CONTENT STATEMENTS associated with ANALOGUE ELECTRONICS

[1] State that an op-amp can be used to increase the voltage of a signal.

[2] State that for the ideal op-amp:

(a) input current is zero, i.e. it has infinite input resistance.
(b) there is no potential difference between the inverting and non-inverting inputs: i.e. both input pins are at the same potential.

[3] Identify circuits where the op-amp is being used in the inverting mode.

[4] State that an op-amp connected in the inverting mode will invert the input signal.

[5] State the inverting-mode gain equation $\frac{V_0}{V_1} = -\frac{R_f}{R_1}$

[6] Carry out calculations using the above gain expression.

[7] State that an op-amp cannot produce an output voltage greater than the positive supply voltage or less than the negative supply voltage.

[8] Identify circuits where the op-amp is being used in the differential mode.

[9] State that a differential amplifier amplifies the potential difference between its two inputs.

[10] State the differential mode gain equation $V_o = (V_2 - V_1) \times \frac{R_f}{R_1}$

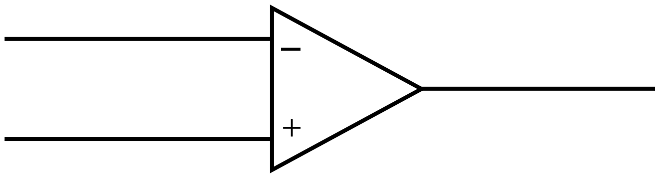
[11] Carry out calculations using the above gain equation.

[12] Describe how to use the differential amplifier with resistive sensors connected in a Wheatstone bridge arrangement.

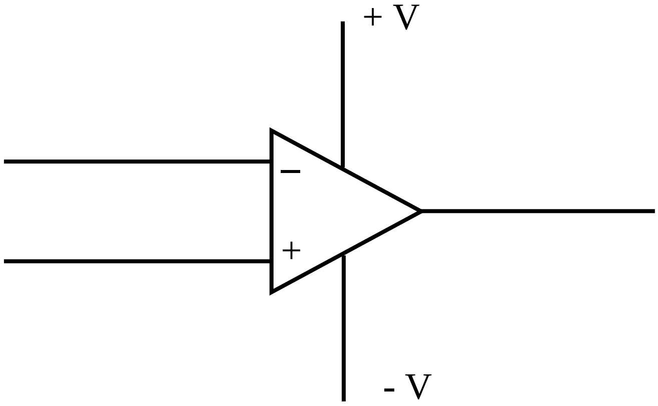
[13] Describe how an op-amp can be used to control external devices via a transistor.

Op-Amps

Op-amps (operational amplifiers) can be used to increase the voltage of a signal.



Remember that op-amps have a power supply across the terminals, but this is rarely drawn as it would clutter circuit diagrams.



Op-amps have enormous gains, but are NEVER used without feedback.

The Golden Rules for Op-amps

1. The voltage difference between the inputs is zero.

2. The inputs draw no current.

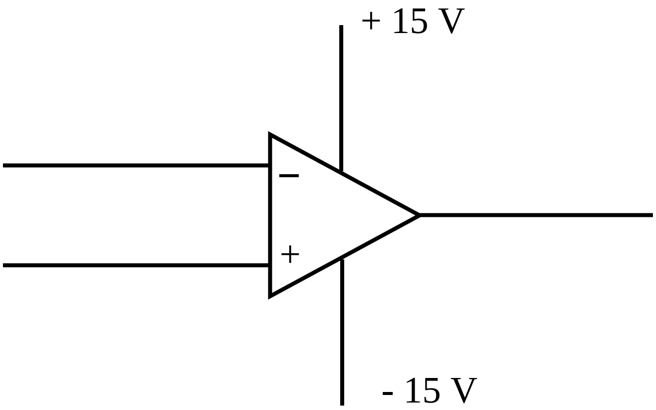
It is best if you don't ask any questions on this one – just learn it!

