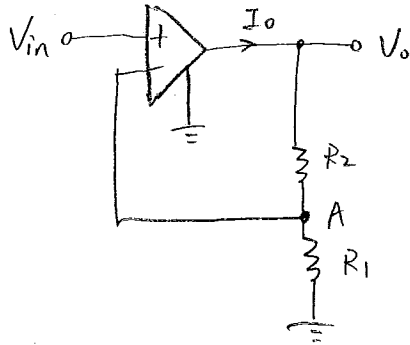


Q1: Determine the gain of the amplifier $\frac{V_o}{V_{in}}$. What is the value of I_o .



$$V_A = V_{in} \quad I_{in} = 0$$

KCL at A:

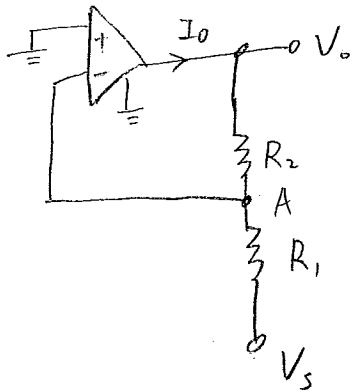
$$\frac{V_{in}}{R_1} + \frac{V_{in} - V_o}{R_2} = 0$$

$$\left(\frac{1}{R_1} + \frac{1}{R_2}\right) V_{in} = \frac{1}{R_2} V_o$$

$$\frac{V_o}{V_{in}} = \frac{\frac{1}{R_1} + \frac{1}{R_2}}{\frac{1}{R_2}} = \frac{R_1 + R_2}{R_1 R_2} \cdot R_2 = \frac{R_1 + R_2}{R_1}$$

$$I_o = \frac{V_o}{R_1 + R_2} = \frac{V_{in}}{R_1}$$

Q2: Find $\frac{V_o}{V_s}$ and I_o .



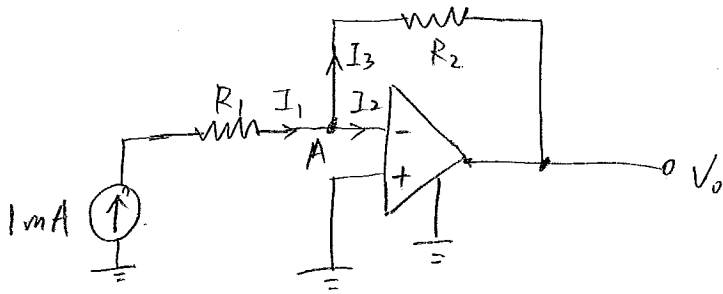
$$V_A = 0V$$

$$\text{KCL at A: } \frac{0 - V_s}{R_1} + \frac{0 - V_o}{R_2} = 0$$

$$\frac{V_o}{V_s} = \frac{-R_2}{R_1}$$

$$I_o = \frac{V_o}{R_2}$$

Q3: find I_1 , I_2 and I_3



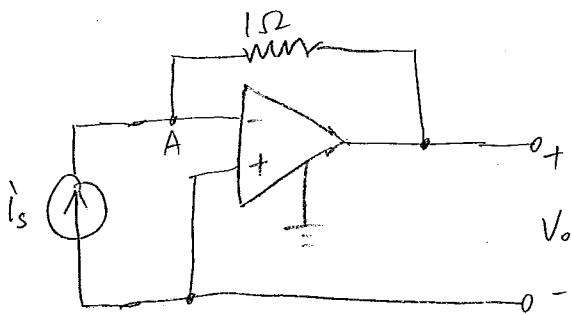
$$V_A = V_- = V_+ = 0V, \quad I_1 = 1mA, \quad I_2 = 0$$

