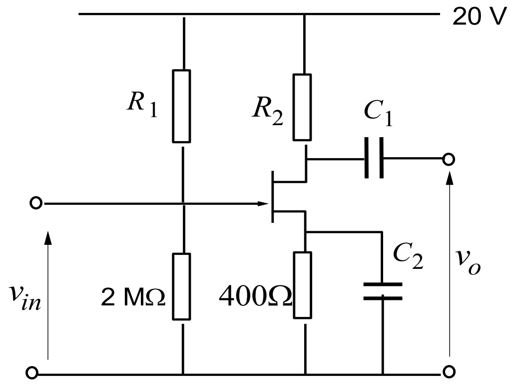
Part 1A paper 3 (Electrical) 2017. Section A Crib

Q1



R1 = 16/4. 2MΩ = **8MΩ**

R2 = 10/2 . 400 = **2kΩ**

$g_m = 5$, C2 = ∞, Gain = $-g_m.\dfrac{r_d R_L}{r_d + R_L}$ = **-9.52**

Q2. go from right to left.

3ohm//6ohm = 2ohm. V' = 6V.

2 + 6 ohm = 8 ohm.

8ohm//8 ohm = 4 ohm, V'' = 3V.

4 ohm + 4 ohm = 8 ohm, 8 ohm// 8 ohm = 4 ohm, V' = 1.5 V.

4 ohm + 16 ohm = 20 ohm.

6 V – 1.5 V = 4.5 V. I = 4.5/20 = **0.225 A**.

Q3 (a) advantages of negative feedback - **a well-defined gain**, reduced distortion, low output impedance, high input impedance (in one configuration), higher cutoff frequency.

b) mid-band gain = (R1+R2)/R2 = **10**

output impedance at output of Amp itself ~ 0 ohm

3dB frequency is when the load capacitance starts to short-circuit the load resistance R4.

$f_T = 1/(2.\pi.75.10^{-9}) = 1/(471\text{x } 10^{-9})$ = **2.12 MHz**.

4(a) Thevenin – replace circuit by voltage source V1 in series with resistor R1,

V1 = open circuit resistance V_{oc}

Short circuit current = I_{sc}, $R1 = V_{oc}/I_{sc}$.

Norton – replace circuit by current source I1 in parallel with resistance R1,

$I1 = I_{sc}$, $R1 = V_{oc}/I_{sc}$.

For the example of fig 4, Voc = 5V, R1 = 10 ohm.

Isc = 0.5 Amp, R1 = 10 ohm.

(b)(i) R, L part -

$X1 = 1.27\text{x}10^{-6}$ x 2π x 5.10^5j = 4j, so Z1 = 4 + 4j.

Z2 = R2//X2. 1/X2 = j 2π. $5.10^5.1.59.10^{-7}$. = j0.5 = j/2.

Z2 = 2(1/(1+j))[(1-j)/(1-j)] = 2x 0.5 x (1-j) = 1-j.

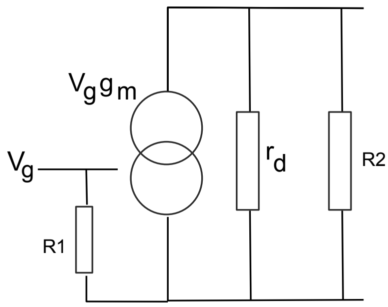
note the values are meant to give nice round numbers.

Ztot = 4(1+j) + (1-j) = **5 + 3j**

(ii) f = $1/2\pi$. $(1.27\text{e-}6 \text{ x } 1.59\text{e-}7)^{1/2}$ = **2.25 MHz**

(iii) V = **2 V**

5) a)



input impedance = **R1**

Gain = $\mathbf{g_m R_2/(1 + g_m R_2)}$ note, should be just less than 1.

Output impedance = **$R2/(1+g_m R_2)$.** Note, should be a lot less than R2, that is the point of a source-follower.

Zin = **20 MΩ, G = 0.978**. Zout = **65 Ω**.

Purpose = low output impedance, high input impedance, drive large current.