Or learn it as:

i) Input current is ZERO, i.e. it has an infinite input resistance.

ii) There is no p.d. between the inverting and non-inverting pins, i.e. both pins are at the same potential.

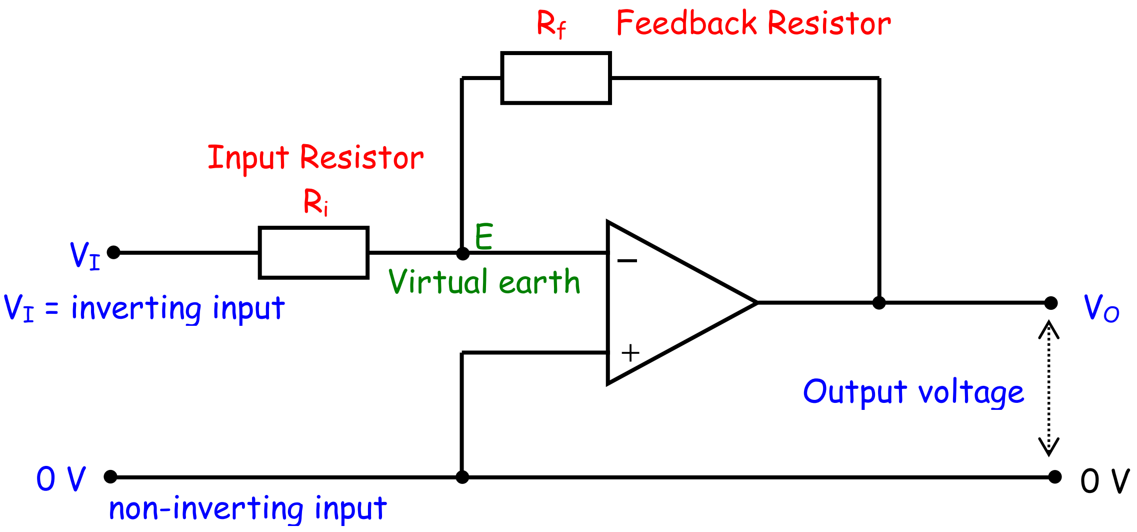
AN OP-AMP CANNOT PRODUCE AN OUTPUT VOLTAGE GREATER THAN THE POSITIVE SUPPLY OR LESS THAN THE NEGATIVE SUPPLY.



Maximum output	=	+ 15 V
Minimum output	=	- 15 V

In reality it would be quite a bit less than this, but this is what the SQA demand! For a ±15V supply the maximum/minimum voltage would be about ±13V

Inverting Mode Op-Amps

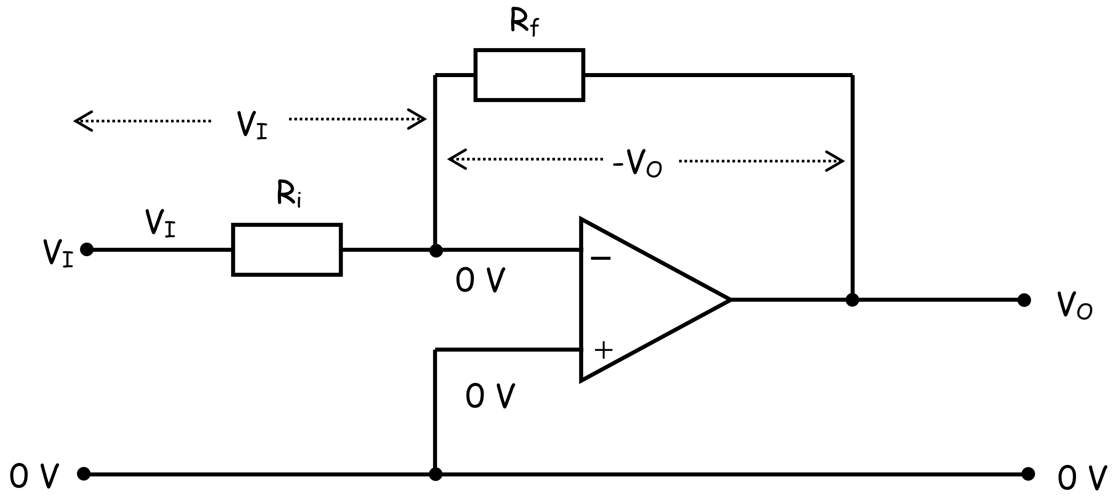


How to tell if your op-amp is in inverting mode:

