$$\frac{1}{s} + \frac{1}{-3s} = 1/(3/4)$$

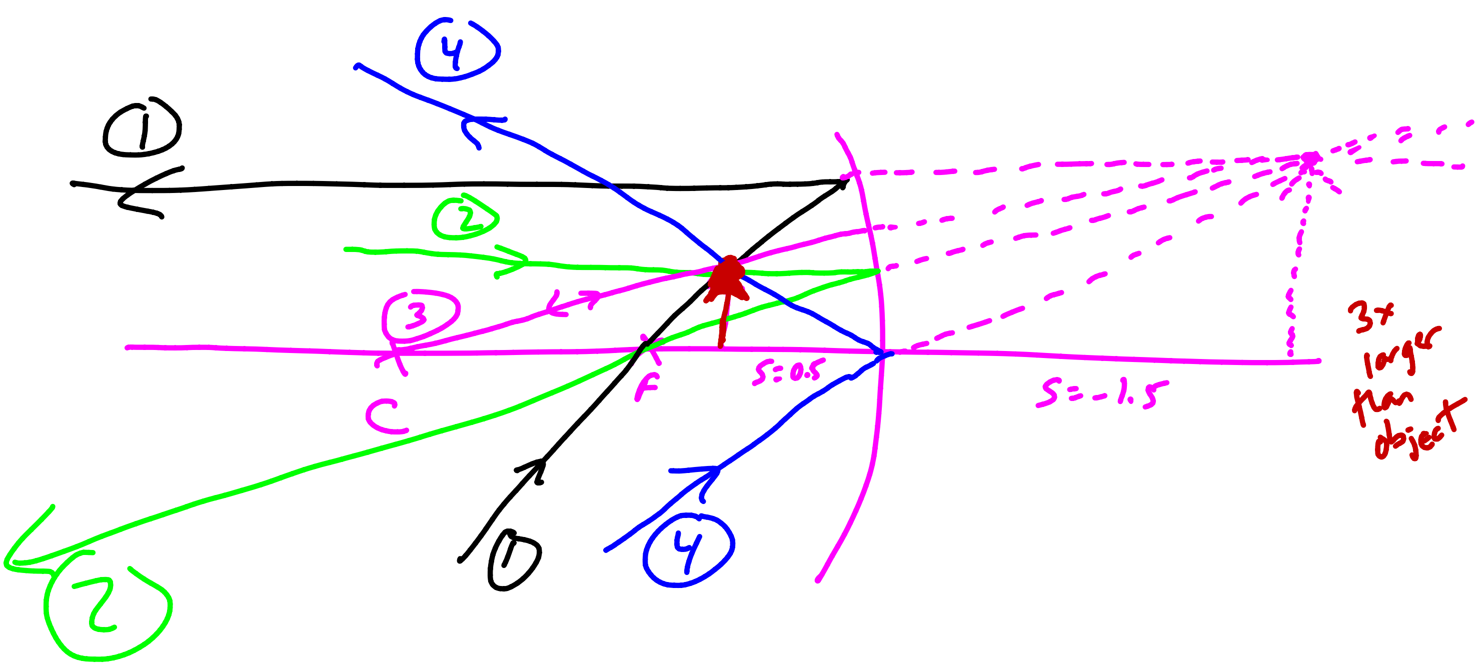
$$\frac{2}{3s} = \frac{4}{3}$$

$$s = 1/2$$

$$\boxed{\begin{array}{ll} s = 0.5 & \text{in front of mirror} \\ s' = -1.5 & \text{behind mirror} \end{array}}$$

(As long as you say "front" or "behind" you don't need the sign.)

b) (8 pts) Draw a diagram of the situation in part a including the object, image, and mirror, drawing at least two "principle rays". (Hint: You need to have done part a correctly in order do to this part, so check your work.)



4) (20 pts) A linearly polarized electromagnetic plane wave in vacuum has a Poynting vector in the *+y* direction. Its electric field always points in the *+z* direction and has a maximum value of 30.0 V/m. It is a sine wave with wavelength 600nm, which corresponds to orange light. The maximum electric field is seen at the origin at *t=0*. Write down an expression for the magnetic field as a function of distance, time, and numbers. (Hint: The answer is a vector.) (For simplicity you can write the numbers without units.)

$$\vec{B}(y,t) = +B_0\,\hat{i}\,\cos(ky-\omega t)$$

propagates into positive y direction

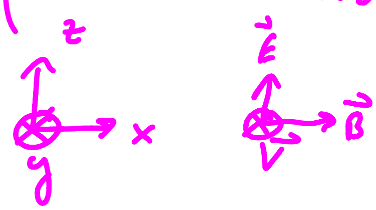
propagates along y

max at $(y=0, t=0)$

perpendicular to $\hat{j}$ and $\hat{k}$

by R.H.R.

method I



method II

$\hat{k}\times\hat{i} = \hat{j}$

$$\boxed{\begin{aligned} B_0 &= E_0/v \\ &= 30/3\times10^8 \\ &= 10\times10^{-8} \\ &= 1\times10^{-7}\ \text{T} \end{aligned}}$$

