HIGHER ENGINEERING SCIENCE

Analogue Electrical Engineering

TEACHERS BOOKLET

Ellon Academy
Technical Faculty

Learning Intentions

- I will learn to Design a voltage divider circuit to meet a given specification
- I will be able to use bipolar transistors as current amplifiers in a circuit
- I will be able to use bipolar transistors as a Darlington pair or in a Push/Pull Follower formation
- I will know how to use n-channel MOSFETs as voltage switching devices
- I will know how to perform calculations using 5 different types of operational amplifier
- I will know how to select an operational amplifier for a given purpose

Success Criteria

I can develop analogue electronic control systems by:

- Designing and constructing circuits using sensor inputs and BJT drivers
- Designing and constructing circuits using sensor inputs and MOSFET drivers
- Designing and constructing operational amplifier circuits
- Testing and evaluating analogue electronic solutions against a specification

YENKA is a free program you can download at home to build electronic circuits and help you with your studies

http://www.yenka.com/en/Free_student_home_licences/

A free website that you can use to simulate breadboarding
http://123d.circuits.io/

What is an Electrical Engineer?

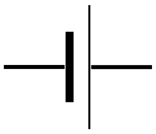
As we know engineering is vital to everyday life - it shapes the world in which we live and its future. Engineers play key roles in meeting the needs of society in fields which include climate change, medicine, IT and transport.

This booklet will focus on Electronic Engineering. Electronic Engineering is an exciting, cutting edge place to work. In the last 10 years alone we have seen the introduction of the iPhone, HDTV's, tablet computers, hybrid cars and 3D printers. All of these technologies are now common place in today's society. All these plus more have all been created by electronics engineers. Electronics are also getting smaller and smarter, allowing people to do more – often while they're on the go – soon people might be reading messages sent to each other through a pair of smart glasses!

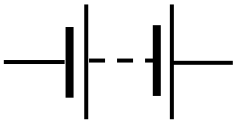
This unit will build on skills learned in National 5 Engineering Science in order to further deepen your understanding of Electronics to enable you to design your own working systems and give you a deeper insight into a possible career route.

www.tomorrowsengineers.org.uk/Electronics

Electrical and Electronic Graphical Symbols



Cell



Battery

Terminal

–

Negative Polarity

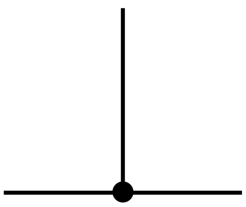
+

Positive Polarity

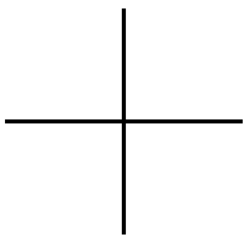
Alternating Current

A.C. Supply

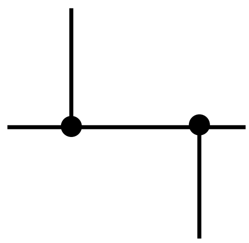
D.C. Supply



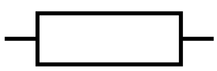
Junction of Conductors



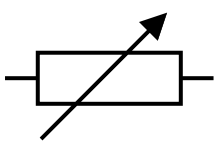
Crossing of Conductors with no Electrical Connection



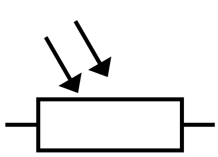
Double Junction of Conductors



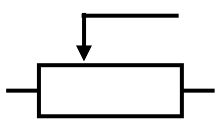
Resistor



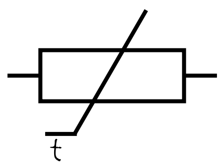
Variable Resistor



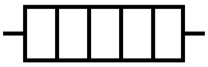
Light Dependant Resistor



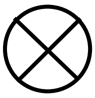
Potentiometer



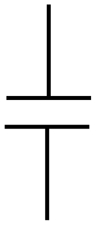
Thermistor



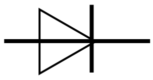
Heating Element



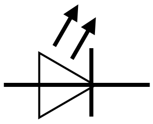
Lamp



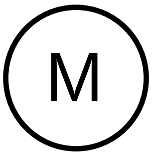
Capacitor



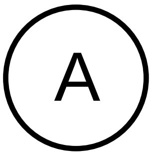
Semi-Conductor Diode



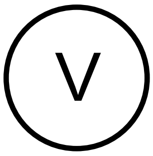
Light Emitting Diode



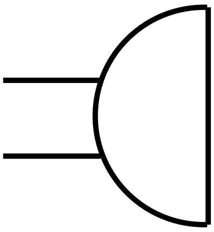
Motor



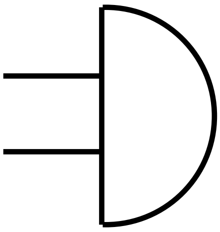
Ammeter



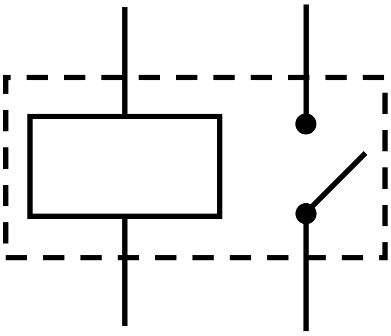
Voltmeter



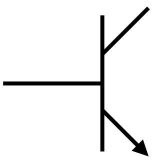
Buzzer



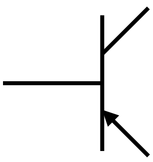
Bell



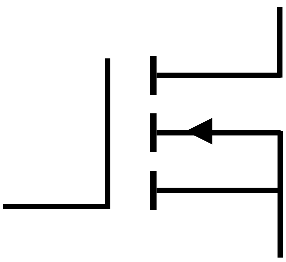
Relay



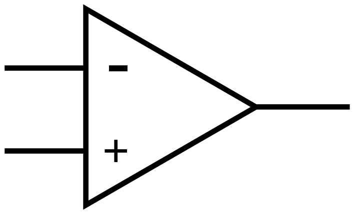
NPN Transistor



PNP Transistor



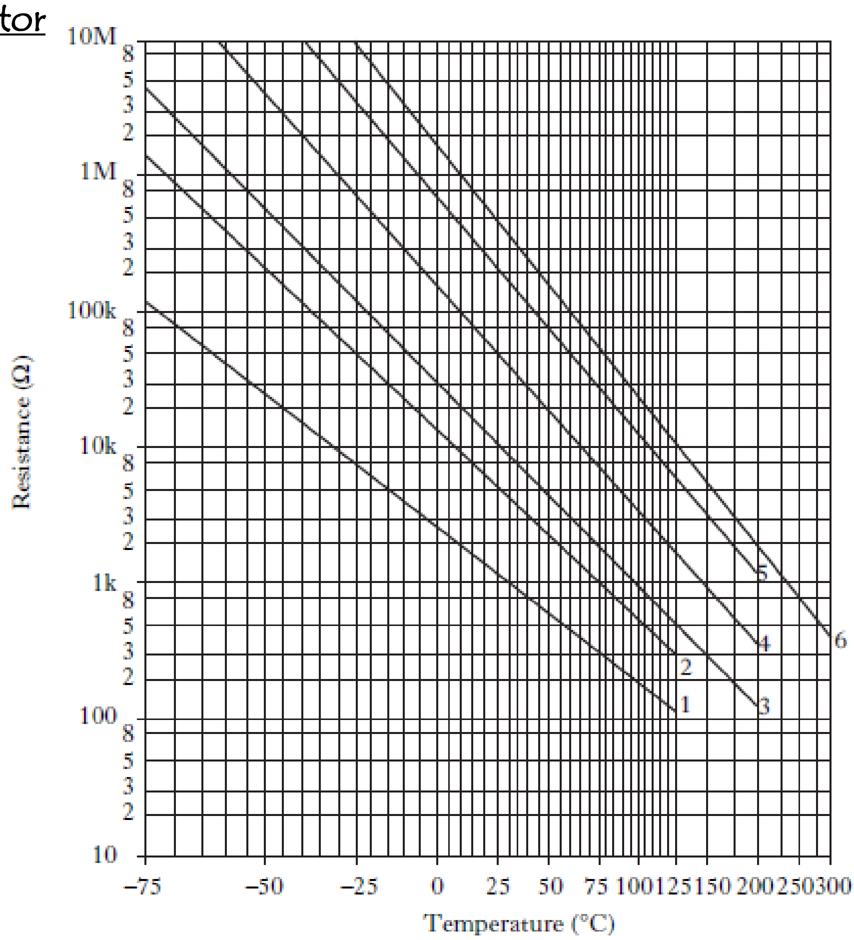
MOSFET



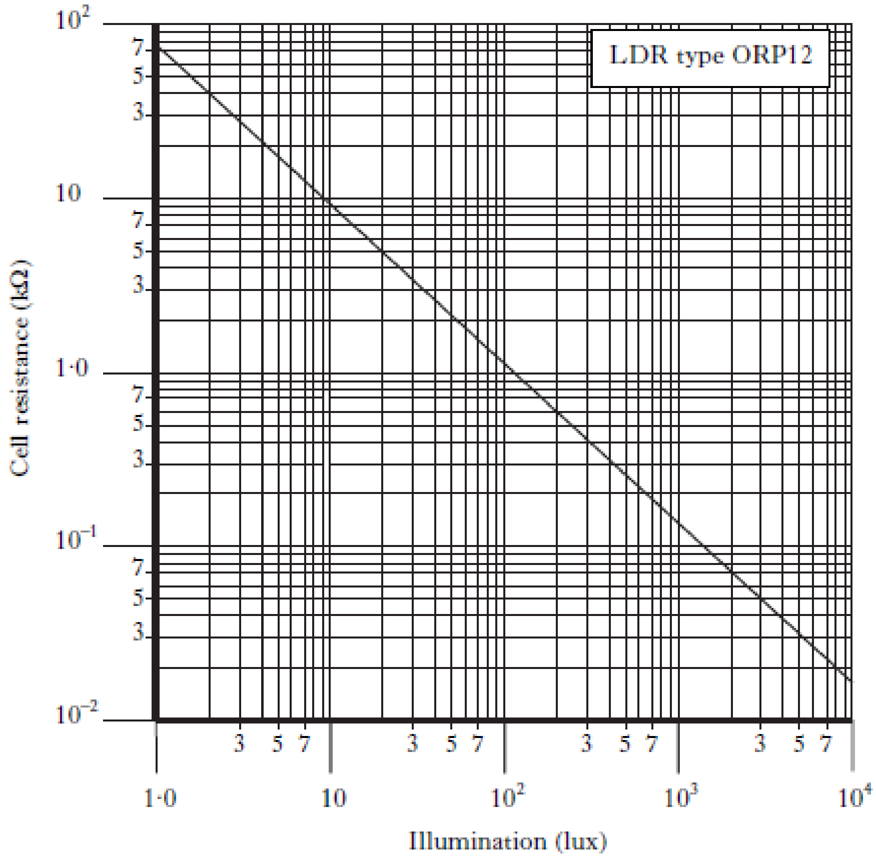
Operational Amplifier

Graphs

Thermistor



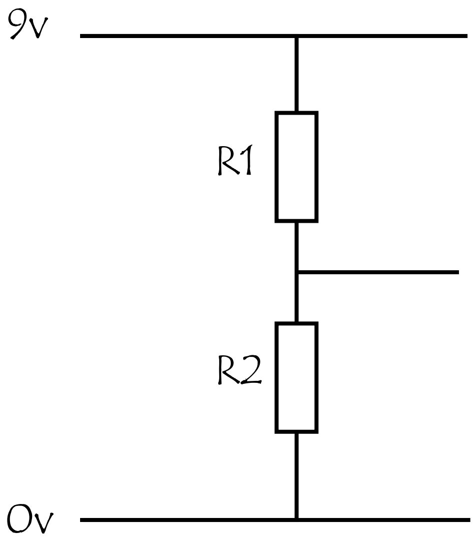
LDR



Voltage Dividers

Any system can be broken down into input, process and output. **Input transducers** in electronics convert one energy form into another energy form.

Changes in the resistance of an input transducer must be converted to changes in voltage before the signal can be processed. This is normally done by using a voltage divider circuit.



Voltage divider circuits work on the basic electrical principle that if two resistors are connected in series across a supply, the voltage load across each of the resistors will be proportional to the value of the resistors. To calculate the voltage across any one resistor in a voltage divider, we can use the following equation.

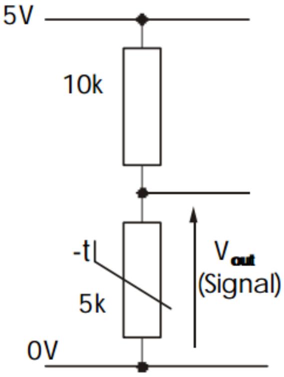
$$V_{out} = \frac{R2}{R1 + R2} \times V_s$$

http://goo.gl/dDEqbG

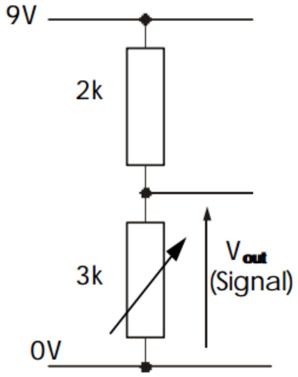
Task 1

Calculate the missing value for each of the following circuits.