1. Two resistors (!?);

2. Positive of the op-amp (non-inverting input) is at zero volts.

Inverting Mode Op-Amps



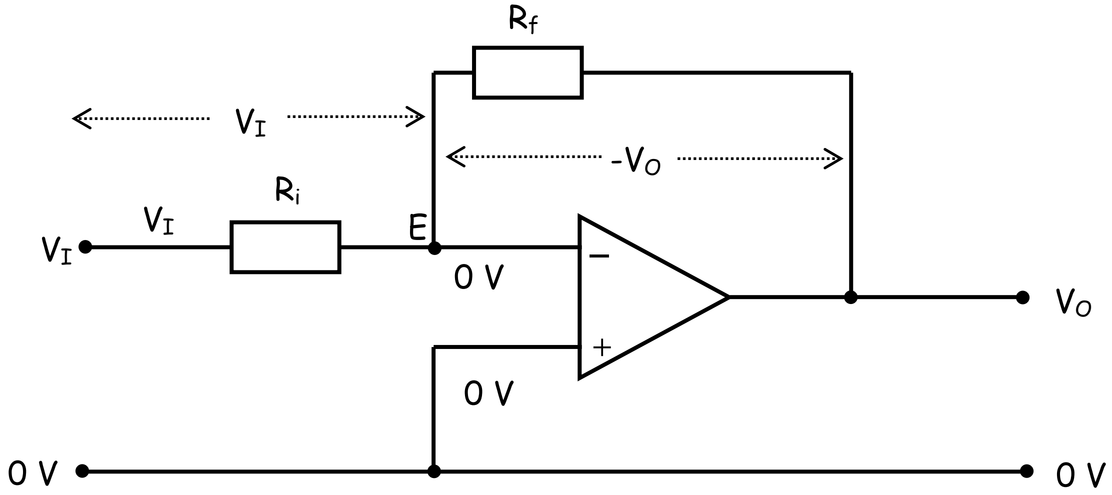
How to tell if your op-amp is in inverting mode:

1. Two resistors (!?);

2. Positive of the op-amp (non-inverting input) is at zero volts.

Deriving the Gain equation for INVERTING MODE

NO LONGER NECESSARY TO DERIVE!



1. E, the virtual earth is at 0 V.

2. The p.d. between V_I and E is V_I volts (i.e. across R_i)

3. The p.d. across R_f is $-V_O$.

$V_I = IR_i$ and $-V_O = IR_f$

BUT Golden Rule 1. says that the current is the same in both resistors. Thus:

$$I = \frac{V_I}{R_i} = \frac{-V_O}{R_f}$$

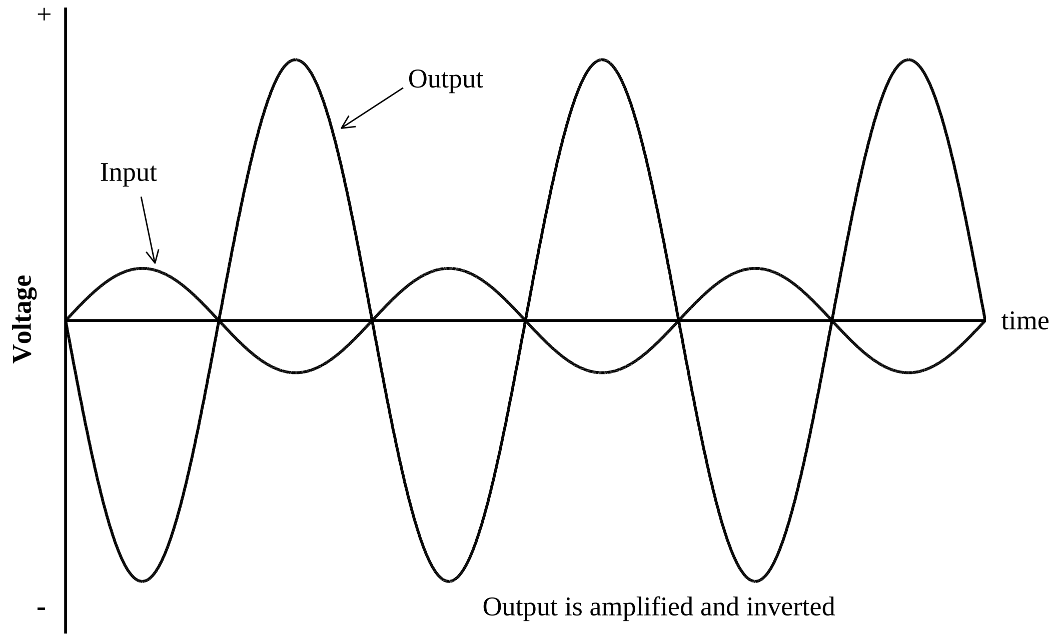
Amplification is the RATIO of V_O to V_I.

$$\text{Gain or } Amplification = \frac{V_O}{V_I} = \frac{-R_f}{R_i}$$

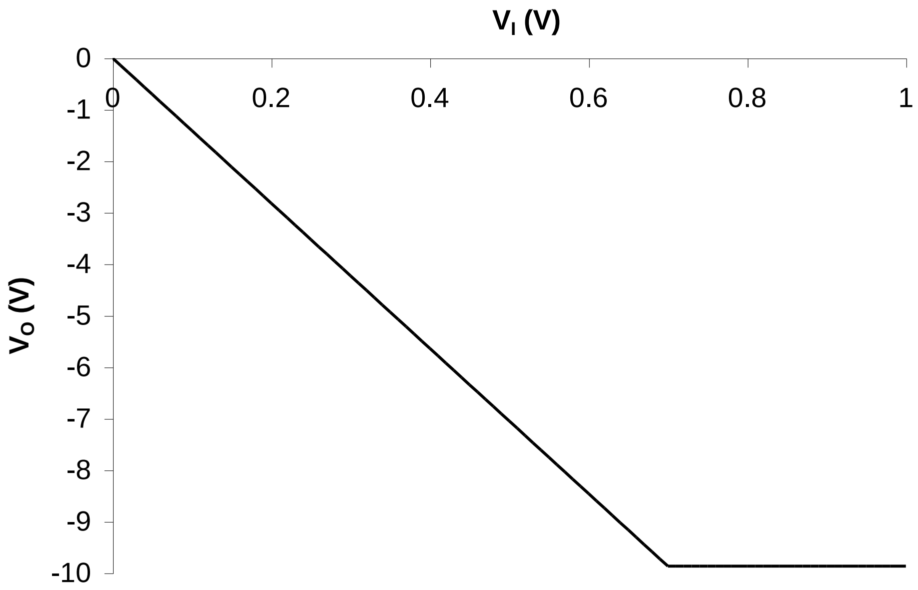
$$V_O = \frac{-R_f}{R_i} \times V_I$$

N.B. IN THIS MODE THE SIGNAL V_O IS INVERTED.