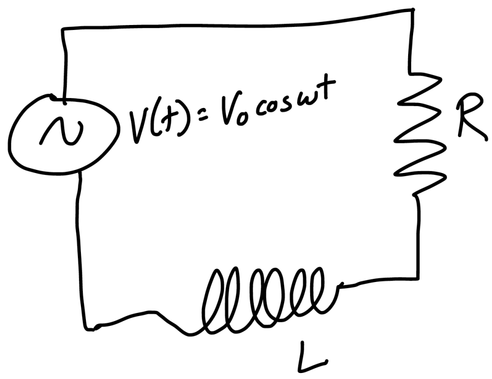
$$k = \frac{2\pi}{\lambda} = \frac{6}{600\times10^{-9}} = 10^7\ \text{rad/m}$$

$$c = \lambda f = \omega/k$$

$$\omega = ck = (3\times10^8)(10^7) = 3\times10^{15}$$

$$\boxed{\vec{B}(y,t) = +(1\times10^{-7})\,\hat{i}\,\cos(10^7 y - 3\times10^{15} t)}$$

5) (16 pts) A series LR circuit as shown below is driven by a sinusoidal voltage source with amplitude, V_0, and angular frequency, ω.



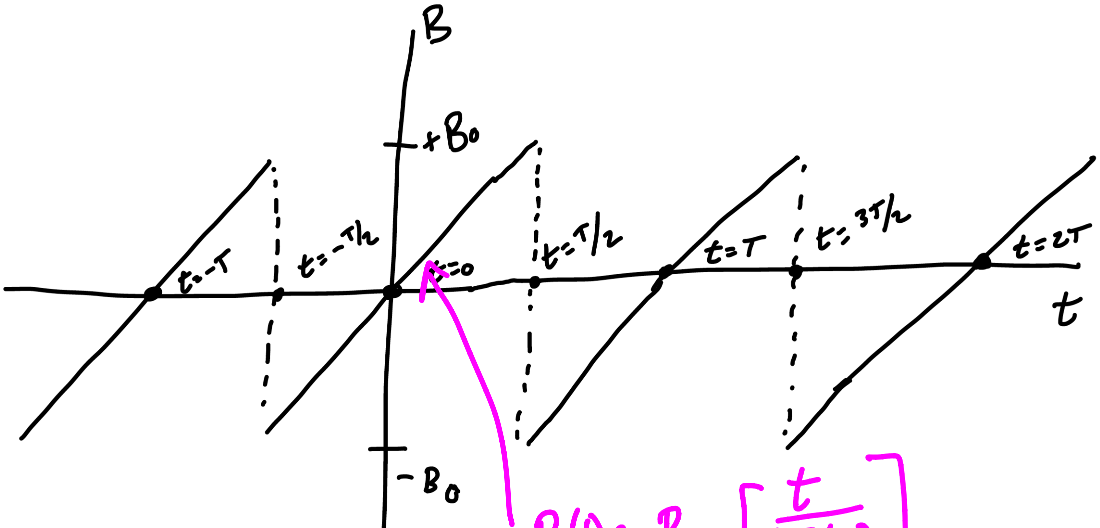
What is the <u>average</u> power dissipated in the resistor in terms of L, R, ω, and V_0?

$$P = I_{rms}^2 R$$

$$= \left(\frac{V_{rms}}{Z}\right)^2 R$$

$$\boxed{P = \left(\frac{V_0^2}{2}\right) \frac{R}{R^2 + (\omega L)^2}}$$

6) (16 pts) We have routinely used the fact that a sinusoidally varying magnetic field with amplitude B_0 has a "root mean square" value of $B_{RMS} = \frac{1}{\sqrt{2}} B_0$. Suppose that instead of a sine function, the time dependence was linear over each period, T, changing from a value $B=-B_0$ to $B=+B_0$ as shown below:



$$B(t) = B_0\left[\frac{t}{(T/2)}\right]$$

The dotted lines are sudden jumps from $+B_0$ to $-B_0$. This is called a "Sawtooth" wave. What is B_{RMS} for this kind of oscillation? (Hint: Using only the piece that goes through the origin may be the easiest way.)

$$B_{rms} \equiv \sqrt{\frac{1}{T}\int_{-T/2}^{+T/2}\left\{B_0 \frac{t}{(T/2)}\right\}^2 dt}$$

$$= \sqrt{B_0^2 \frac{1}{T}\frac{4}{T^2}\int_{-T/2}^{T/2} t^2 dt}$$

$$= \sqrt{B_0^2 \frac{4}{T^3}\left.\frac{t^3}{3}\right]_{-T/2}^{T/2}}$$

$$= \sqrt{B_0^2 \cancel{4}\, \frac{\cancel{T^3}}{\cancel{T^3}}\, (\cancel{2})\left(\frac{1}{3}\right)\left(\cancel{\frac{1}{8}}\right)}$$

$$= \boxed{\frac{1}{\sqrt{3}} B_0}$$

Note $\frac{1}{\sqrt{3}} < \frac{1}{\sqrt{2}}$ because $\sin x$ spends more time near maximum than x does.