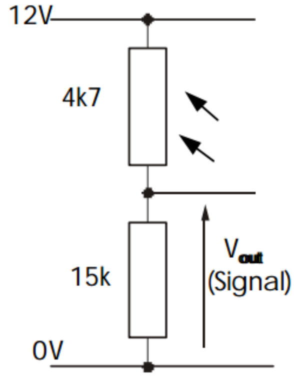
a)



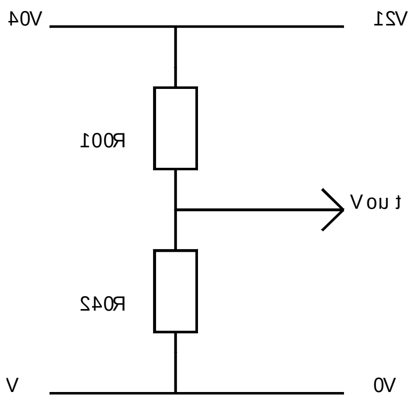
b)



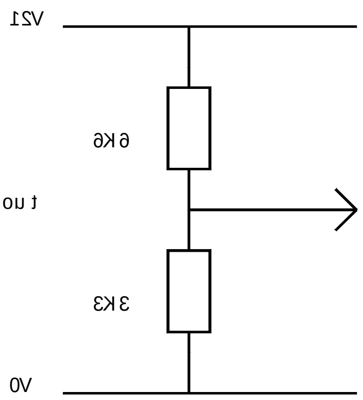
c)



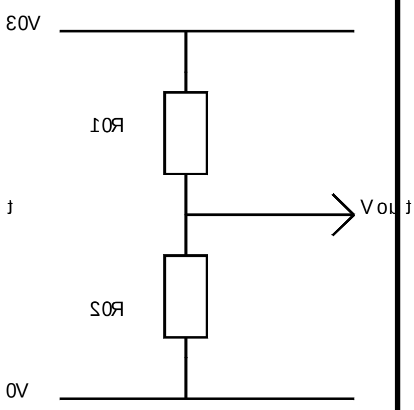
d)



e)



f)

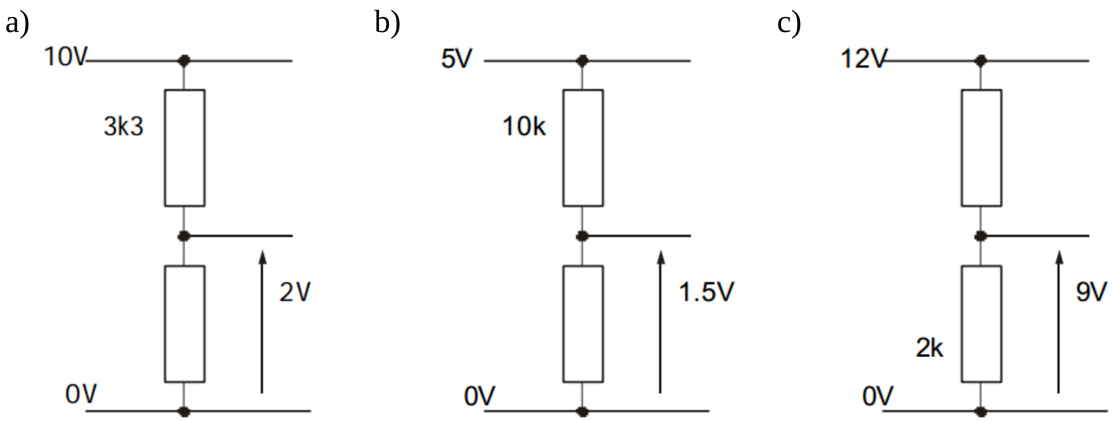


If we know more information in our diagrams we can also use the equation:

$$\frac{V1}{V2} = \frac{R1}{R2}$$

Task 2

Calculate the missing value for each of the following circuits



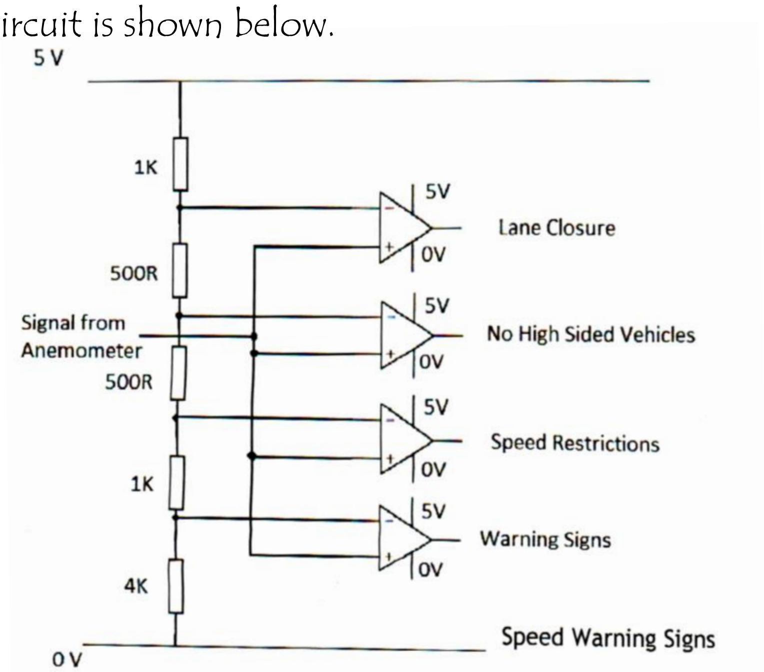
Task 3

The Forth Road Bridge control room continuously monitors conditions which could affect the safe operation of the bridge. One of the most important is wind speed.

As wind speed increases there are 4 levels of response:

- Speed warning signs will be switched on
- Speed restrictions put in place
- High sided vehicles will be diverted away from the bridge
- Bridge closed to all vehicles

The wind is monitored by an anemometer, which gives an increasing voltage of 0.07V per ms^{-1} as the wind speed increases. Part of the control circuit is shown below.



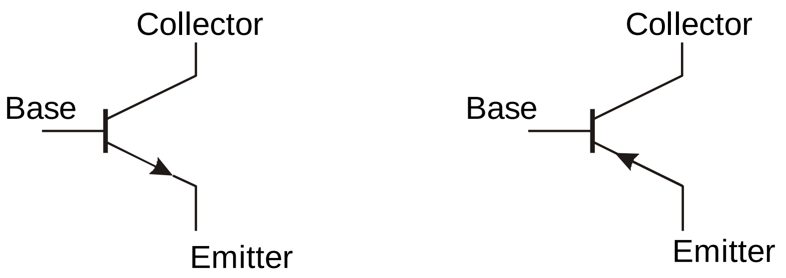
With reference to the diagram, calculate the wind speed which will:

(i) Switch on the 'Lane Closure' signs

(ii) Switch on the 'Speed Restrictions' signs

Amplification

Input transducers that produce voltage, rarely produce sufficient voltage for most applications. Their outputs have to be amplified.
Amplifying devices are said to be active components, as oppose to non-amplifying components (resistors, capacitors etc.) which are known as passive components. The extra energy required to operate the active component comes from an external power source.
The most common active device in an electronic system is the bipolar junction transistor (or simply transistor for short). Two types are available, PNP or NPN.

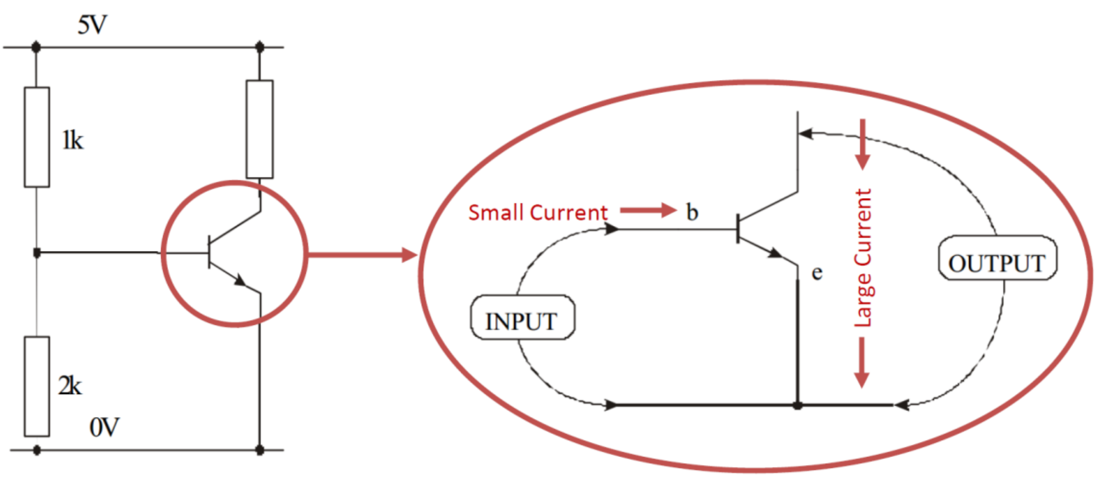


npn Type pnp Type

NPN transistors operate when the base is made Positive

PNP transistors operate when the base is made Negative

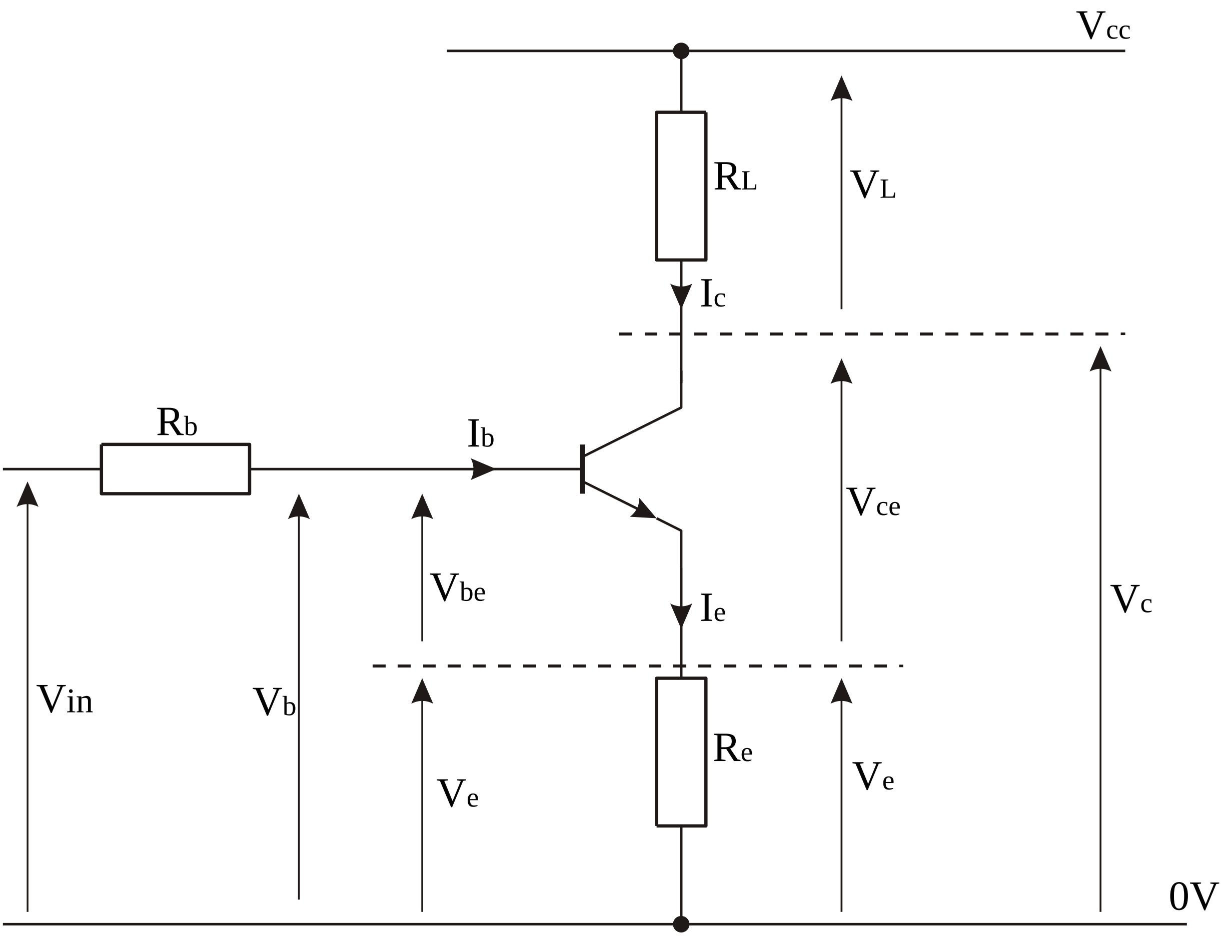
When the emitter and the voltage divider are connected to the same ground line, a small current flowing between the base and emitter junction will allow a large current to flow between the collector and emitter.



Transistor Notation

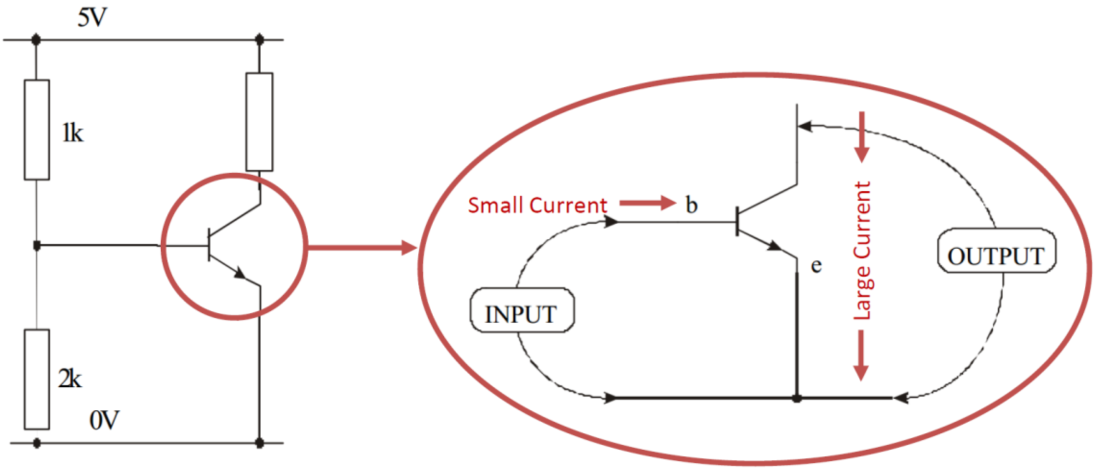
To save writing full terms subscripts are used.

I_c	– Collector current
I_b	– Base current
I_e	– Emitter current
V_{cc}	– Voltage of supply (relative to ground line)
V_b	– Voltage at the base junction (relative to ground line)
V_e	– Voltage at the emitter junction (relative to ground line)
V_{ce}	– Voltage between the collector and emitter junction
V_{be}	– Voltage between the base and emitter junction
V_L	– Voltage over the load resistor



It can be seen from the diagram that $V_b = V_{be} + V_e$

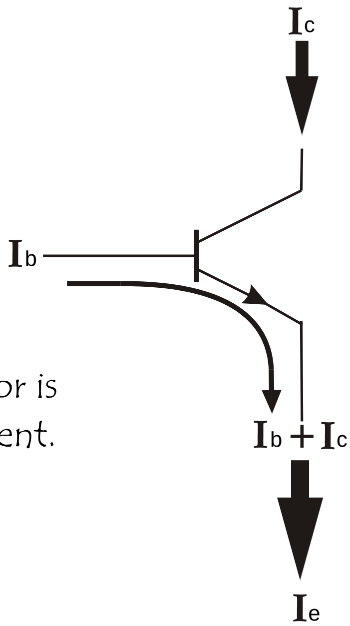
$V_{CC} = V_L + V_{ce} + V_e$ …..etc.



As you have previously learned, a small current flowing between the base and emitter will allow a large current to flow between the collector and emitter.

It can be seen that: Ie = Ib + Ic

Since Ib is usually much smaller than Ic,
it follows that Ie is approximately = Ic



The current gain (or amplification) of the transistor is defined as the ratio of collector current : base current.