$$\text{KCL at A: } I_1 = I_3 + I_2$$

$$1mA = I_3 + 0$$

$$\therefore I_3 = 1mA$$

Q4: find $\frac{V_o}{i_s}$

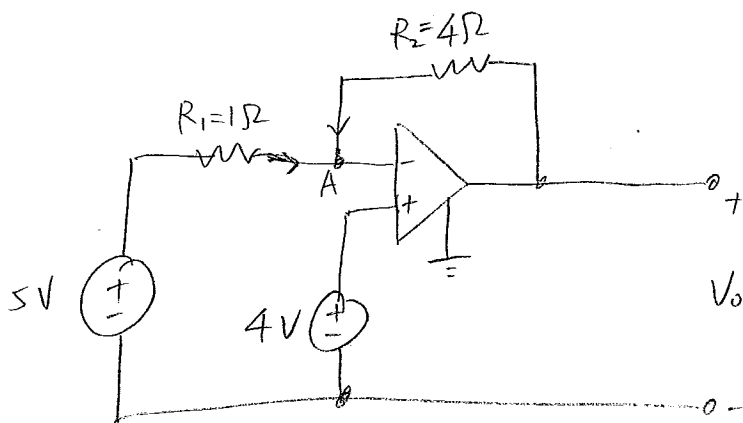


$$V_A = 0V$$

$$\text{KCL at A: } i_s = \frac{0 - V_o}{1\Omega}$$

$$\frac{V_o}{i_s} = -1\Omega$$

Q5 Find V_o



$$V_A = V_- = V_+ = 4V$$

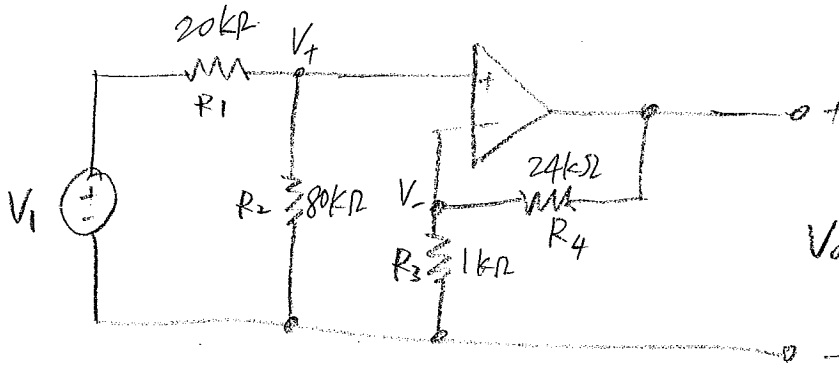
KCL at A

$$\frac{5V - 4V}{R_1} + \frac{V_o - 4V}{R_2} = 0$$

$$\frac{1}{1} + \frac{V_o - 4}{4} = 0$$

$$V_o = 0V$$

Q 6. Find the voltage gain $\frac{V_o}{V_i}$



$$\text{KCL at } V_+ \quad \frac{V_+ - V_i}{R_1} + \frac{V_+ - 0}{R_2} = 0$$

$$\frac{V_+ - V_i}{20k\Omega} + \frac{V_+}{80k\Omega} = 0$$

$$4V_+ - 4V_i + V_+ = 0$$

$$V_i = \frac{5}{4} V_+$$

$$\text{KCL at } V_- \quad \frac{V_- - 0}{R_3} + \frac{V_- - V_o}{R_4} = 0$$

$$\frac{V_-}{1k\Omega} + \frac{V_- - V_o}{24k\Omega} = 0$$

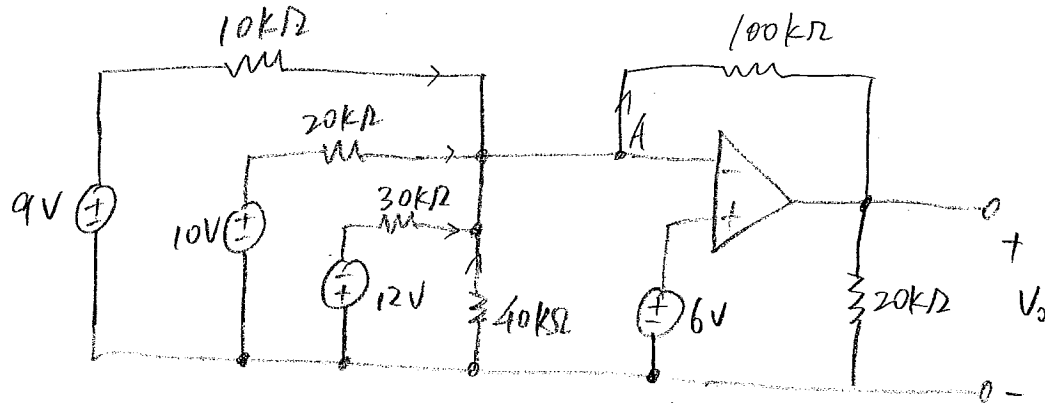
$$24V_- + V_- - V_o = 0$$

$$V_o = 25V_-$$

Ideal op-amp: $V_+ = V_-$

$$\frac{V_o}{V_i} = \frac{25V_-}{\frac{5}{4}V_+} = 20$$

Q7. Find V_o



$$V_+ = 6V$$

$$V_- = V_+ = 6V$$

KCL at A :