6 (short)

(a) The Boolean expression for exclusive-NOR gate can be written as:

$\overline{A \cdot \overline{B} + \overline{A} \cdot B}$

$= \left(\overline{A \cdot \overline{B}}\right) \cdot \left(\overline{\overline{A} \cdot B}\right)$

$= \left(\overline{A} + \overline{\overline{B}}\right) \cdot \left(\overline{\overline{A}} + \overline{B}\right)$

$= (\overline{A} + B) \cdot (A + \overline{B})$

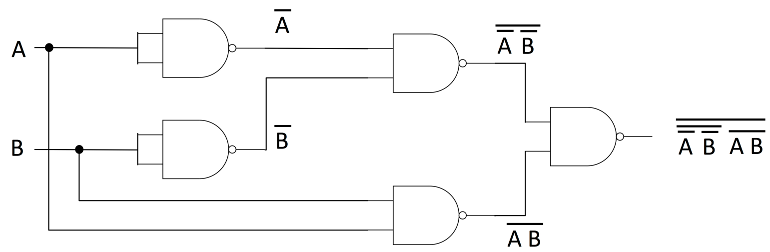
$= \overline{A} \cdot \overline{B} + A \cdot B$

Implementation using NAND gates:

$\overline{A} \cdot \overline{B} + A \cdot B$

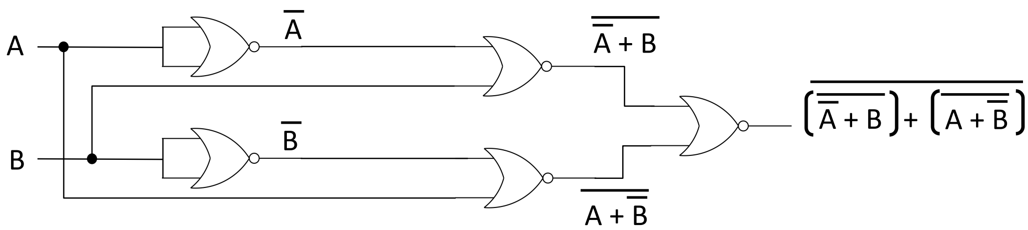
$= \overline{\overline{\overline{A} \cdot \overline{B} + A \cdot B}}$

$= \overline{\overline{(\overline{A} \cdot \overline{B})} \cdot \overline{(A \cdot B)}}$



Implementation using NOR gates:

$(\overline{A} + B) \cdot (A + \overline{B})$



7 (short)

(a) Considering ideal OP-Amp, the inverting terminal is a virtual ground. Hence, the voltages at the inputs D_0-D_4 contribute to currents to the summing junction and is inversely proportional to the corresponding resistor values. Thus, V_{out} is also inversely proportional to these resistors.

Drawbacks are:

- Resistor accuracy requirement is very high.
- Difficult to implement the resistors because of their size, especially for DACs with higher bit count.
- May require the use of different materials for different resistors due to their wide variation in values. This may result in drifting of values with temperature.

(b) When all inputs are set, the resolution is 1/($2^4 - 1$) = 1/15 = 6.67%.

$$V_{out[1001]} = -\left[\frac{10\times5}{25} + \frac{10\times5}{200}\right]V = -2.25V$$

$$V_{out[1011]} = -\left[\frac{10\times5}{25} + \frac{10\times5}{100}\right]V = -2.75V$$

Change is V_{out} = - 0.05 V.

8 (short)

(a)

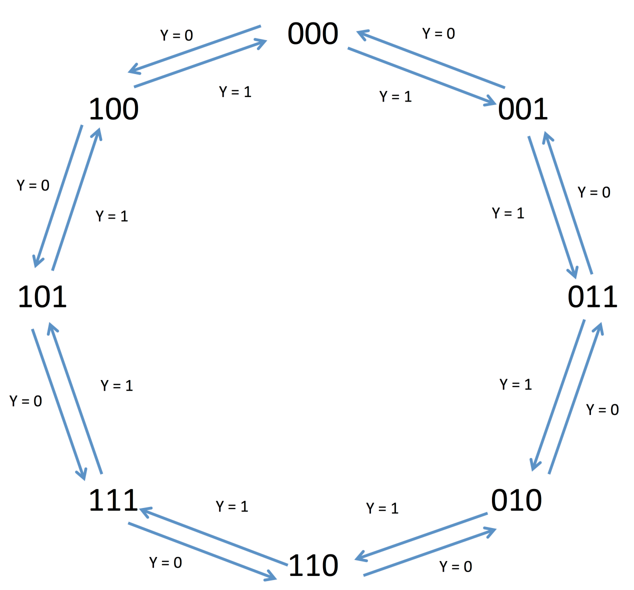
main	**movlw 111 ;**	moves decimal 111 to w
	movwf 0x33 ;	moves content of w (111) into loc. 0x33
	movf 0x30, W ;	move content of 0x30 (unknown) into w
	call label ;	calls subroutine 'label'
	movwf 0x32 ;	moves content of w (10) to 0x32
	btfsc 0x32, 2 ;	test bit2 (Z), if zero, skips next instruction
	clrf 0x33 ;	clears content of 0x33
	……..	
label	**subwf 0x31, W ;**	subtracts w from contents of 0x31
	return ;	returns to main program