…so $$\text{Current Gain} = \frac{\text{Collector current}}{\text{Base current}}$$

$$H_{FE} = \frac{\Delta\, Ic}{\Delta\, Ib}$$

Task 4

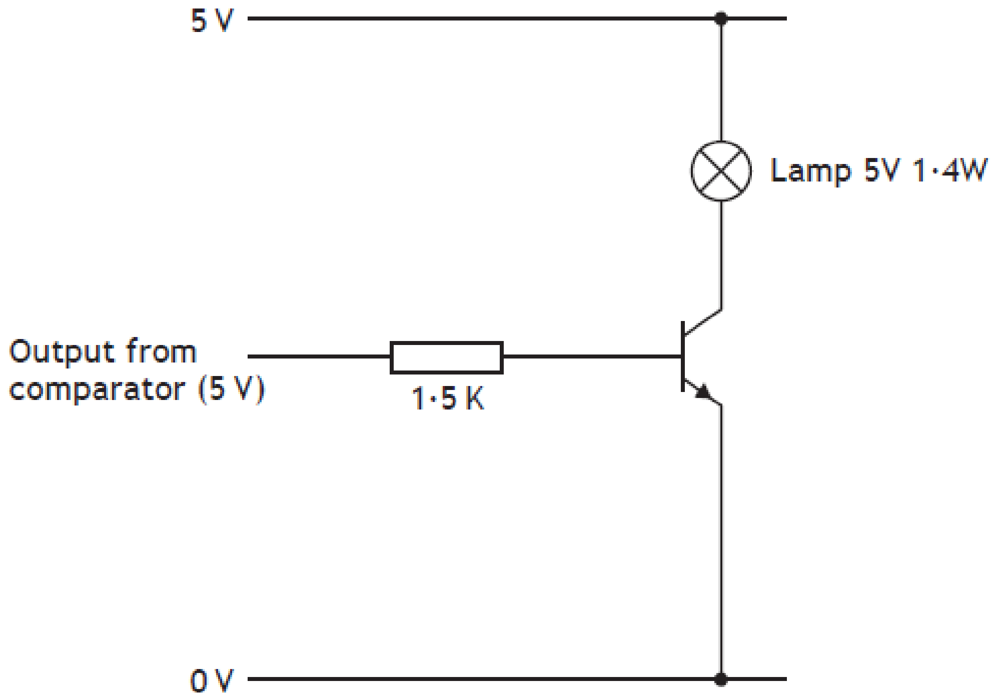
a) Calculate the gain of a transistor if the collector current is measured to be 10 mA when the base current is 0.25 mA.

b) Calculate the collector current through a transistor if the base current is 0.3 mA and h_{FE} for the transistor is 250.

c) What collector current would be measured in a BC107 transistor if the base current is 0.2 mA and h_{FE} is 100?

Task 5

An electric speed control sign has 5 V lamps which have a power rating of 1·4 W. The driver circuit for each light is shown below. The transistor is fully saturated when VBE = 0·7 V.



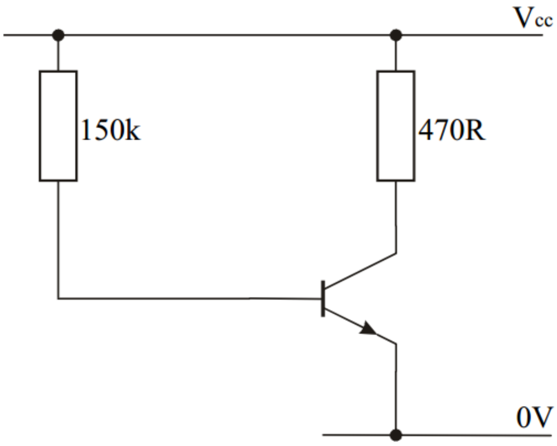
Calculate the minimum current gain required by the transistor

Transistor Switching Circuits

In order to generate a current in the base of the transistor, a voltage must be applied between the base emitter junction (V_{be}). It has been found that no current flows in the base circuit unless the base emitter voltage reaches 0.7 V.

It can be assumed that if the transistor is turned ON then V_{be} = 0.7 V. This is called the saturation voltage.

Example



If the transistor is ON, calculate the collector current and Vce if h_{FE}=200 and V_{CC} = 9 Volts.

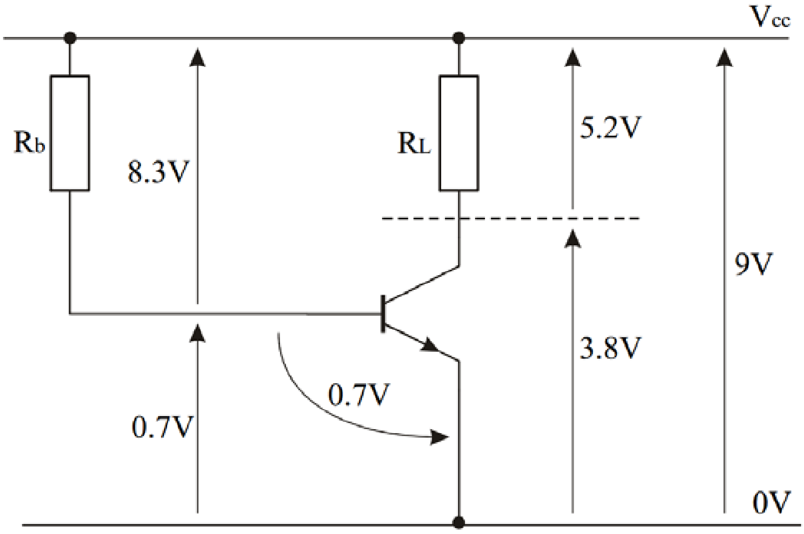
Step 1

Calculate the voltage dropped going into the transistor. In this case, as the base resistor is connected directly to the Vcc, the calculation would simply be:

Voltage dropped $= V_{cc} - V_b$

$= 9 - 0.7$

$\underline{\underline{= 8.3\ V}}$



<u>Step 2</u>

Calculate the base current using Ohm's law:

$$I_b = \frac{V\ dropped}{R_b} = \frac{8.3}{150k} = \underline{\underline{0.00553\ mA}}$$

<u>Step 3</u>

I_c is calculated knowing h_{FE}

$I_c \quad = h_{FE} \times I_b$

$\quad = 200 \times 0.0553$

$\quad = \underline{\underline{11.06\ mA}}$

<u>Step 4</u>

Use I_c and Ohm's law to calculate V_c.

$V_L \quad = I_c \times R_L$

$\quad = 11.06\ mA \times 470$

$\quad = \underline{\underline{5.2\ V}}$

<u>Step 5</u>

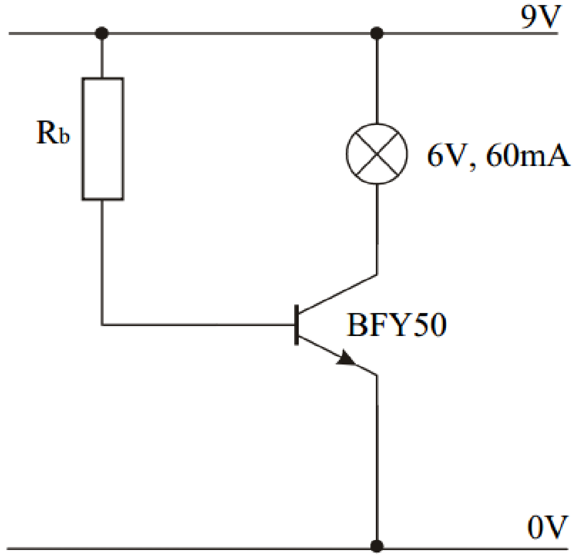
Therefore $V_{ce} \quad = Vcc - VL$

$\quad = 9 - 5.17$

$\quad = \underline{\underline{3.8\ V}}$

Task 6

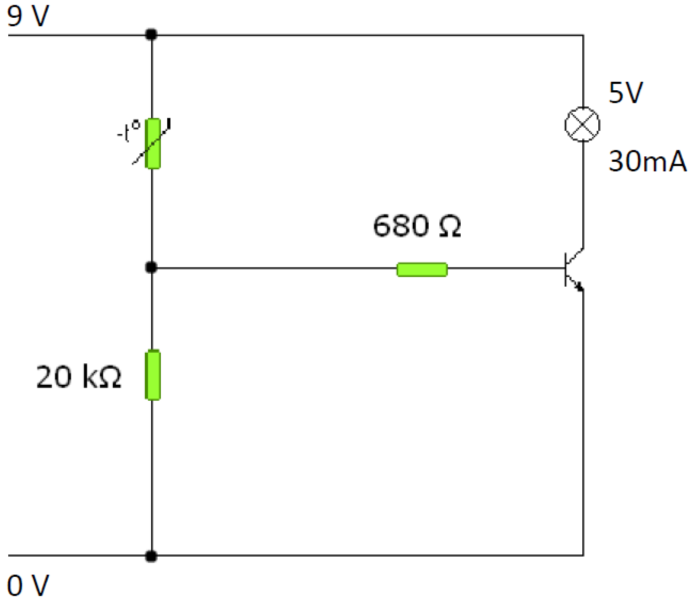
A 6V, 60 mA bulb is connected to the collector of a BFY50 transistor as shown.



If the gain of the transistor is 30, determine the size of the base resistor R_b required to ensure that the bulb operates at its normal brightness.

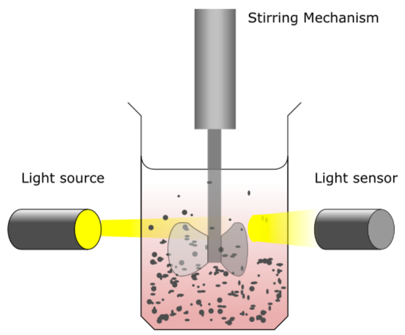
Task 7

Calculate the resistance the thermistor is currently giving in this circuit. The H_{FE} of the transistor is 20.



Task 8

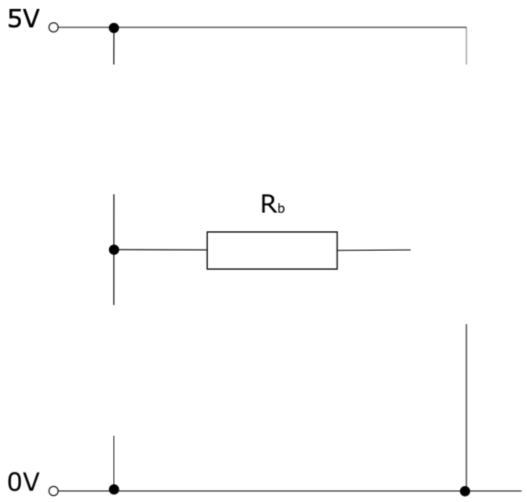
In a science laboratory, a system is required to sense when particles sink to the bottom of a beaker. When enough light gets through, a stirring mechanism must be activated.



The system is required to meet the following criteria:

- It must switch on a motor when it senses light.
- The sensitivity of the light sensor must be adjustable.
- The output driver must include a bipolar transistor.

a) Complete the circuit diagram to perform the required function.



b) Construct the circuit on prototype board. Attach a photo below.

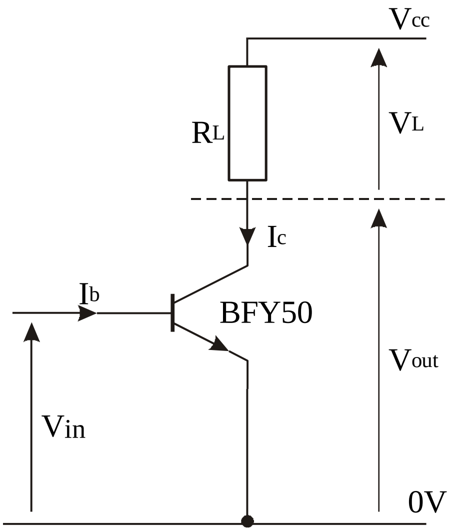
Task 8 (contined)

c) Describe the tests you performed and the results you observed.

d) Suggest at least one adaptation to your system that would make it perform better in a real environment.

Voltage Amplification

Although the transistor is a current amplifier, it can easily be modified to amplify voltage by the inclusion of a load resistor, R_L in the collector and/or emitter line.



Here, applying the voltage V_{in} to the base gives rise to the base current I_b This in turn causes a proportional increase (depending on the gain) in the collector current I_c

Since the current through the load resistor (I_c) has increased, the voltage over R_L has increased ($V_L = I_c R_L$) and hence V_{out} has decreased. ($V_{out} = V_{CC} - V_L$)

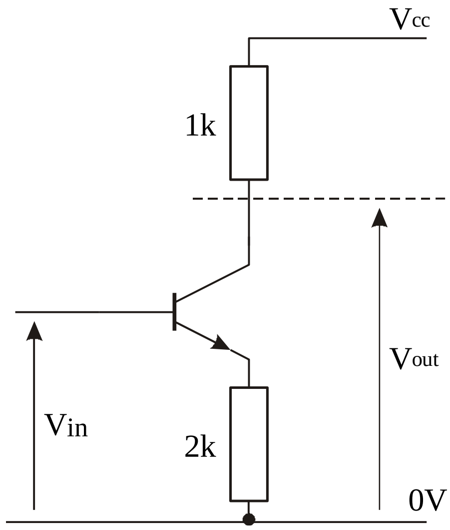
The Voltage gain of any amplifier is defined as:

$$\text{Voltage Gain} = \frac{\text{Voltage output}}{\text{Voltage Input}}$$

$$Av = \frac{Vo}{Vi}$$

Example

Calculate the voltage gain of this circuit if V_{in} =1.7 V, h_{FE} = 100 and V_{CC} = 6V.