Inverting the Output Signal



Op-amps from Graphs



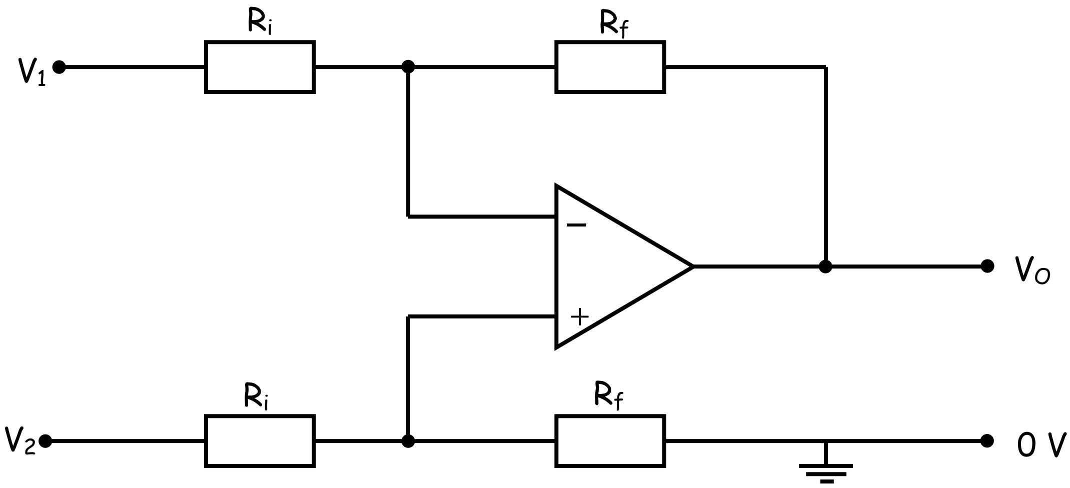
Must be in inverting mode.

$$G = \frac{V_O}{V_I}$$

Flattens out due to SATURATION.

Thus the power supply to this op-amp MUST be ± 10 V.

Differential Mode



In differential mode the amplifier amplifies the p.d. between its 2 inputs (V_1 + V_2).

It is not necessary to derive the equation – just learn it!

Amplification in differential mode:

$V_O = \frac{R_f}{R_i}(V_2 - V_1)$ where V_2 is the positive and V_1 the negative connection.

As an aside, this equation becomes the inverting mode equation if V_2 is connected to 0 V.

$$V_O = \frac{R_f}{R_i}(V_2 - V_1)$$

$$V_O = \frac{R_f}{R_i}(0 - V_1)$$

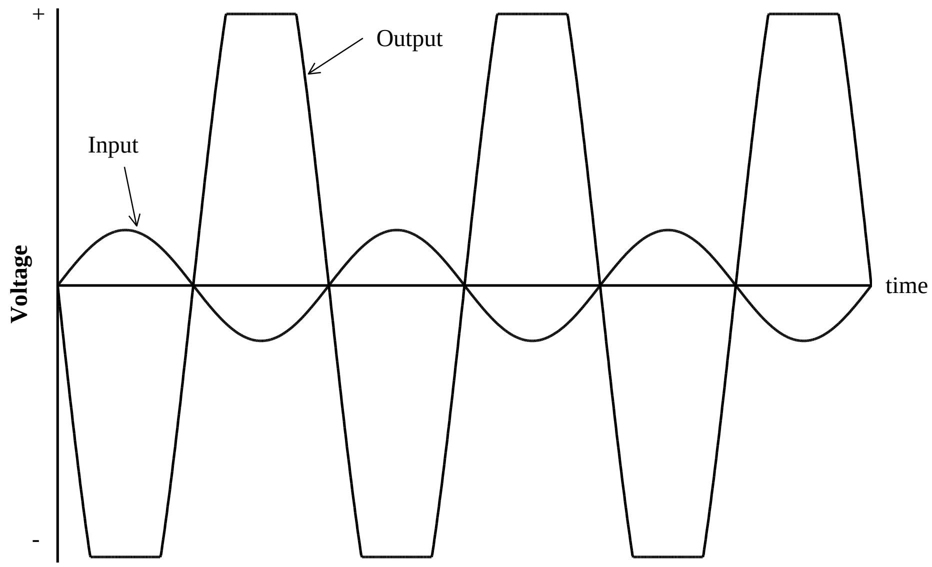
$$V_O = -\frac{R_f}{R_i}V_1$$

What limits V_O?