(b) Contents:

0x32 = 10 (decimal)
0x33 = 111 (decimal)
Bit 2 in status register (Z flag) = 0

9 (long)

(a) Consider: control input = Y. The state diagram will be:



(b) The state transition table:s

Q_2	Q_1	Q_0	Q_{2+}	Q_{1+}	Q_{0+}	Q_{2+}	Q_{1+}	Q_{0+}
Present State			Next State Y=0			Next State Y = 1		
0	0	0	1	0	0	0	0	1
0	0	1	0	0	0	0	1	1
0	1	1	0	0	1	0	1	0
0	1	0	0	1	1	1	1	0
1	1	0	0	1	0	1	1	1
1	1	1	1	1	0	1	0	1
1	0	1	1	1	1	1	0	0
1	0	0	1	0	1	0	0	0

(c) Resulting Karnaugh maps:

Q_2Q_1 \ Q_0Y	00	01	11	10
00	1	0	0	0
01	0	1	0	0
11	X	X	X	X
10	X	X	X	X

J2 Map

Q_2Q_1 \ Q_0Y	00	01	11	10
00	X	X	X	X
01	X	X	X	X
11	1	0	0	0
10	0	1	0	0

K2 Map

Q_2Q_1 \ Q_0Y	00	01	11	10
00	0	0	1	0
01	X	X	X	X
11	X	X	X	X
10	0	0	0	1

J1 Map

Q_2Q_1 \ Q_0Y	00	01	11	10
00	X	X	X	X
01	0	0	0	1
11	0	0	1	0
10	X	X	X	X

K1 Map

Q_2Q_1 \ Q_0Y	00	01	11	10
00	0	1	X	X
01	1	0	X	X
11	0	1	X	X
10	1	0	X	X

J0 Map

Q_2Q_1 \ Q_0Y	00	01	11	10
00	X	X	0	1
01	X	X	1	0
11	X	X	0	1
10	X	X	1	0

K0 Map

Thus, the Boolean expressions are:

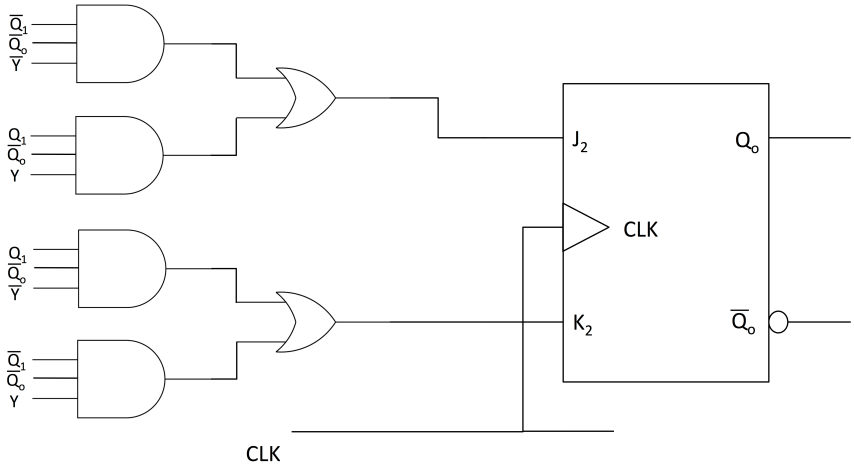
$J_2 = \overline{Q}_1\overline{Q}_0\overline{Y} + Q_1\overline{Q}_0Y$
$K_2 = Q_1\overline{Q}_0\overline{Y} + \overline{Q}_1\overline{Q}_0Y$
$J_1 = \overline{Q}_2Q_0Y + Q_2Q_0\,\overline{Y}$
$K_1 = Q_2Q_0Y + \overline{Q}_2Q_0\,\overline{Y}$