Step 1

Calculate Ve:

$V_e = V_{in} - 0.7$

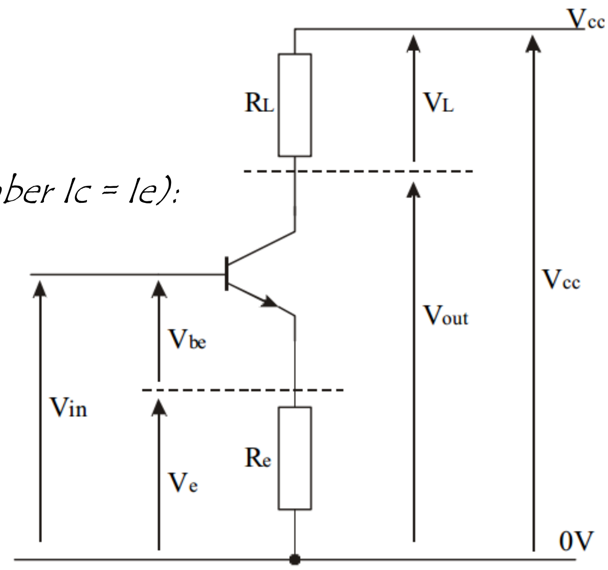
$= 1.7v - 0.7$

$\underline{\underline{= 1\ V}}$

Step 2

Calculate current through R_e using Ohm's Law:

$Ie = \frac{Ve}{Re} = \frac{1}{2k} = \underline{\underline{0.5\ mA}}$



Step 3

Calculate the voltage over RL (remember Ic = Ie):

$V_L = I_c \times R_L$

$= 0.5\ mA \times 1k$

$= \underline{\underline{0.5\ V}}$

Step 4

Calculate the output voltage:

$Vout = V_{CC} - V_L$

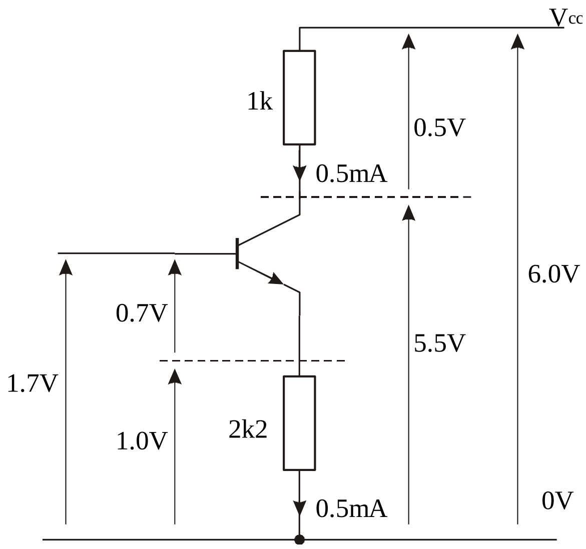
$= 6 - 0.5$

$= \underline{\underline{5.5\ V}}$

Step 5

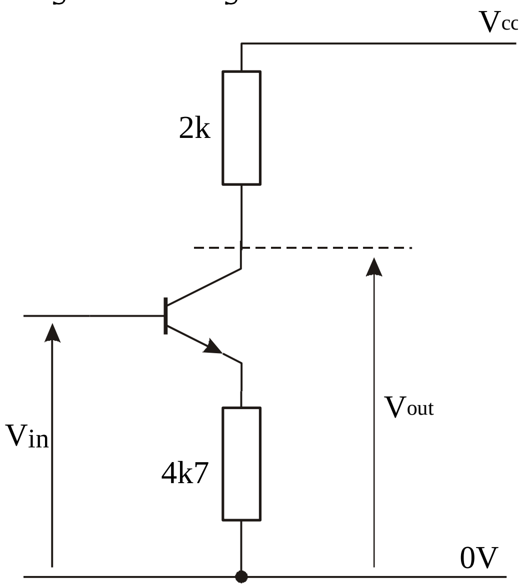
Calculate the voltage gain:

$Av = \frac{Vo}{Vi} = \frac{5.5}{1.7} = \underline{\underline{3.2}}$



Task 9

A transistor of very high current gain is connected to a 9 Volt supply as shown.

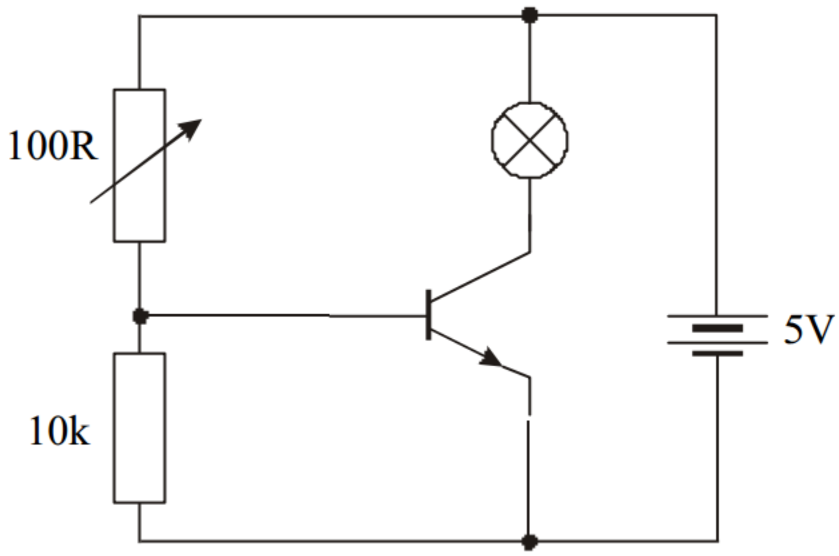


Determine the output voltage and the voltage gain when an input of 3 Volts is applied.

Task 10

Every transistor has a maximum allowable base current. This can be found by calculating: $Ib = \frac{Vcc}{R1}$

Find the maximum allowable base current for the circuit below. Then construct the circuit using circuit simulation software to see what happens when the value of R1 (Variable resistor) decreases.



Describe what happens.

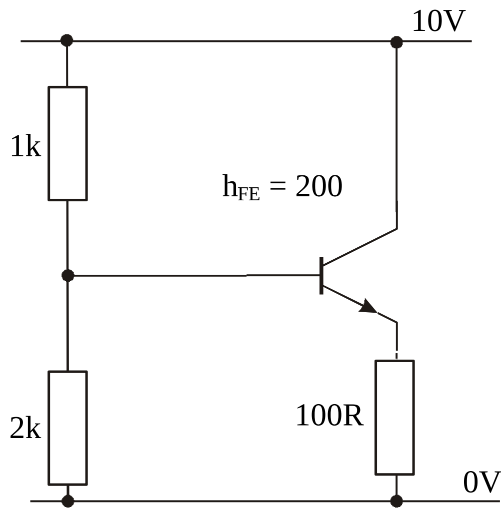
Task 11

Calculate:

a) The base current

b) The collector current;

c) Vout

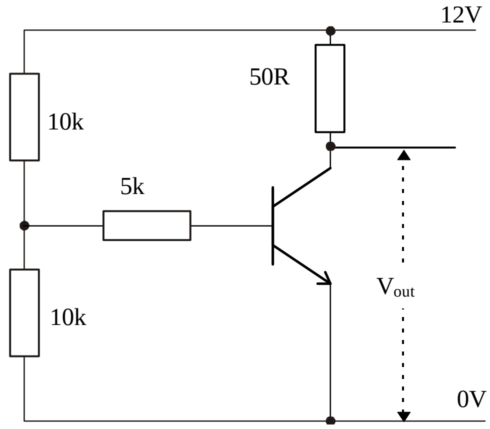


Task 12

Calculate:

a) the base current

b) the output voltage



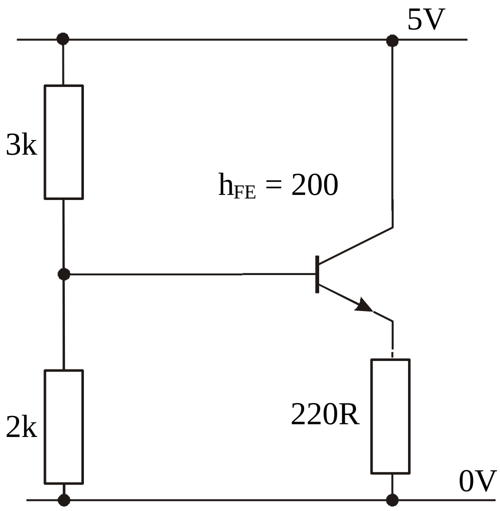
Task 13

Calculate:

a) the emitter voltage;

b) the emitter current;

c) the base current



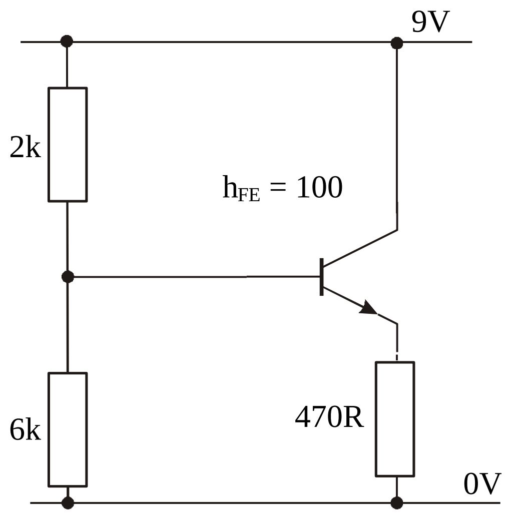
Task 14

Calculate:

a) the emitter voltage;

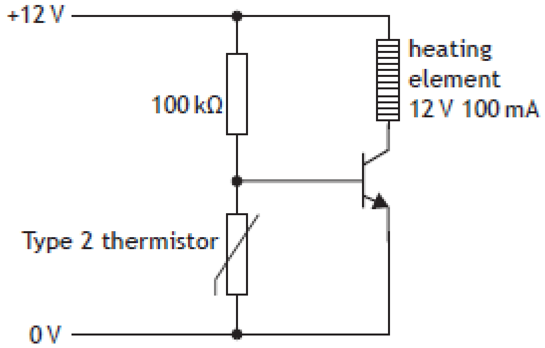
b) the emitter current;

c) the base current



Task 15

The circuit shown below is being designed by an electronic engineer, to switch on a heated seed tray when the temperature falls to 15 °C.



a) At 15 °C, with the transistor switched on and saturated, the resistance of the thermistor is 8 kΩ and the current through the 100 kΩ resistor is 0·113 mA.

Calculate:

(i) the current flowing through the thermistor;

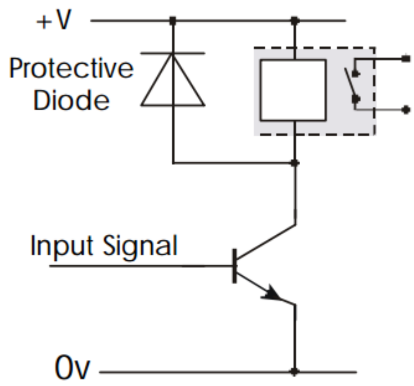
(ii) the current flowing into the base of the transistor.

(b) The heating element is rated at 12 V, 100 mA.

Calculate the minimum current gain hFE required for the heating element to fully switch on at 15 °C.

Driving Large Loads

In some circumstances, the current (or voltage) required to operate an output transducer may be too large for a transistor to handle e.g. for heating elements, heavy motors or for machines operating from the mains supply, etc. In these circumstances, the transistor circuit can be used to drive a relay. The contacts of the relay are then used in a **separate** circuit to operate the output transducer.



Note the diode protects the transistor from back EMF. Back EMF is produced when the relay switches position

However, if you want to drive a large load using the **same** power supply, you have two options; the first of which is the Darlington pair.

Darlington Pair

To achieve more current gain, more than one transistor can be used. By increasing the gain, switching in the circuit becomes more immediate and only a very small base current is required.

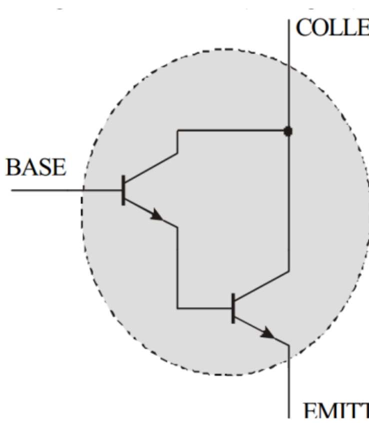


fig 23

For the circuit to operate, both transistors would need to be saturated. As it takes 0.7 V to saturate one transistor, it takes 1.4 V to saturate a Darlington Pair.

The current gain of the "pair" is equal to the product of the two individual h_{FE}'s. E.g. if two transistors, each of gain 50 are used, the overall gain of the pair will be 50 x 50 = 2500

$$A_I = h_{FE1} \times h_{FE2}$$

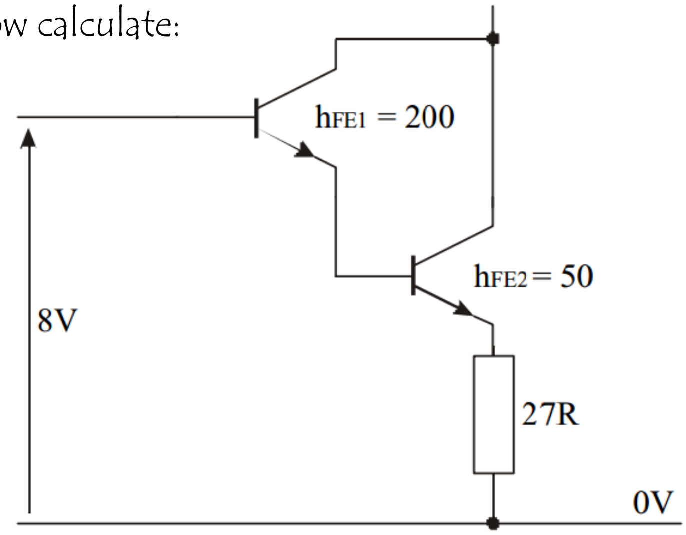
Task 16

For the circuit shown below calculate:

a) the gain of the pair;

b) the emitter current;

c) the base current.

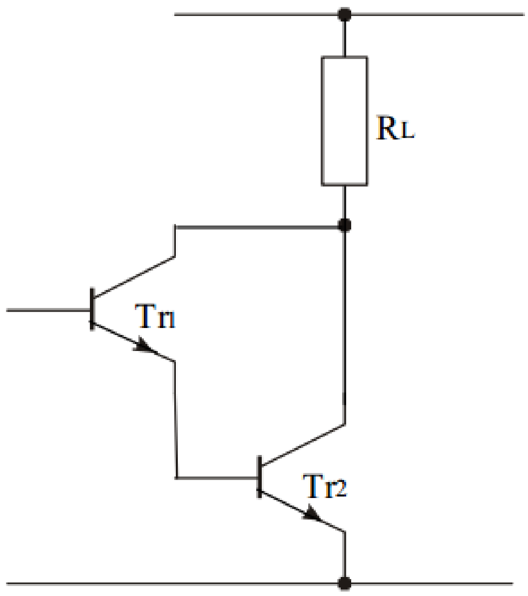


Task 17

For the circuit shown below, the gain of Tr1 is 150 and the gain of Tr2 is 30. Calculate:

a) The overall gain of the darlington pair.

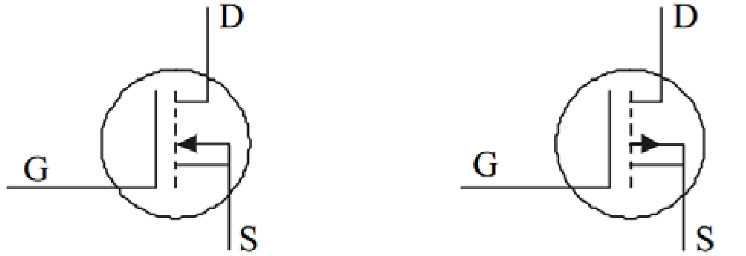
b) the base current required to give a current of 100mA through the load resistor.