1. SATURATION

The op-amp cannot produce an output voltage greater than the positive supply voltage or less than the negative supply voltage. (Think in terms of energy – where would the energy come from?).

If V_O ought to be larger than V_s then clipping occurs.

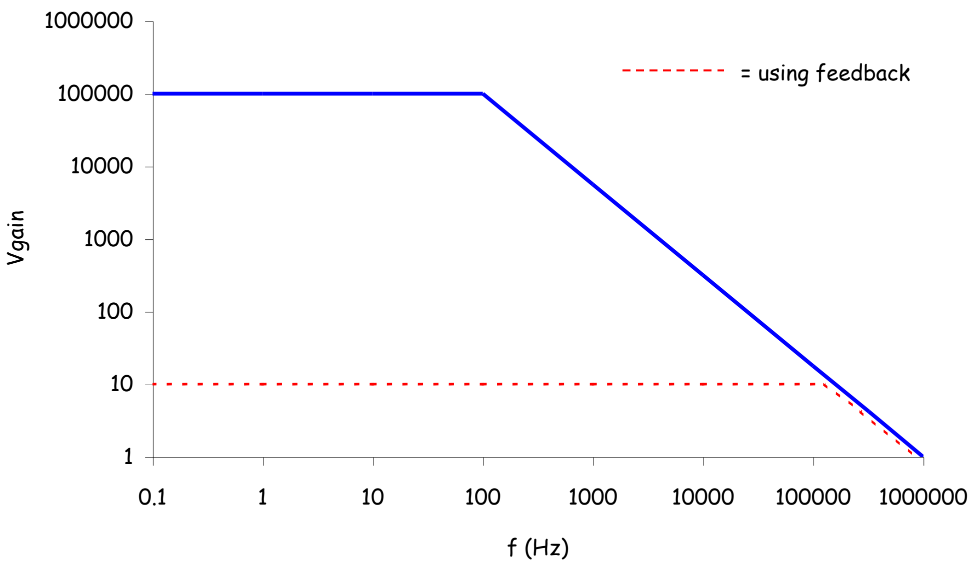


If the gain is very big then this can change an analogue signal into a digital (square wave) signal.

2. BANDWIDTH

Op-amps do not always amplify the same at all frequencies.

Bandwidth is the range of frequencies that can be amplified with constant gain.



If one input is negative it is possible to get the circuit to SUBTRACT one value from another.

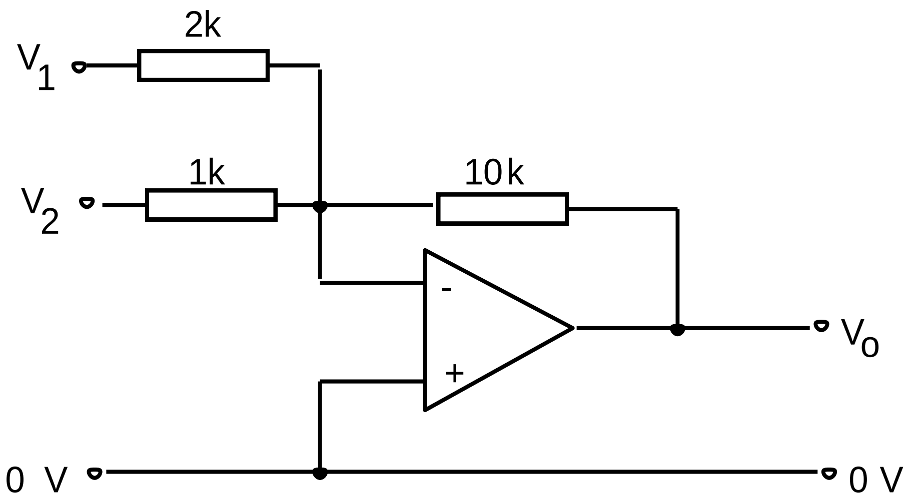
If R_i is different for each signal, the amplifier will amplify each signal with a different gain. (eg Lockerbie Academy Physics Course Tutorial 3 Q2 (see below))

$$V_o = \frac{-R_f}{R_i}(V_i) \qquad V_o = G \times (V_i)$$

$$V_o = \frac{+R_f}{R_i}(V_2 - V_1) \qquad V_o = G \times (V_2 - V_1)$$

$$V_o = \frac{R_f}{R_i}\Delta V \qquad V_o = G \times \Delta V$$

2.