$$\frac{9V-6V}{10k\Omega} + \frac{10V-6V}{20k\Omega} + \frac{-12V-6V}{30k\Omega} + \frac{0-6V}{40k\Omega} = \frac{6V-V_o}{100k\Omega}$$

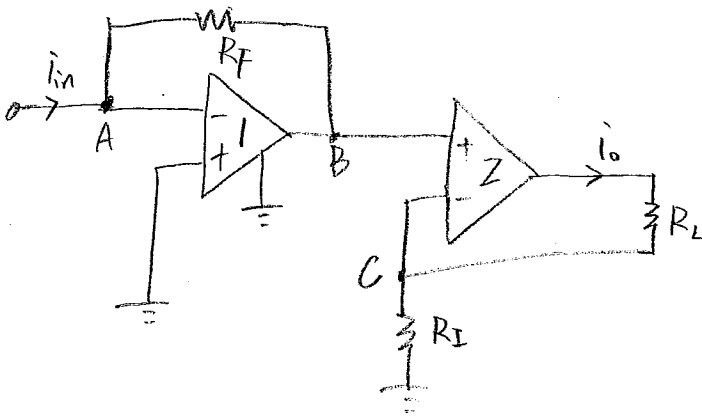
$\times 1200 k\Omega$

$$3 \times 120 + 4 \times 60 - 18 \times 40 - 6 \times 30 = (6 - V_o) \times 12$$

$$360 + 240 - 720 - 180 = (6 - V_o) \times 12$$

$$V_o = 6 + \frac{300}{12} = 6 + 25 = 31V$$

Q8 Find $\frac{i_o}{i_{in}}$



op-amp 1: $V_A = V_- = V_{i+} = 0$

KCL at A: $i_{in} = \frac{V_A - V_B}{R_F} = \frac{-V_B}{R_F}$

$$V_B = -i_{in} R_F$$

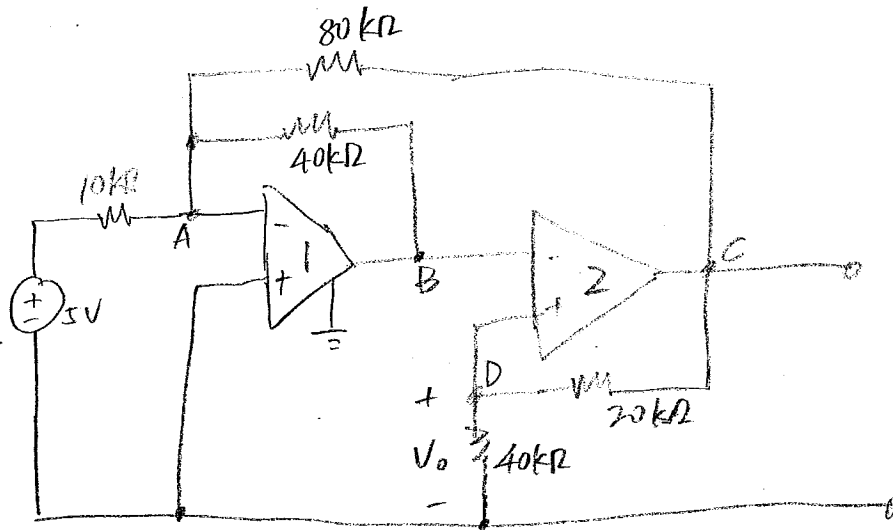
op-amp 2: $V_C = V_B$

KCL at C:

$$i_o = \frac{V_C - 0}{R_I} = \frac{V_B}{R_I} = \frac{-i_{in} R_F}{R_I}$$

$$\frac{i_o}{i_{in}} = -\frac{R_F}{R_I}$$

Q9. Find V_o



$$\text{op-amp 1 : } V_A = V_{i-} = V_{i+} = 0$$

$$\text{KCL at A : } \frac{V_A - 5V}{10k\Omega} + \frac{V_A - V_B}{40k\Omega} + \frac{V_A - V_C}{80k\Omega} = 0$$