$J_0 = \overline{Q}_2\overline{Q}_1Y + \overline{Q}_2Q_1\overline{Y} + Q_2\overline{Q}_1\overline{Y} + Q_2Q_1Y$
$K_0 = \overline{Q}_2\overline{Q}_1\overline{Y} + \overline{Q}_2Q_1Y + Q_2Q_1\overline{Y} + Q_2\overline{Q}_1Y$

(c) Gates required for this design:

1 inverter (for control input Y)
3 JK bistables
16 3-input NAND gates
4 2-input NOR gates and 2 4-input NOR gates

Implementation:



Numerical answers:

7(b)
6.67%, - 0.5V

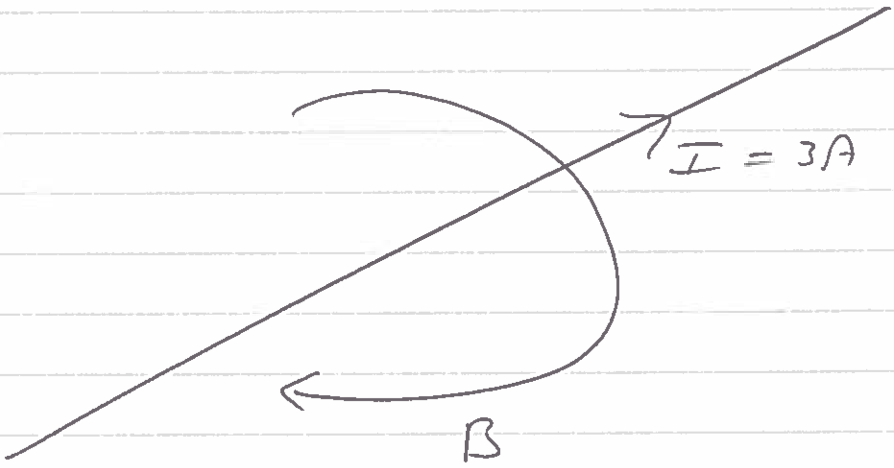
8(b)
0x32 = 10 (decimal), 0x33 = 111 (decimal), Z flag = 0.

9(d)
1 x inverter (for control input Y)
3 x JK bistables
16 x 3-input NAND gates
4 x 2-input NOR gates and 2 x 4-input NOR gates
Note: Other combinations possible.

Paper 3 . Section C

C

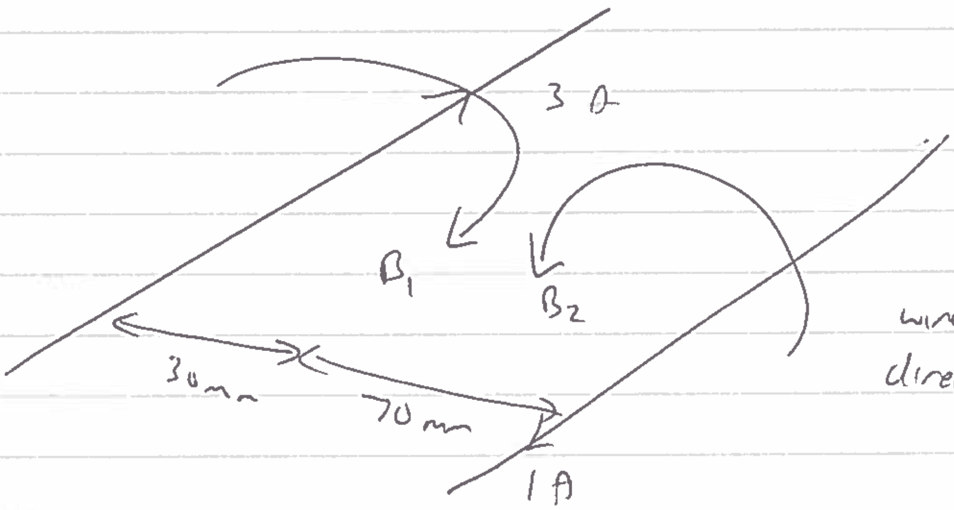
16) a)



$\bar{B}$ circulates the wire $|B| = \dfrac{\mu_0 I}{2\pi r}$

$= \dfrac{4\pi \times 10^{-7} \times 3}{2\pi \times (100\times10^{-3})} = 6\times10^{-6}\,T$