MOSFETs

The other option of driving large loads in a circuit is to use a MOSFET. Like bipolar transistors, these come in n-type and p-type.

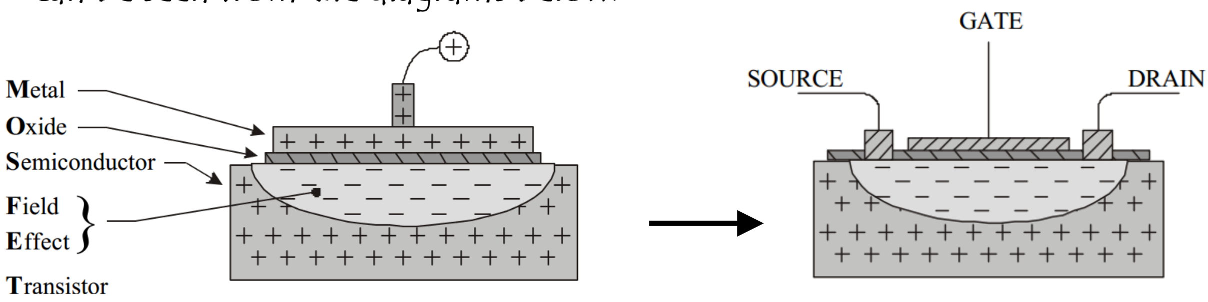
G = Gate
D =Drain
S = Source



N-CHANNEL ENHANCEMENT MOSFET

P-CHANNEL ENHANCEMENT MOSFET

In an n-type MOSFET, the field channel is negative. This means that when the gate voltage is low, the circuit is incomplete. However, when the gate voltage reaches the threshold voltage, the circuit completes as can be seen from the diagrams below.

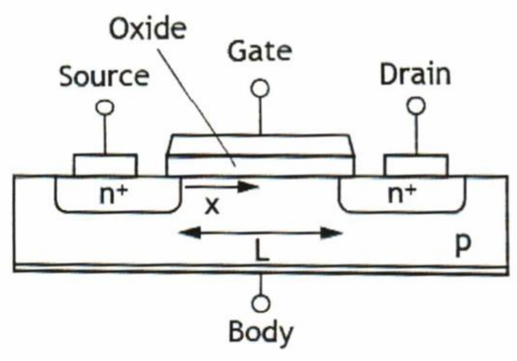


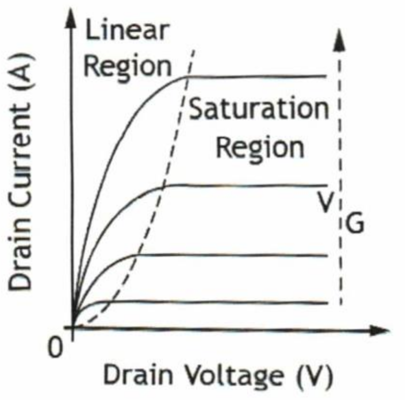
MOSFETs are voltage switching devices. They have very high input resistances, unlike bipolar transistors. This means they only need a very small current to operate them. The threshold voltage at which a MOSFET switches at is different depending on which MOSFET you are using - it is different from the 0.7 V used in bipolar transistors.

A MOSFET can operate in **enhancement mode**. This means when there is no voltage on the gate there is in effect no channel. This means the device will not conduct.
A channel can be produced by the application of voltage to the gate.
In **linear mode**, the greater the gate voltage, the better the device conducts

Task 18

A block diagram of a MOSFET and character operation curves are below.

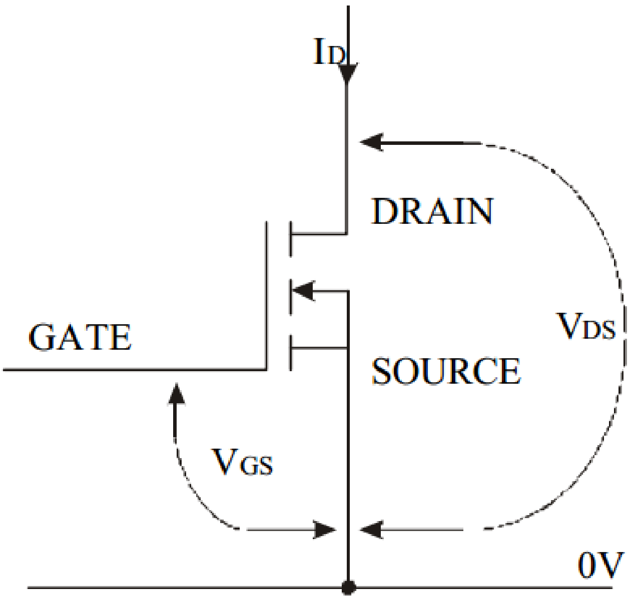




Describe the basic operation of a MOSFET making reference to the diagrams shown.

MOSFET Calculations

For a given MOSFET, the size of the current between the Drain and Source will therefore depend on the Gate voltage (VGS) and the voltage between the Drain and Source (VDS).



Like a bipolar transistor, if the Gate voltage is below a certain level (the threshold value, VT), no current will flow between the Drain and Source (the MOSFET will be switched off).

If the Gate voltage is above VT, the MOSFET will start to switch on. Increasing the Gate voltage will increase the thickness of the channel, increasing the number of charge carriers in the channel and hence increasing I_D.

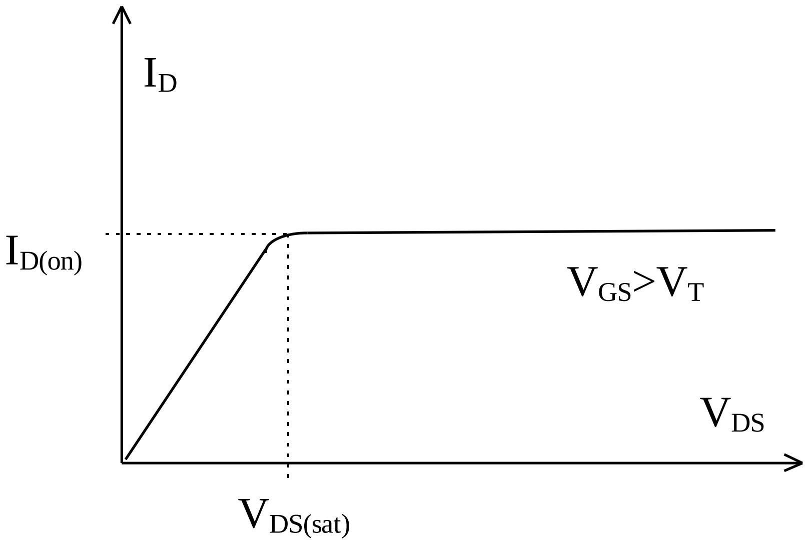
For a given value of V_{GS}, increasing V_{DS} increases the current until saturation occurs. Any further increase will cause no further increase in I_D. The MOSFET is fully ON and can therefore be used as a switch.

Saturation occurs when the voltage between the gate and the source minus the threshold voltage is equal to the voltage between the drain and the source.

$$V_{DS} = V_{GS} - V_T$$

When saturation occurs, the current at ID is the same as it was before saturation.

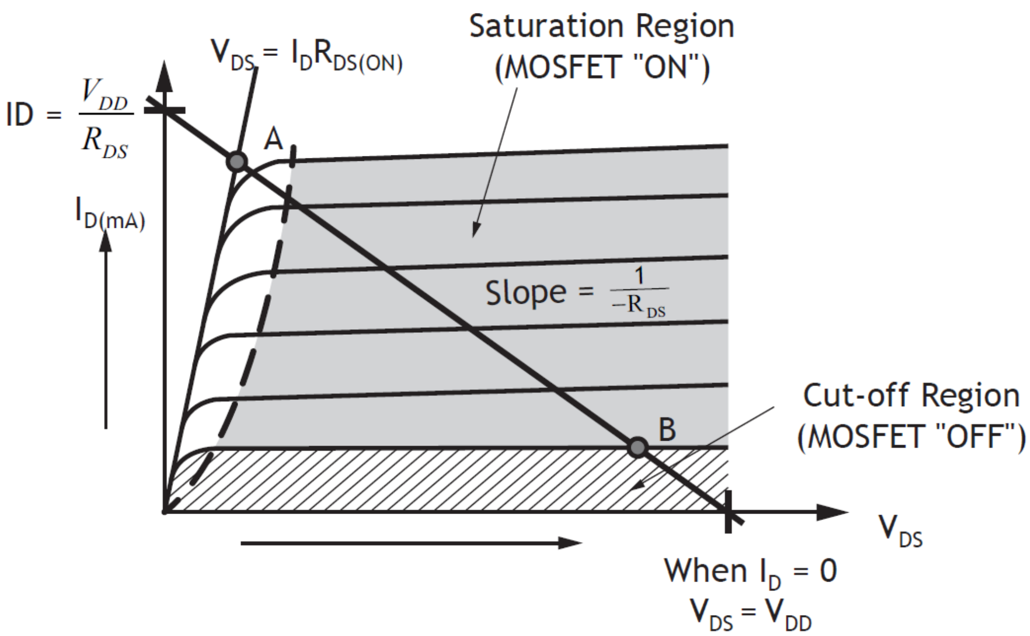
$$I_D = I_{D\,(ON)}$$



When saturation occurs, the resistance of the channel, R_{DS}, is normally low ($R_{DS(on)}$ less than 1Ω for power MOSFET's)

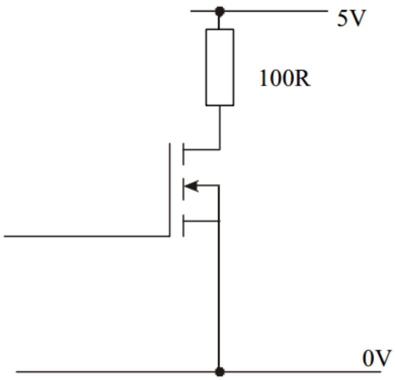
All other transistor rules apply.

For example, rather than $V_{CC} = V_{Out} + V_{Load}$ we can now say $V_{CC} = V_{DS} + V_{Load}$

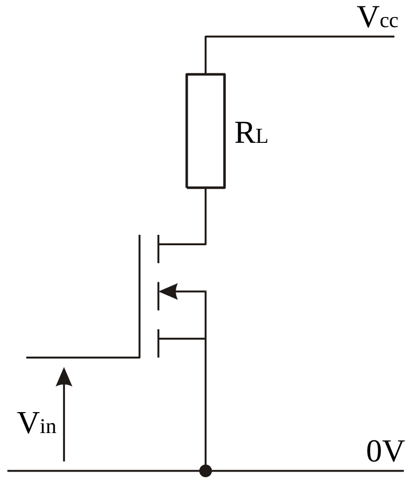


Task 19

The threshold gate voltage for the MOSFET shown below is 2V. Calculate the gate voltage required to ensure that a saturation current of 10 mA flows through the load resistor.

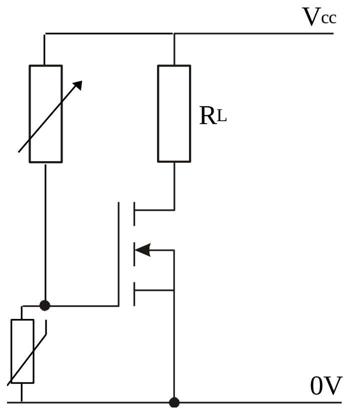


MOSFET's can be designed to handle **very high drain currents**, this means that they can be used to drive high current output transducers drivers without the need for relay switching circuits (unlike the bipolar transistor).



The load resistor could be any output transducer, bulb, motor, relay etc. Since MOSFET's are particularly sensitive to high voltages, care must be taken to include a reverse biased diode over transducers that may cause a back emf when switched off.

A variable resistor can be used in a voltage divider circuit and adjusted to ensure that the input voltage to the gate = V_T



Changes in V_{GS} (ΔV_{GS}) above the threshold value causes changes in I_D (ΔI_D)
Whereas the performance of a bipolar transistor is measured by its' amplification (h_{fe}), the performance of a FET is measured by its *transconductance* (g_m) and is calculated by

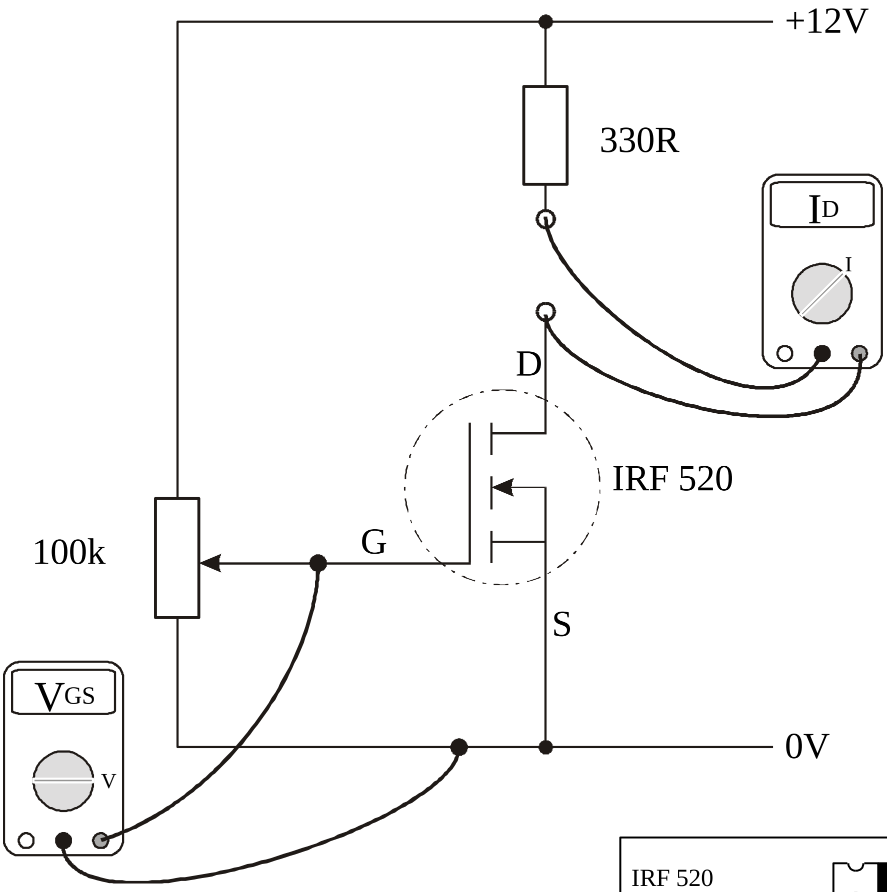
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

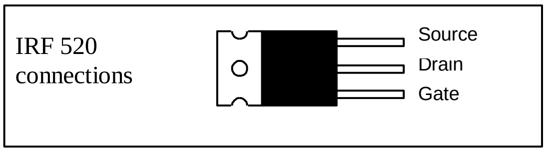
g_m is measured in Amps per Volt (AV^{-1})
[These units are sometimes referred to as siemens or mhos]

MOSFET's connected as shown in figure 33b are said to be in common-source mode (c.f. common-emitter mode for bipolar transistors).