What is the output voltage if,

a) V_1 is 0.5 volts and V_2 is zero?

b) V_2 is 0.8 volts and V_1 is zero?

c) V_1 is 0.5V and V_2 is 0.8V?

2 a)

$$G = \frac{-R_f}{R_i} \Rightarrow G_1 = \frac{-10}{2}$$

$$= -5$$

$$\Rightarrow V_o' = -5 \times 0.5$$

$$= -2.5$$

$$G_2 = \frac{-10}{1} = -10 \Rightarrow V_o' = -10 \times 0$$

$$= 0$$

Thus the actual output V_O = -2.5V + 0

= -2.5V

b) V_O = -8V + 0 = -8V

c) V_O = -2.5V + (-8V) = -10.5V

Use of Differential Mode Op-amps

The op-amp in this mode amplifies the difference between two voltages. It is widely used to monitor systems.

The op-amp in this mode can be connected across the bridge of a Wheatstone bridge and can replace the galvanometer.

Op-amps can also be used to control external devices.

This is usually done with the aid of a TRANSISTOR. This is because the output voltage of the op-amp is rarely big enough to provide a big enough current to power the devices. The V_O is usually big enough to power a transistor.

Refer to Higher Core Physics pp 117-119 for good examples (and pretty diagrams!) TO FOLLOW!!!!!!!

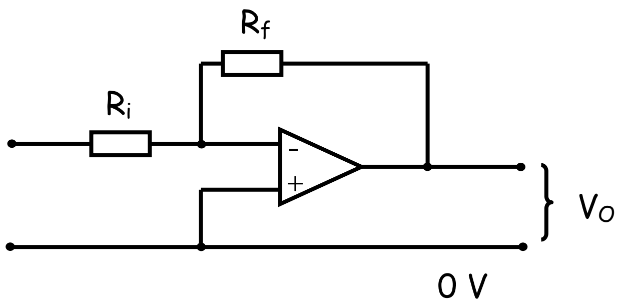
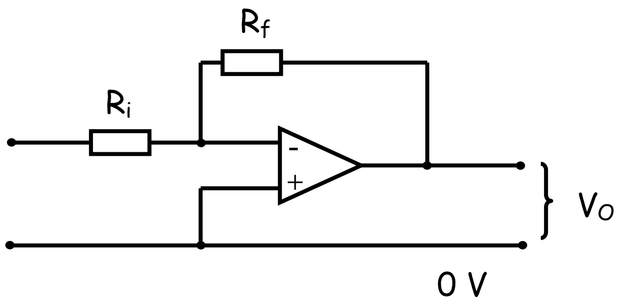
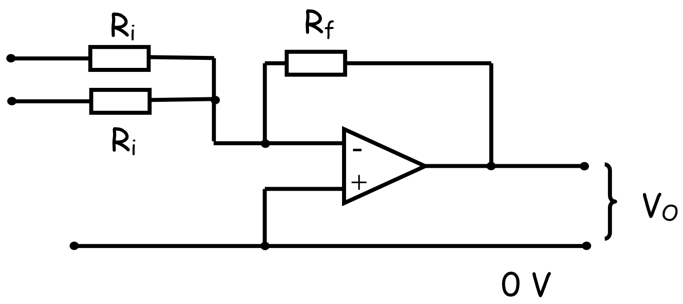
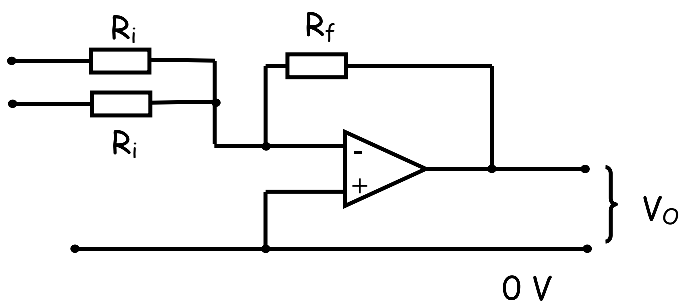
If R_f and R_i are not the same for both inputs then the amplifier will amplify each signal with a different gain.