(x 80)

$$40 + 2V_B + V_C = 0 \quad (1)$$

$$\text{op-amp 2 : } V_o = V_{2+} = V_{2-} = V_B$$

$$\text{KCL at D : } \frac{V_o}{40k\Omega} + \frac{V_o - V_C}{20k\Omega} = 0$$

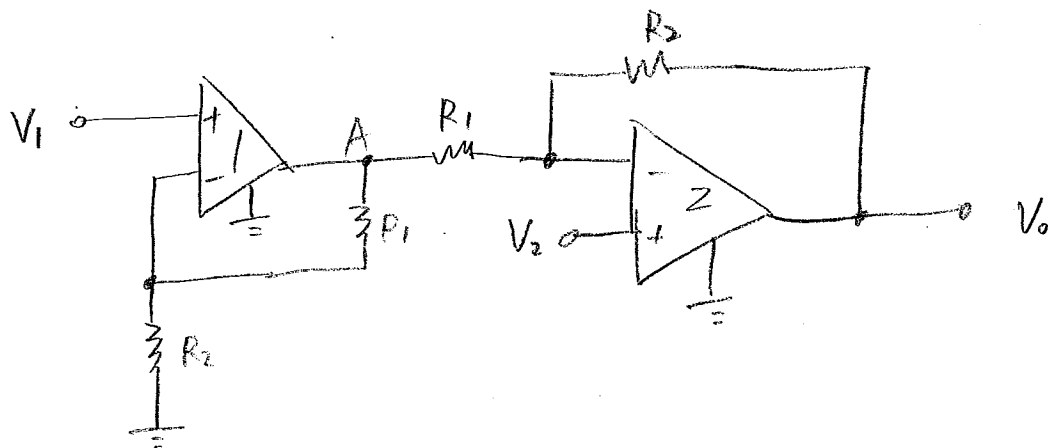
$$V_o + 2V_o - 2V_C = 0 \quad (2)$$

(1) x 2 + (2)

$$80 + 4V_B + 3V_o = 0$$

$$V_o = -\frac{80}{7} V$$

Q.10. Find V_o



KCL at V_1 of the first op-amp:

$$\frac{V_1}{R_2} + \frac{V_1 - V_A}{R_1} = 0 \quad \Rightarrow \quad V_A = \left(\frac{V_1}{R_2} + \frac{V_1}{R_1} \right) \cdot R_1 = \left(\frac{R_1}{R_2} + 1 \right) V_1$$

KCL at V_2 of the second op-amp:

$$\frac{V_2 - V_A}{R_1} + \frac{V_2 - V_o}{R_2} = 0$$

$$V_o = \left(\frac{V_2}{R_2} + \frac{V_2 - V_A}{R_1} \right) \cdot R_2$$

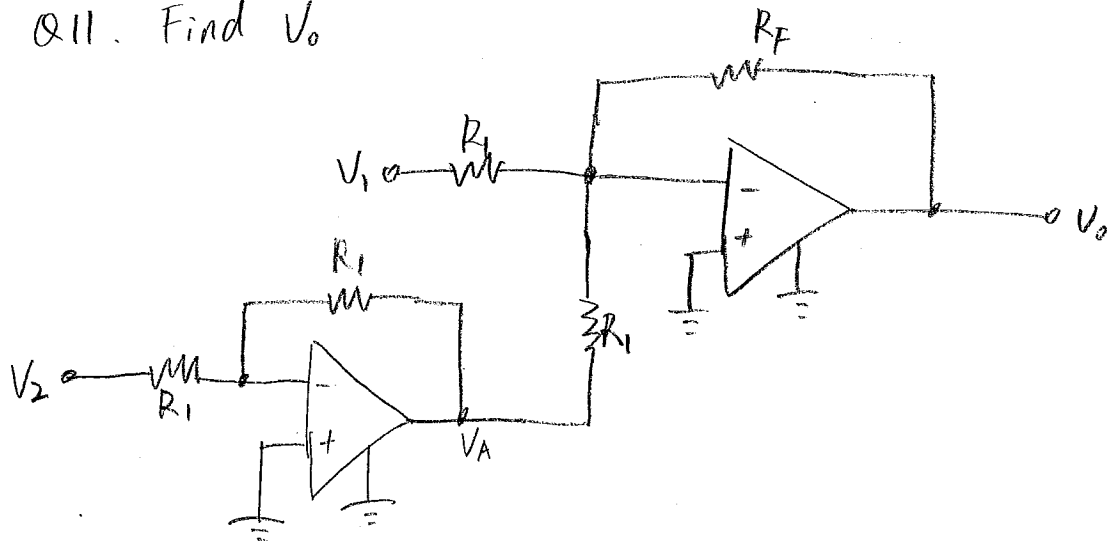
$$= \left(1 + \frac{R_2}{R_1} \right) V_2 - \frac{R_2}{R_1} \cdot V_A$$