Task 20

Construct the circuit shown below using multimeters to measure the drain current and the gate voltage.





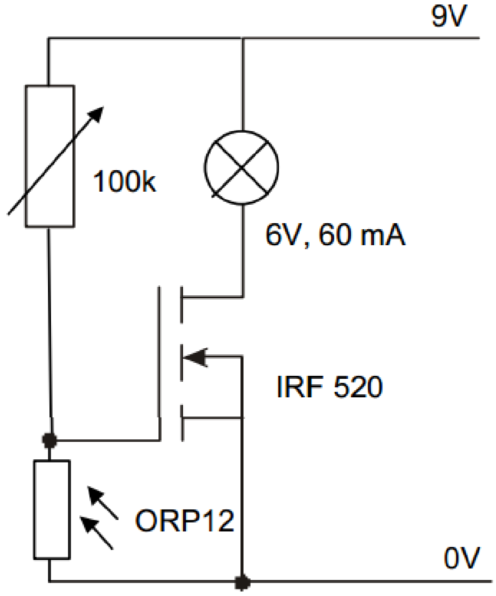
Adjusting the potentiometer will allow you to change V_{GS}.

Complete the table below for recording your results

VGS (V)	ID (mA)

Task 21

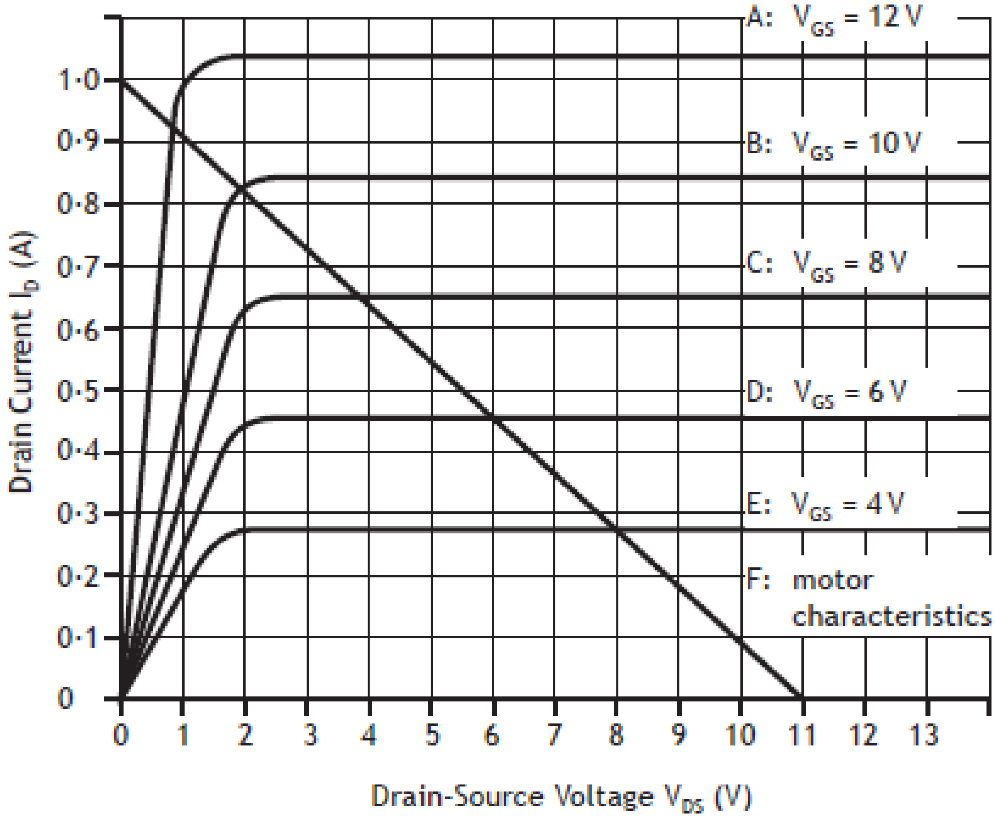
Create this circuit using Crocodile Clips or Yenka.



Plot a graph of ID against VGS for this MOSFET. What do you notice?

Task 22

A MOSFET output-driver circuit provides current a motor controlling a crane. The graph below shows the operational characteristics of the output-driver circuit. Lines A, B, C, D, and E show the characteristics of the MOSFET for five different gate-source voltages (VGS). Line F shows the characteristics of the motor.



For a signal of 4 V on the microcontroller output pin:

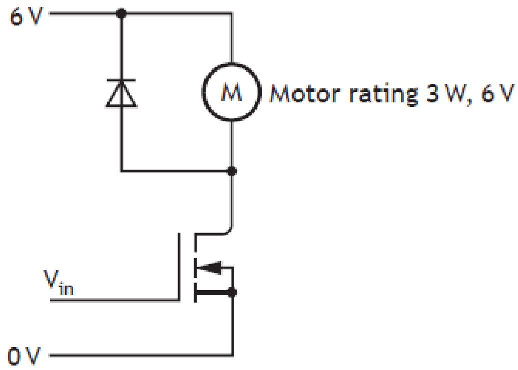
(i) determine the Drain-Source Voltage;

(ii) determine the Drain Current;

(iii) calculate the power dissipated in the MOSFET.

Task 23

The motor driver circuit shown below is used to switch a motor on and off.



a) Calculate the resistance of the motor. Show all working and final unit. When the circuit is switched on, the resistance of the MOSFET is 0·5 Ω.

b) Calculate the MOSFET drain current. Show all working and final unit.

c) Calculate the power dissipated in the MOSFET when it is switched on.

Show all working and final unit.

Operational Amplifiers

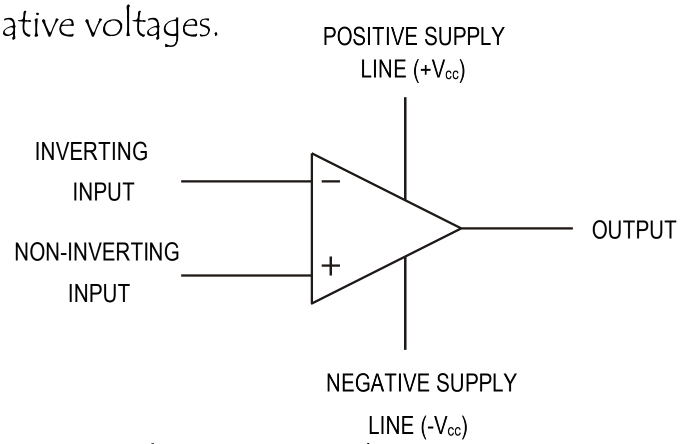
As you know from the previous topic Operational Amplifiers can be used to add, subtract, multiply, divide, integrate and differentiate electrical voltages. It can amplify both d.c. and a.c. signals.

An 'ideal' amplifier should have the following qualities:

- An infinite input resistance so very little current is drawn from the course (V=IR)
- Zero output resistance
- An extremely high gain
- No output when the output is 0, though this is rarely achieved.

http://goo.gl/s6dVbo

The symbol for an op amp is shown below. We can see there are two inputs, one output and an external power supply to both positive and negative voltages.

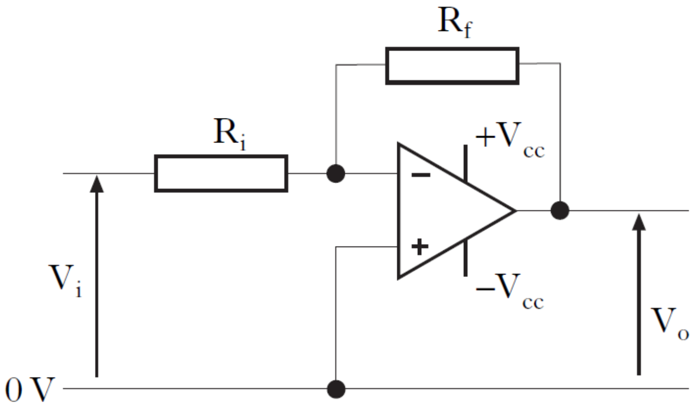


http://goo.gl/qILM3K

Voltages to the positive rail are treated as positive voltages. Voltages to the negative rail are treated as negative voltages. **If the voltage at the positive rail is higher than the voltage at the negative rail, the output will be high. If the voltage at the negative rail is higher than the voltage at the positive rail, the output will be negative. If both inputs are the same the output should be zero.**

The output from an op amp **CAN NOT** be greater than **85%** of the supply voltage. If an op amp had +10V and -10V supply, the output would need to be between +8.5V and -8.5V. This **must** be remembered!

Inverting Op-Amp



The signal is connected to the op amp through an input resistor, R1. The non-inverting input is connected directly to the ground. Sometimes a resistor is placed between the non-inverting input and the ground. If this is done, the non-inverting resistor must be equal to the combined resistance of R_1 and R_f connected in parallel.

How it works: Lets assume the voltage across R1 is +5V. The op amp compares the voltages. So 0V-5V is equal to -5V which is then amplified by the gain. If the voltage across R1 is -5V: The op amp compares the voltages. So 0V -(-5V) is equal to +5V which is then amplified by the gain.

How to calculate the gain:

$$Av = -\frac{Rf}{R1}$$

The negative symbol simply represents that the output is the inverse of the input.

http://goo.gl/gNPpba

Example

An op. amp. is used in a circuit as shown in the diagram above with R1 = 15 k and Rf = 470 k.

Calculate the output voltage when an input signal of 0.2 v is applied.

Step 1

Calculate the gain:

$$A_v = -\frac{R_f}{R_1} = -\frac{470k}{15k} = \underline{\underline{-31.33}}$$

Step 2:

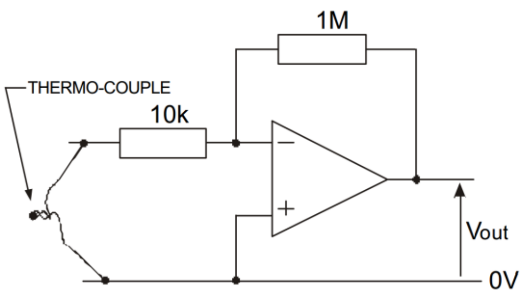
Calculate the output voltage:

$$V_{out} = A_v \times V_{in}$$
$$= -31.33 \times 0.2$$
$$\underline{\underline{= -6.266\ v}}$$

Task 24

A thermocouple known to produce an output of 40µ volts per °C is connected to an op. amp.

a) Calculate the gain of the circuit
b) Determine the output voltage if the thermocouple is heated to a temperature of 1000°C.



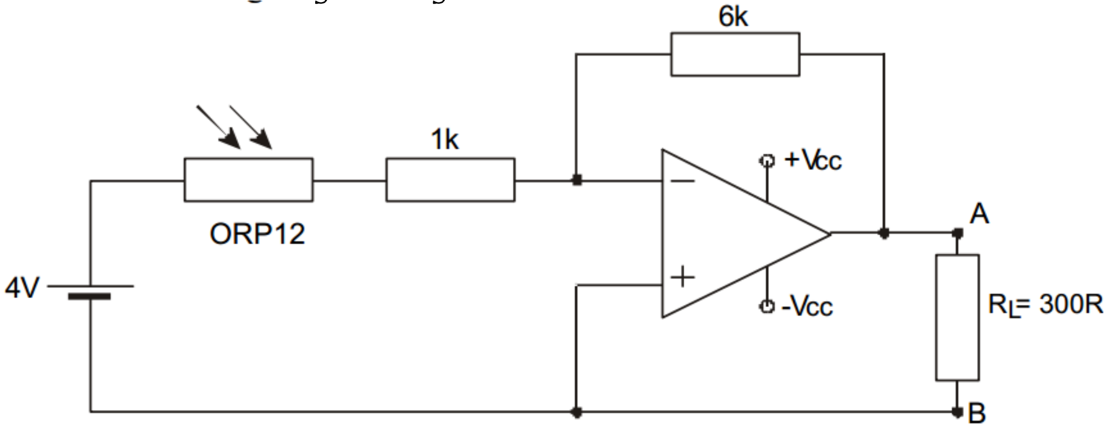
Task 25

For the circuit below the light level is 50 lux, calculate:

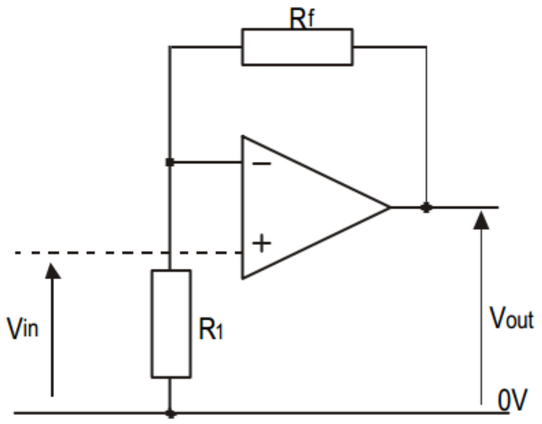
a) The resistance of the LDR

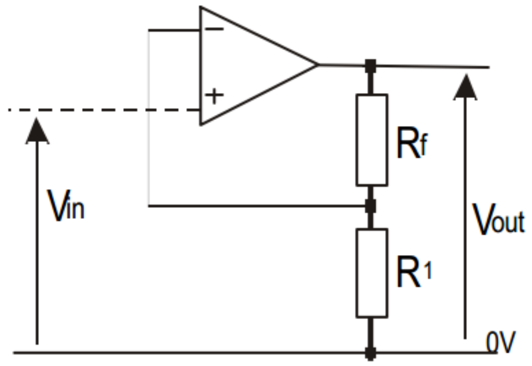
b) The voltage gain of the operational amplifier

c) The current flowing through load resistor RL.



Non-Inverting Op-Amp





The signal is connected directly to the non-inverting input. This means that the output voltage is always high if the input voltage is high and always low if the input voltage is low. R_f and R_1 form a voltage divider, this feeds back some of the output signal to the inverting input signal. This ensures the output is non-inverting. Note there are two ways to draw the non-inverting op amp.