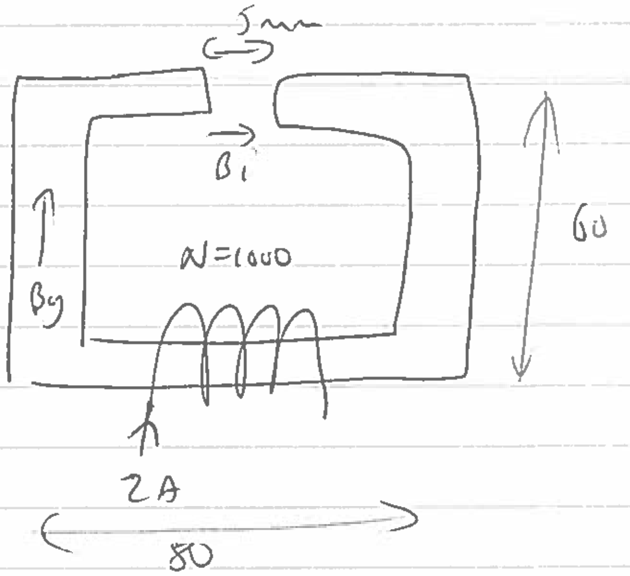
b)



Between the wires B in same direction ⇒ adds

$B_T = B_1 + B_2 = \dfrac{4\pi\times10^{-7}}{2\pi}\left(\dfrac{3}{30\times10^{-3}} + \dfrac{1}{70\times10^{-3}}\right) = 2.3\times10^{-5}\,T$

11) a)



$A = 100\,mm^2$

Amperes Law $\quad \sum Hl = NI$ $\quad i = \text{iron}$, $g = \text{gap}$

$\Rightarrow H_i l_i + H_g l_g = NI$

In the air gap $\quad B_g = \mu_0 H_g$

Flux conservation (no fringing fields)

$B_g = B_i$

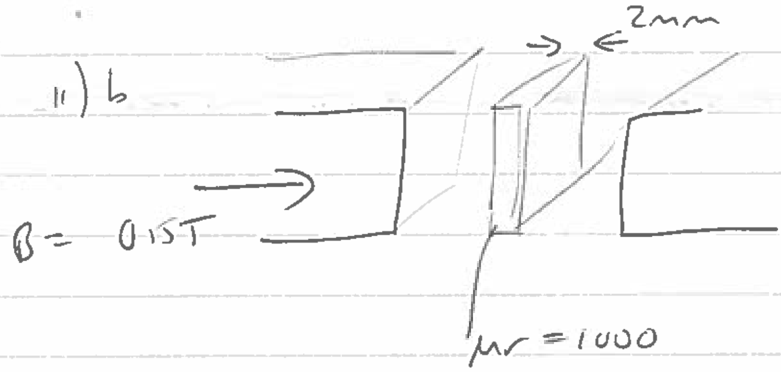
$$\Rightarrow H_i l_i + \frac{B_i l_g}{\mu_0} = NI$$

$l_i = 80 + 80 + 60 + 60 - 5 = 275\,mm$

$\Rightarrow 0.275\, H_i = 2000 - 4000\, B_i$

From data book graph $\quad B = 0.5\,T$

ii) b



A/C $\quad H_i l_i + H_m l_m + H_g l_g = NI$ $\quad$ m ≡ metal sheet

From flux conservation $B_i = B_g = B_m$

$$\Rightarrow H_i l_i + \frac{B_i l_m}{\mu_0 \mu_r} + \frac{B_i l_g'}{\mu_0} = NI$$