$$= \left(1 + \frac{R_2}{R_1} \right) V_2 - \frac{R_2}{R_1} \cdot \left(\frac{R_1}{R_2} + 1 \right) V_1$$

$$= \left(1 + \frac{R_2}{R_1} \right) V_2 - \left(1 + \frac{R_2}{R_1} \right) V_1$$

$$= \left(1 + \frac{R_2}{R_1} \right) (V_2 - V_1)$$

Q11. Find V_o



KCL at V_- of the first op-amp:

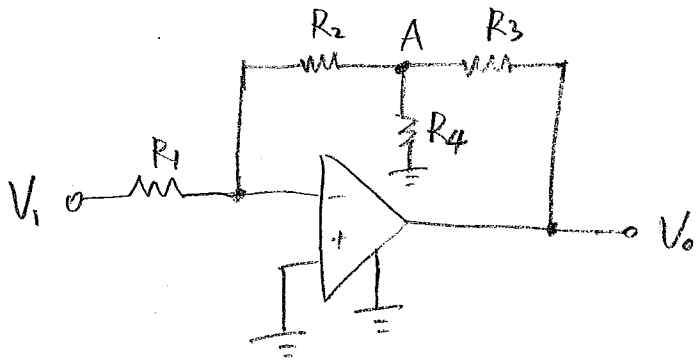
$$\frac{0 - V_2}{R_1} + \frac{0 - V_A}{R_1} = 0 \Rightarrow V_A = -V_2$$

KCL at V_- of the second op-amp:

$$\frac{0 - V_1}{R_1} + \frac{0 - V_A}{R_1} + \frac{0 - V_o}{R_F} = 0$$

$$V_o = R_F \cdot \frac{-V_1 - V_A}{R_1} = \frac{R_F}{R_1} (V_2 - V_1)$$

Q12. Find V_o



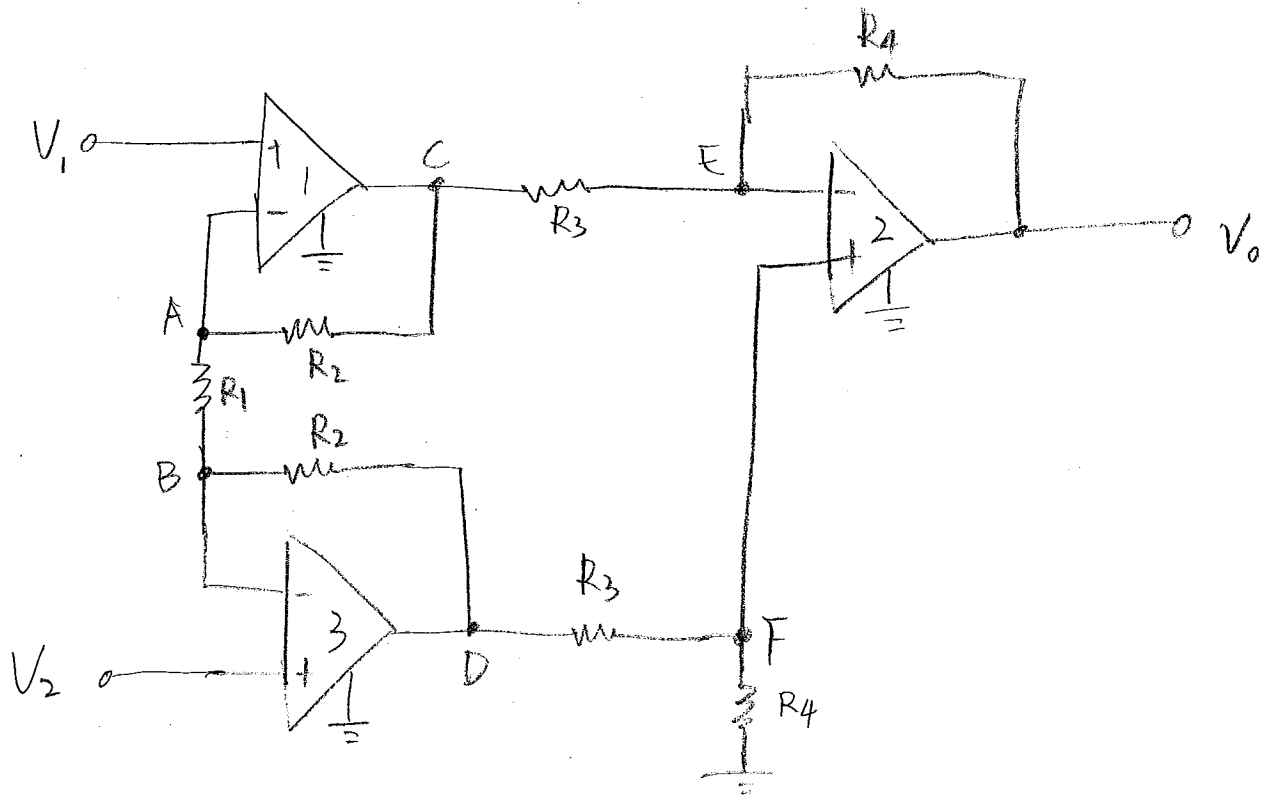
$$\text{KCL at } V_i: \quad \frac{0 - V_i}{R_1} + \frac{0 - V_A}{R_2} = 0 \Rightarrow V_A = -\frac{R_2}{R_1} V_i$$

$$\text{KCL at } A \quad \frac{V_A - 0}{R_2} + \frac{V_A - 0}{R_4} + \frac{V_A - V_o}{R_3} = 0$$

$$V_o = R_3 \left(\frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{R_3} \right) \cdot V_A$$

$$= -\frac{R_2 R_3}{R_1} \left(\frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{R_3} \right) V_i$$

Q13. Find V_o



$$\text{KCL at A: } \frac{V_1 - V_C}{R_2} + \frac{V_1 - V_2}{R_1} = 0 \Rightarrow V_C = R_2 \left(\frac{1}{R_2} + \frac{1}{R_1} \right) V_1 - \frac{R_2}{R_1} V_2$$

$$= \left(1 + \frac{R_2}{R_1} \right) V_1 - \frac{R_2}{R_1} V_2$$

$$\text{KCL at B: } \frac{V_2 - V_1}{R_1} + \frac{V_2 - V_D}{R_2} = 0 \Rightarrow V_D = R_2 \left(\frac{1}{R_1} + \frac{1}{R_2} \right) V_2 - \frac{R_2}{R_1} V_1$$

$$= \left(1 + \frac{R_2}{R_1} \right) V_2 - \frac{R_2}{R_1} V_1$$

$$\text{KCL at F: } \frac{V_F - V_D}{R_3} + \frac{V_F}{R_4} = 0 \Rightarrow V_F = \frac{R_4}{R_3 + R_4} V_D$$

$$V_E = V_F$$

$$\text{KCL at E: } \frac{V_E - V_C}{R_3} + \frac{V_E - V_o}{R_4} = 0 \Rightarrow V_o = \left(\frac{1}{R_3} + \frac{1}{R_4} \right) R_4 V_E - \frac{R_4}{R_3} V_C$$

$$V_o = \left(\frac{R_4}{R_3} + 1 \right) \cdot \frac{R_4}{R_3 + R_4} V_D - \frac{R_4}{R_3} V_C = \frac{R_4}{R_3} V_D - \frac{R_4}{R_3} V_C = \frac{R_4}{R_3} (V_D - V_C)$$

$$= \frac{R_4}{R_3} \cdot \left(1 + \frac{2R_2}{R_1} \right) (V_2 - V_1)$$