MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.014 Electrodynamics

	Issued:	April 30, 2002
Problem Set 12	Due in Recitation:	May 10, 2002

Suggested Reading: *Notes for Lectures 19-22 (both slides and text).*
Prof. Bers's notes, pp 1-5, 23-56.

Problem 12.1

A one-micron wavelength laser diode is forward biased with 1-ma current.

a) If every physical process in this diode were 100-percent efficient and ideal, what then is the maximum optical power output we could expect from this laser? A numerical answer is expected.

b) If this laser has a cavity 1-mm long and its permittivity is $\varepsilon = 9\varepsilon_o$, how far apart (Hz) are its resonant frequencies?

Problem 12.2

A four-level fiber amplifier has a pump wavelength of 0.4 microns (between levels 1 and 3) and an operating wavelength of 1.6 microns (between levels 2 and 4) (see Fig. L19-5).

a) If this amplifier were 100-percent efficient and ideal in every aspect, what is the maximum ratio of output to input power that could be expected? A numerical answer is desired.

b) If the amplifier of part (a) were operated so as to have the maximum possible gain, what would be the relative populations of levels 1, 2, 3, and 4?

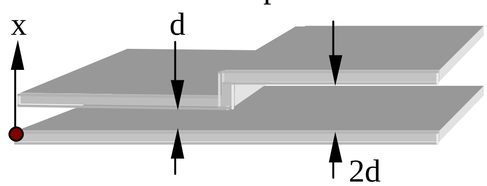
c) If $A_{41} >> A_{32} >> A_{24}$ for the otherwise ideal amplifier of part (a), approximately what value of A_{32} would reduce the maximum conceivable amplifier gain (dB/m) by ~one-half, assuming the amplifier output is one watt? [Hint: the gain is proportional to the population of state 2, assuming A_{41} is large; see Fig. L19-5.]

Problem 12.3.

A certain MEMS actuator mirror steers reflected laser beams when electrostatic forces between two parallel conducting plates of area A deflect it.

a) Starting from the Lorentz force law, $\overline{f} = q(\overline{E} + \overline{v} \times \overline{H}\mu_o)$ [Newtons], find the force between the plates if they have V volts across them and separation d.

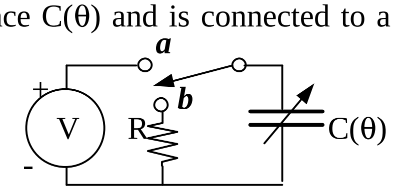
b) Find this force on the bottom plate if one of the two plates is not flat, but bent as shown; half the area has plate separation d, and the other half has separation 2d.



c) Repeat (b) by calculating the force using energy derivatives, where the energy is related to the capacitance C of the structure. If the force you find is attractive, then probably your answer is too.

Problem 12.4

Consider an ideal electrostatic 4-segment device similar to that of Figure L20-7, where the stator and rotor have zero overlap when θ = 0, and perfect overlap when θ = 90°. The rotor has a diameter of 2 mm and is being driven at a constant shaft speed of 500,000 rpm. This variable-capacitor device has capacitance C(θ) and is connected to a V = 10-volt battery through a switch, as illustrated.



a) If the switch is continuously connected to the battery, what is the charge Q(t) on C? Please sketch and dimension your answer.

b) For case (a), sketch and dimension the torque T(θ) [Nm] applied to the rotor and the environment. On average, is this a motor, generator, or something else?

c) Sketch on the graph (b) an additional line indicating at what times the switch should be in position ***a*** or ***b*** in order to maximize the time-average torque on the rotor so that it could be used as a motor.

d) What numerical value of R (ohms) might you recommend to maximize the time-average torque for part (c)?

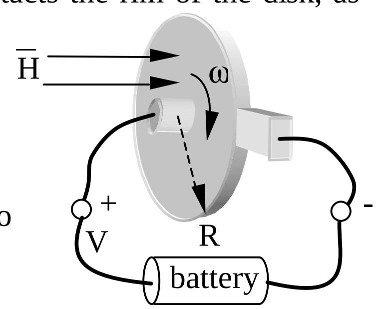
e) What is the time-average mechanical power P delivered by this motor of part (d)?

f) For the optimum motor of part (d), what fraction of the battery power is converted to useful work, and what fraction is lost in the resistor?

g) Replacing the resistor by an inductor L that stores energy can avoid the resistive loss found in (f). This inductor is then disconnected from the capacitor as soon as the capacitor charge reaches zero the first time, and before the rotor rotates another 90^o, when the switch will again return to position ***a***. Clever switching can then use this stored magnetic energy to partially recharge the battery and boost motor efficiency. What value of L might you recommend for this? Briefly explain your reasoning. Similar energy switching is responsible for the fact that semiconductor circuits often dominate high-efficiency small magnetic motor costs, except that capacitors are usually used instead of inductors.

Problem 12.5

A homopolar generator consists simply of a conducting disk (rotor) of radius R spinning at ω radians/s in a uniform magnetic field H. One output terminal is connected to the rotor axle and the other to a stationary brush that contacts the rim of the disk, as illustrated.



a) What is the open-circuit voltage V?

b) If the battery (V volts) being charged by this generator draws I amperes, what is the torque T [Nm] required to keep the rotor spinning at constant ω?

c) What is the mechanical power P_m delivered to this generator?

d) What is the electrical power P_e into the battery as it charges? Explain any discrepancy between your answers to (c) and (d).