$$H_i l_i + \frac{B_i}{\mu_0}\left[\frac{l_m}{\mu_r} + l_g'\right] = NI$$

negligible

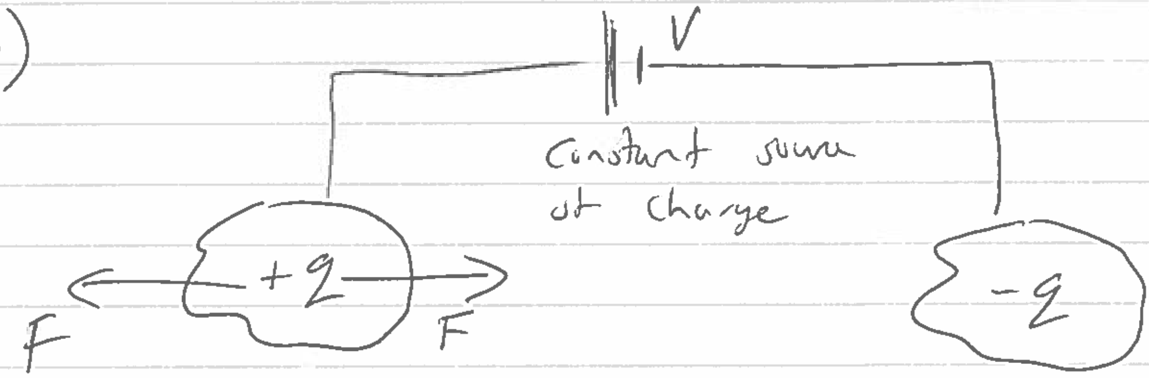
$$l_g' = 5 - 2 = 3\text{mm}$$

$$\Rightarrow 0.275 H_i = 2000 - 2400 B_i$$

From graph $B_g = B_i = 0.8$ T

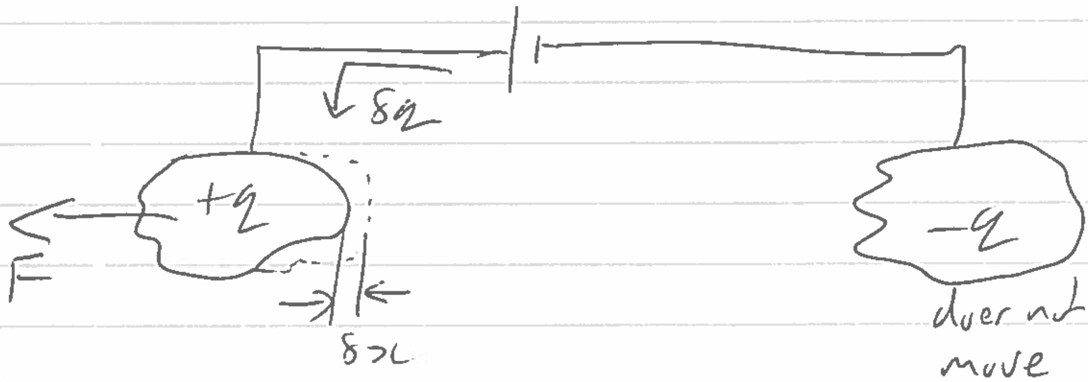
12) a) Electrostatic equillibrium is maintaned between two charge objects. In order to do this a restoring force must act on the objects. If one of the objects then moves a distance δx then work is done $(-F\delta x)$ mechanically. To maintain equillibrium, the battery with constant voltage must do work $(\delta q V)$ and there is also a change in the electrostatic energy in the complete system $(\frac{1}{2}\delta q V)$.

b)



Attractive force F is balanced by restoring force $(-F)$ to maintain equilibrium

If left hand object moves a distance δx



$\Rightarrow$ Mechanical work $= -F\delta x$

Work done by battery $= \delta q V$

Change in electrostatic energy $= \frac{1}{2} q V$ (only one charge moves)