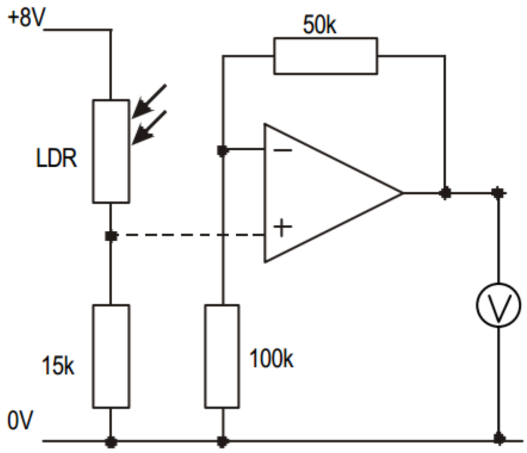
How to calculate the gain:

$$Av = 1 + \frac{Rf}{R1}$$

http://goo.gl/OUayIO

Task 26

A circuit for a light meter is shown below. In bright sunlight the LDR has a resistance of 1K. In the shade its resistance increases to 15K.

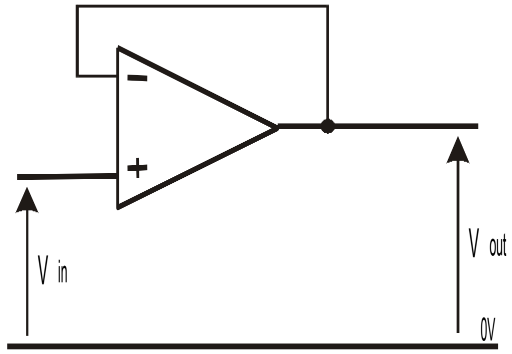


a) Determine the voltages that would appear on the voltmeter in both light conditions.

b) How could the circuit be altered to indicate changes in temperature?

The Voltage Follower

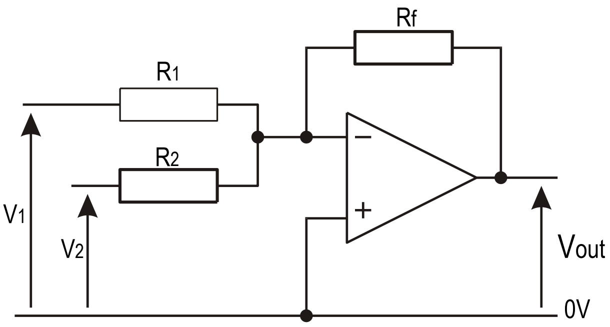
This is a special case of the non-inverting amplifier in which 100% negative feedback is obtained by connecting the output directly to the inverting input.



Since R_f = 0, the gain of this circuit is 1 i.e. The output voltage = input voltage.

The practical application of this circuit is that it has a very high input resistance and a very low output resistance. It is therefore used in matching a source that can only produce a low current to a load which has a low resistance.

The Summing Op-Amp



Here, two (or more) signals are connected to the inverting input via their own resistors. The op. amp. effectively amplifies each input in isolation of the others and then sums the outputs.

Each input signal is amplified by the appropriate amount (see inverting mode)

How to calculate:

$$V_{out} = \left(\frac{-Rf}{R1} \times V1\right) + \left(\frac{-Rf}{R2} \times V2\right) + (\text{any other inputs})$$

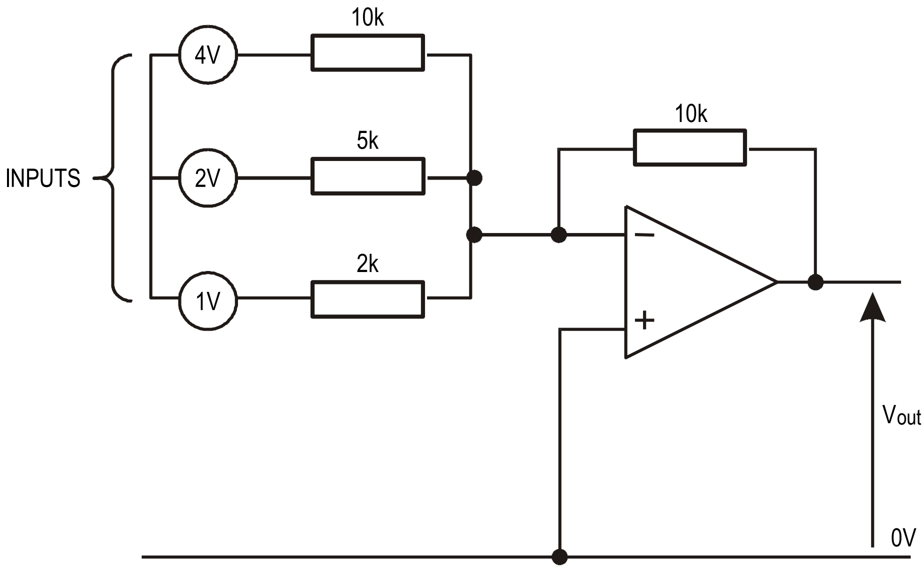
$$V_{out} = -Rf\left(\frac{V1}{R1} + \frac{V2}{R2} + \ldots\ldots\right)$$

Notes:

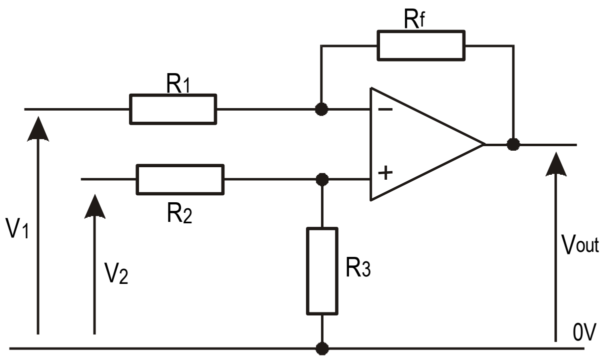
- any number of inputs can be added in this way.
- R_f affects the gain of every input.
- if all the resistors are the same size, then the gain for each input will be -1 and $V_{out} = -(V_1 + V_2 + V_3 + \ldots\ldots)$

Task 27

Determine the output voltage for the circuit shown below



The Difference Op-Amp



Here both inputs are used. The op. amp. amplifies the difference between the two input signals. To ensure that each input is amplified by the same amount, the circuit is designed so that the ratio:

$$\frac{Rf}{R1} = \frac{R3}{R2}$$

To ensure that the input resistance of the circuit for each input is the same,

$$R_1 = R_2 + R_3$$

Characteristics of the difference amplifier

$$Av = \frac{Rf}{R1} \qquad Vout = \frac{Rf}{R1} \times (V2-V1)$$

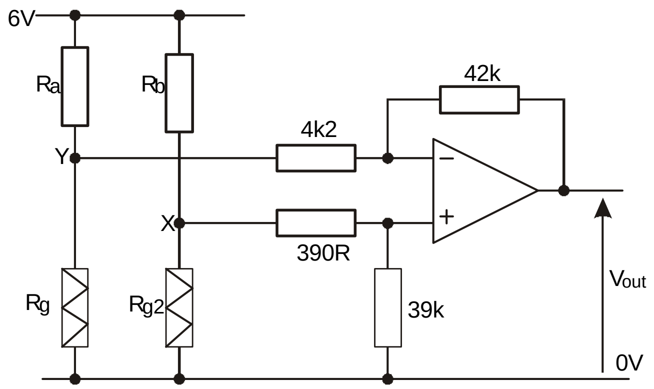
input resistance = R_1

Notes:

- if $R_1 = R_f$ then $A_V = 1$ and $V_{out} = (V_2 - V_1)$, the circuit works as a "subtracter".
- the output will be zero if both inputs are the same.
- This circuit is used when comparing the difference between two input signals.

Task 28

Two strain gauges are connected to a difference amplifier as shown



$R_A = R_B = 1$ k, when not under strain, $R_{g1} = R_{g2} = 200\ \Omega$

a) Calculate the voltage at X and Y when both gauges are not under strain and hence determine the output voltage of the amplifier.

b) As the strain of R_{g2} increases, its resistance increases from 200 to 210 Ω, determine the new output voltage.

c) What would you expect to happen to the output voltage if both gauges were put under the same amount of strain?

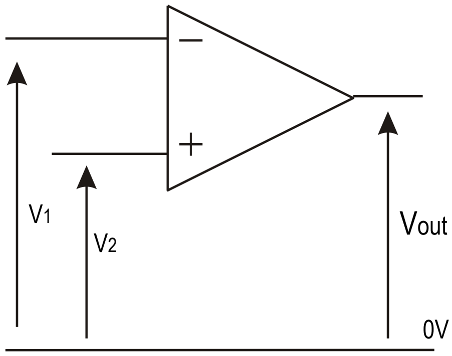
The Comparator

This is a special case of the difference amplifier in which there is no feedback. The gain of the circuit is therefore A_o and any small difference in the two input signals is amplified to such an extent that the op. amp. saturates (either positively or negatively).

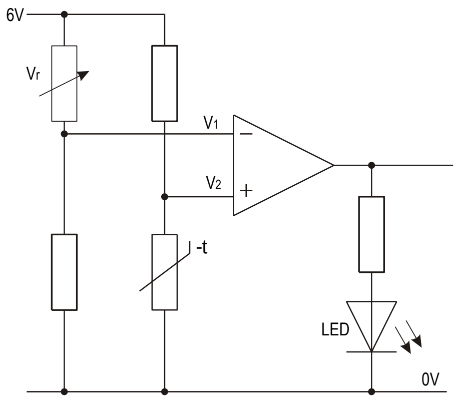
$A_V = A_O$

$V_{OUT} = A_O \times (V_2 - V_1)$

hence if $V_2 > V_1$, V_{out} is **positive**,
if $V_2 < V_1$, V_{out} is **negative**

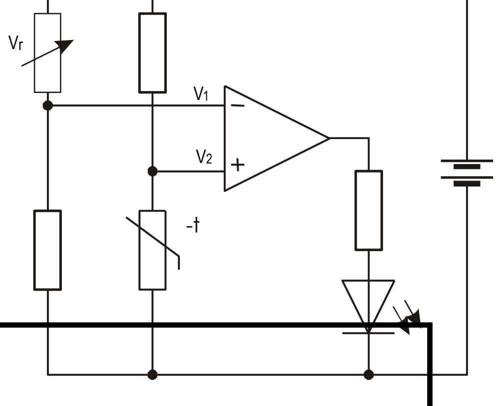


This is commonly used in control circuits in which loads are merely switched on and off. e.g. The circuit shown below would give an indication when the temperature falls below a preset value (0°C for example).



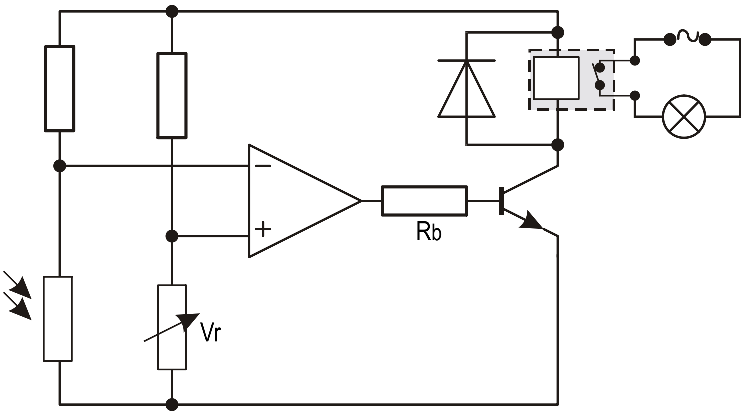
V_r is adjusted until V_1 is just greater than V_2, the output will therefore be negative and the led will be off.
As the temperature falls, the resistance of the ntc thermistor rises and therefore V_2 starts to rise. Eventually, $V_2 > V_1$, the output goes positive and the led lights.

Since nothing happens when the output of the op. amp. goes negative, this circuit could be operated from a single power rail (as oppose to a dual power rail) as shown below
Here, when $V_1 > V_2$, the output will try and go "as negative as possible" i.e. down to 0 volts and the led will be off.



Task 29

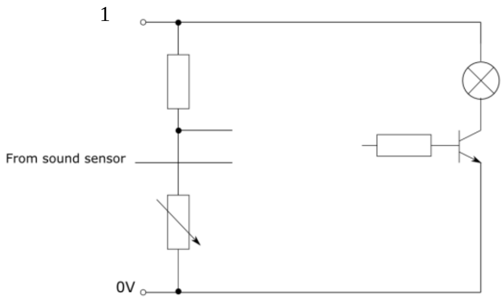
Describe the operation of the circuit shown below and state the purpose of the variable resistor V_r and the fixed resistor R_b
(for clarity, the d.c. power supply has not been shown)



Task 30

A music venue uses a lamp as a lighting effect, whose brightness varies proportionally with the sound level measured by a sound sensor.

a) Complete the control circuit by adding a suitable op-amp.



b) Construct the circuit on prototype board. (Use a potentiometer to simulate the input from the sound sensor.)
Attach photo below

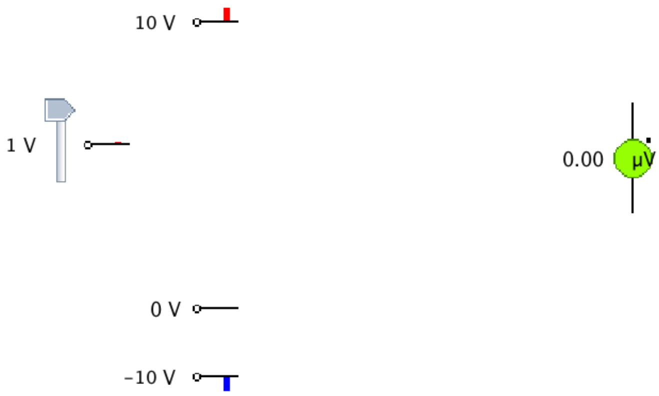
Task 30 (continued)

c) Describe the tests you performed and the results you observed.

d) Suggest at least one adaptation to your system that would make it perform better in a real environment.