You will have to work out each part separately (see above)

SUMMARY

Using op-amps to complete mathematic problems.

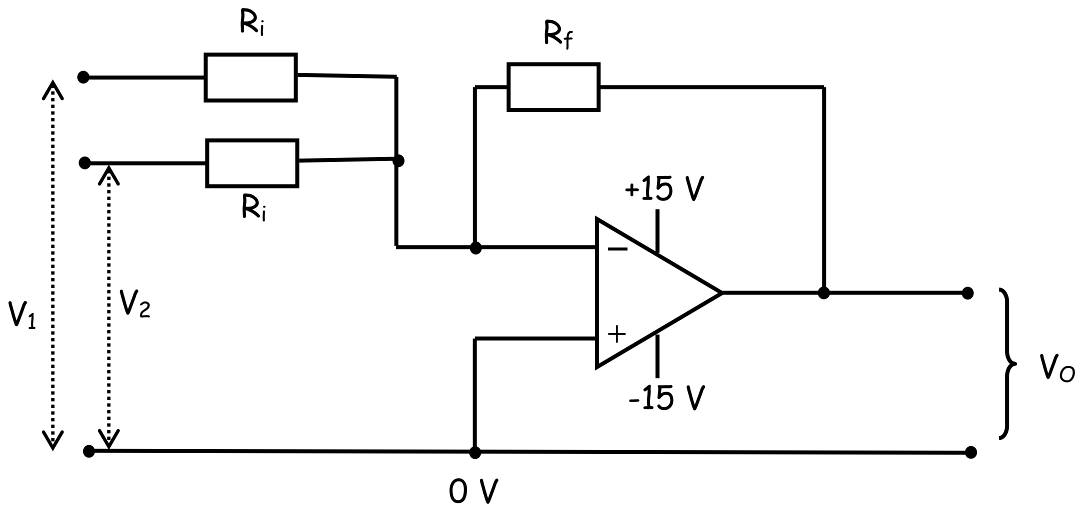
USE THE OP-AMP IN INVERTING MODE.

TASK	DIAGRAM	Notes
Multiply		R_f is > R_i by the value by which you want to multiply.
Divide		R_f is < R_i by the value by which you want to divide.
Add		Gain of –1 i.e. $R_f = R_i$
Subtract		Gain of –1 i.e. $R_f = R_i$ One input has a negative value, one input has a positive value.

Using Op-amps to add signals

The op-amp is set up in INVERTING MODE.

In this mode signals can be added together. the circuit is set up below.



NB. If you are not careful this circuit can easily be mistaken for differential mode. SO DO YOUR CHECKING.

The gain equation is used separately for EACH input and then the two inputs are added together separately.

If R_f = 10 kΩ, R_i and R_i are each 10 kΩ then:

$$G = \frac{-R_f}{R_i} = \frac{-10k\Omega}{10k\Omega} = -1$$

If V_1 = 3 V and V_2 = 1 V then the following occurs:

$$For\,V_1 : V_{o_1} = \frac{-R_f}{R_i}V_1 = \frac{-10k\Omega}{10k\Omega} \times 3 = -3\text{V}$$

$$For\,V_2 : \quad V_{o_2} = \frac{-R_f}{R_i}V_2 = \frac{-10k\Omega}{10k\Omega} \times 1 = -1\text{V}$$

$$V_o = V_{o_1} + V_{o_2} = -3 + -1 = -4 \text{ V}$$