⇒ These energy changes must balance assuming constant V

⇒ Mech work + work by battery = changes in electrostatic energy

$$-F\delta x + \delta q V = \tfrac{1}{2}\delta q V$$

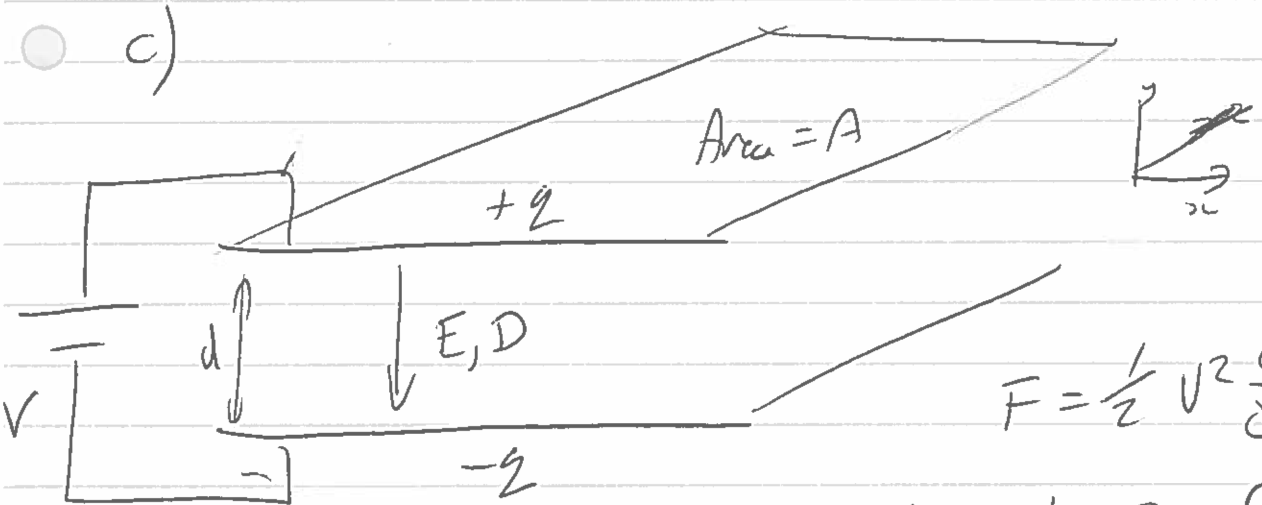
$$\Rightarrow -F\delta x = -\tfrac{1}{2}\delta q V$$

$$F = \frac{1}{2} V \frac{\delta q}{\delta x}$$

$$q = CV \Rightarrow \frac{\delta q}{\delta x} = V\frac{\delta C}{\delta x}$$

$$\Rightarrow F = \frac{1}{2} V^2 \frac{\delta C}{\delta x}$$

c)



$$F = \frac{1}{2} V^2 \frac{\partial C}{\partial y}$$

⇒ want $C = f(y)$

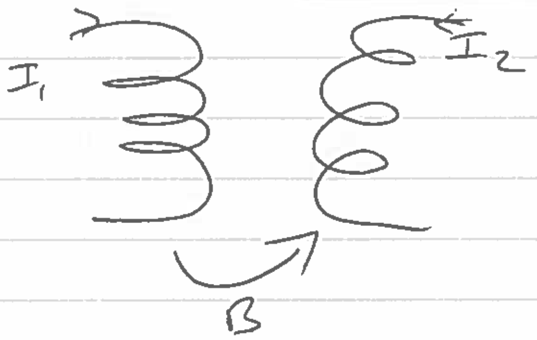
Parallel plate capacitor $C = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon_0 A}{y}$

$$\frac{\partial C}{\partial y} = \frac{-\varepsilon_0 A}{y^2}$$

$$\Rightarrow F = \frac{-1}{2} V^2 \frac{\varepsilon_0 A}{y^2} = \frac{-1}{2} V^2 \frac{\varepsilon_0 A}{d^2}$$

$$C = \frac{\varepsilon_0 A}{d} \Rightarrow F = \frac{-1}{2} V^2 \frac{C}{d}$$

d)



$$\phi_1 = L_1 I_1 + M I_2$$

$$\phi_2 = L_2 I_2 + M I_1$$

$$V_1 = \frac{d\phi_1}{dt} = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt}$$

$$V_2 = \frac{d\phi_2}{dt} = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt}$$

$$P_{ow} = VI = \frac{dW}{dt} = V_1 I_1 + V_2 I_2$$

$$= L_1 I_1 \frac{dI_1}{dt} + M I_1 \frac{dI_2}{dt} + L_2 I_2 \frac{dI_2}{dt} + M I_2 \frac{dI_1}{dt}$$

$$= \frac{L_1}{2} \frac{d(I_1^2)}{dt} + \frac{L_2}{2} \frac{d(I_2^2)}{dt} + M \frac{d(I_1 I_2)}{dt}$$

$$\Rightarrow W = \underbrace{\frac{1}{2} L_1 I_1^2}_{self_1} + \underbrace{\frac{1}{2} L_2 I_2^2}_{self_2} + \underbrace{M I_1 I_2}_{mutual}$$

When evaluating virtual work, there is a restoring force between the coils which means that when a coil moves a distance δx the only change in energy between the coils is due to their mutual inductance M. The self inductance terms remain constant when the coils move with respect to each other, hence the force between them must only depend on their mutual inductance.