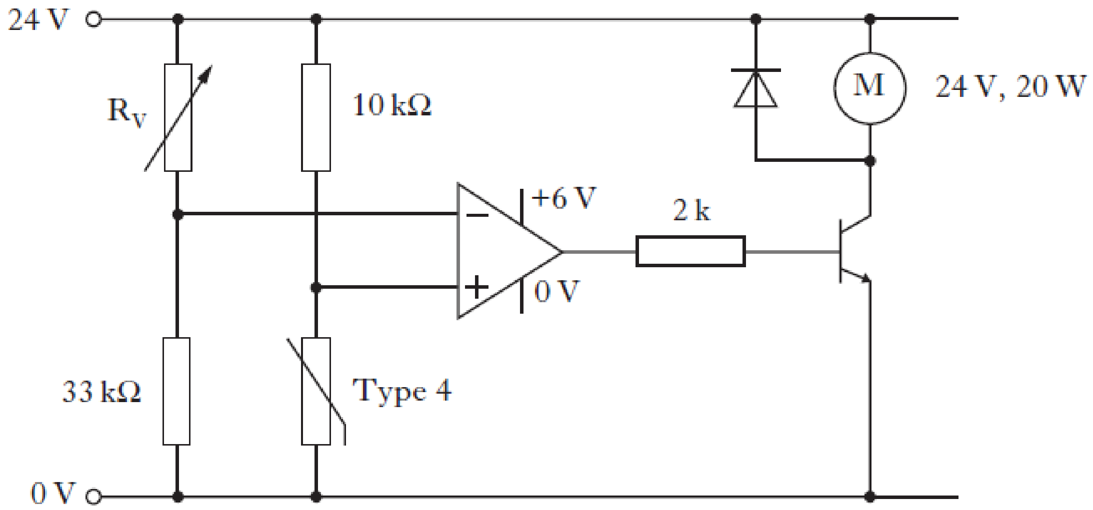
An amplifier is required to increase the size of the signal from an electric guitar.

e) Design and simulate an op-amp circuit, which will amplify output voltages in the range 0–1V from the guitar to voltages in the range 0-3V.



Task 31

The circuit shown below is used to control the operation of a motorised valve in a central-heating system.



The motor should operate when the room temperature sensed by the thermistor is 16 °C.

(a) Calculate the required value of resistor RV.

(b) Calculate the minimum required gain of the transistor.

(c) Explain the reason for the inclusion of a diode in this circuit.

Task 31 (continued)

The motorised valve is to be replaced by another unit containing a motor rated at 24 V, 50 W. This motor requires a Darlington Pair driver circuit.

(*d*)

(i) Calculate the minimum current gain required to operate the new valve.

(ii) Sketch the required transistor circuit.

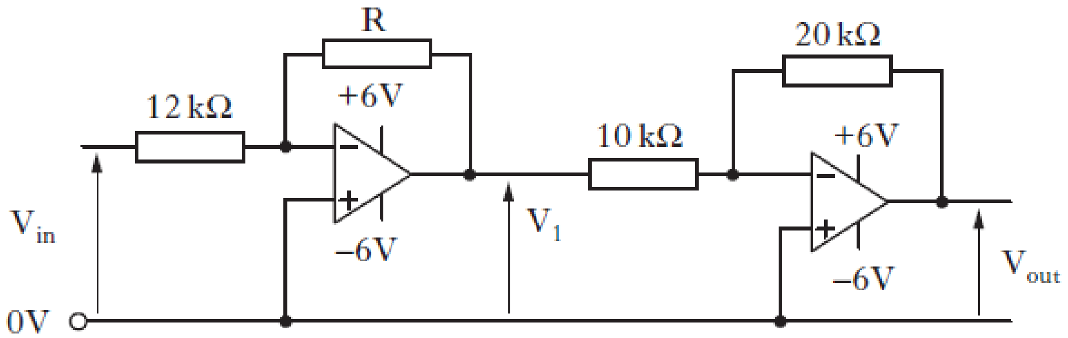
The first transistor in the Darlington Pair is a BC182L with the operating characteristics shown in the table below.

Device	V_{CE} max (V)	I_C max (mA)	h_{FE}
BC107	45	200	100
BC182L	50	100	120
2N3705	30	600	50

(*e*) Calculate the minimum required current gain for the second transistor in the Darlington Pair.

Task 32

The circuit shown below is used to amplify the signal produced by a flow sensor in part of a chemical plant.



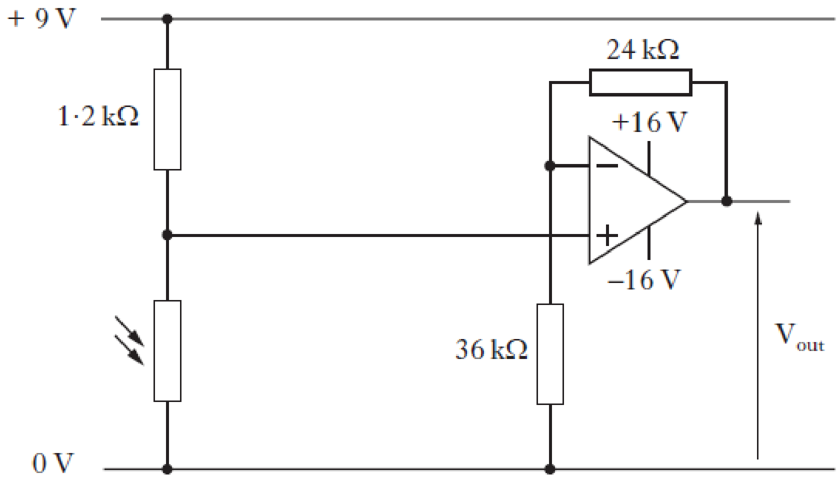
a) (i) State the name of the op-amp configuration used in the circuit shown above

(ii) Explain the reasons for the inclusion of the second op-amp in this circuit.

(b) Calculate the required value of resistor, R, so that Vout reaches its maximum value when Vin is 0·68 V.

Task 33

The circuit shown below is used in a light-sensing system for a camera.



(*a*) Calculate the output voltage, Vout, when the light level is 80 lux.

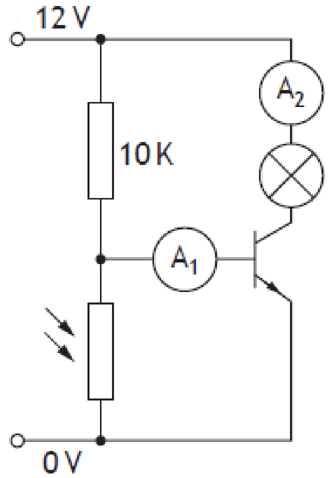
(*b*) Determine the minimum light level that this system can respond to before the operational amplifier (op-amp) saturates.

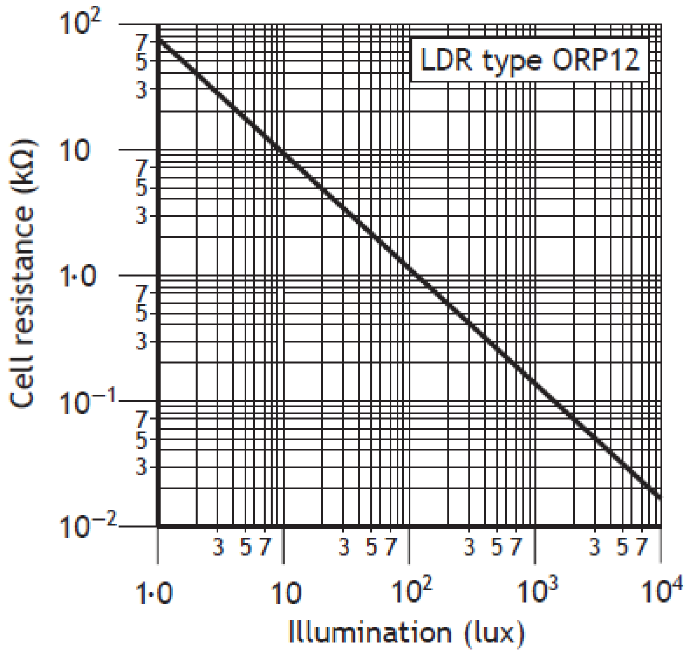
MOSFET transistors are used in the camera.

(*c*) State **two** advantages of a MOSFET transistor, when compared with a bipolar transistor.

Task 34

An engineering technician is testing the circuit shown below to determine the gain of the bipolar junction transistor (BJT).





(a) Determine the light level to fully saturate the transistor. Refer to the graph shown, which shows how the resistance of the LDR responds to light level. Assume VBE = 0·7 V.

The two currents measured at A1 and A2 were 1·2 mA and 110 mA respectively.

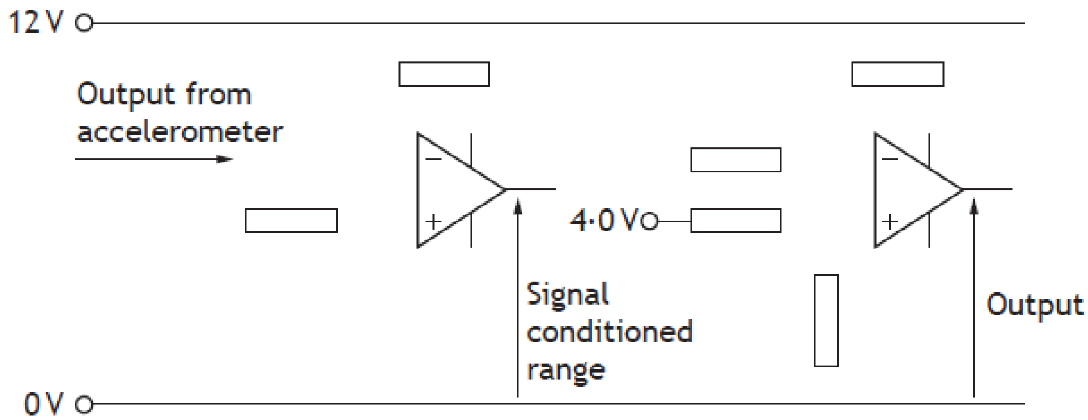
(b) Calculate the hFE value.

Task 35

An electronic engineer is designing an op-amp control system for a laser level device and has developed the following specification:

- The voltage which represents the laser being horizontal is 4·0 V
- The accelerometer produces an output in the range 10–30 mV
- The output from the accelerometer must be amplified to a range of 2·0–6·0 V
- The amplified range should be compared to the desired level voltage (4·0 V), and the difference between them amplified by 3·0 to produce the output.

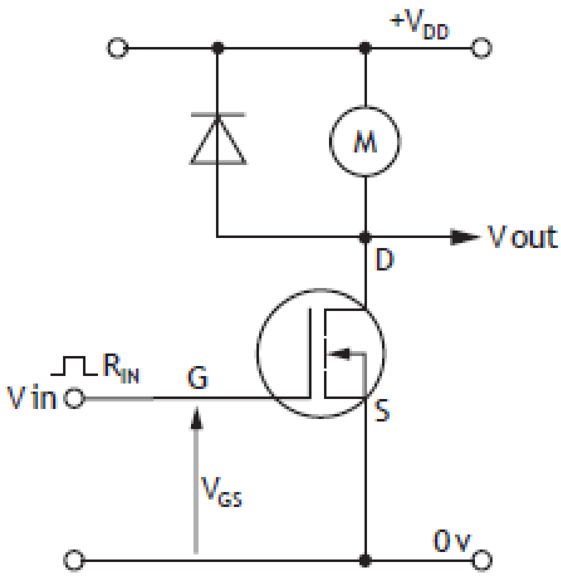
a) Complete the op-amp control system below. Show all working and component values. You do not need to show the +ve and −ve supplies to the op-amps.



Show working here

Task 35 (continued)

An electronic engineer decided that one of the platform levelling motors would be controlled using the circuit shown below. The motor is controlled by a microcontroller using Pulse Width Modulation (PWM) and it is important the control system uses as little power as possible. The motor has a power rating of 12 V 200 W and the n-channel MOSFET has an RDS value of 0·1 Ω and is fully saturated



b) Explain why the electronic engineer might choose to use a MOSFET rather than a BJT for this particular application.

c) Describe an emerging technology which may significantly change the design of transistors and other electronic components in the near future.

Task 36

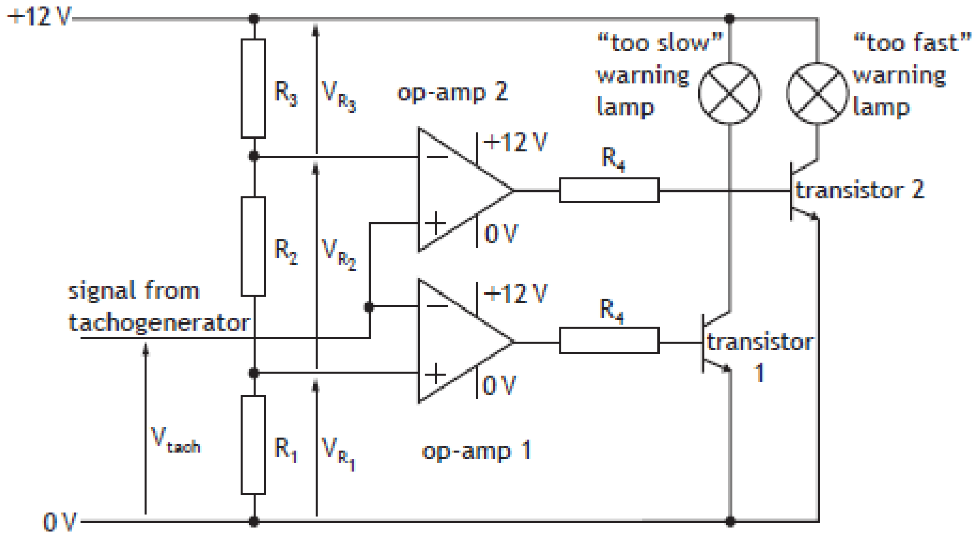
An electrical engineer is designing a small-scale community-based hydroelectric scheme. It will use the water in a river to turn a turbine and generator. The turbine should turn at a constant speed.

A tachogenerator on the turbine shaft generates a voltage proportional to the shaft speed. A control system processes this signal to control a motorised valve, which either increases or decreases water flow to the turbine, in order to control its shaft speed.

(a) Draw a control diagram for this control system. Label all sub-systems.

Task 36 (Continued)

The circuit shown gives a warning if the turbine speed is either too fast or too slow.



(b) Explain the operation of the circuit shown above.

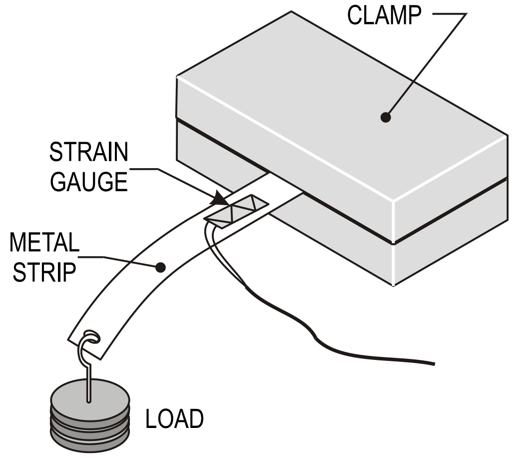
A warning lamp shows when the turbine speed varies by more than 5% (±0·15 V) from the output of 3 V.

(c) The total resistance of the resistor ladder in the circuit above is 12kΩ.
Calculate appropriate values for resistors R1, R2, and R3.

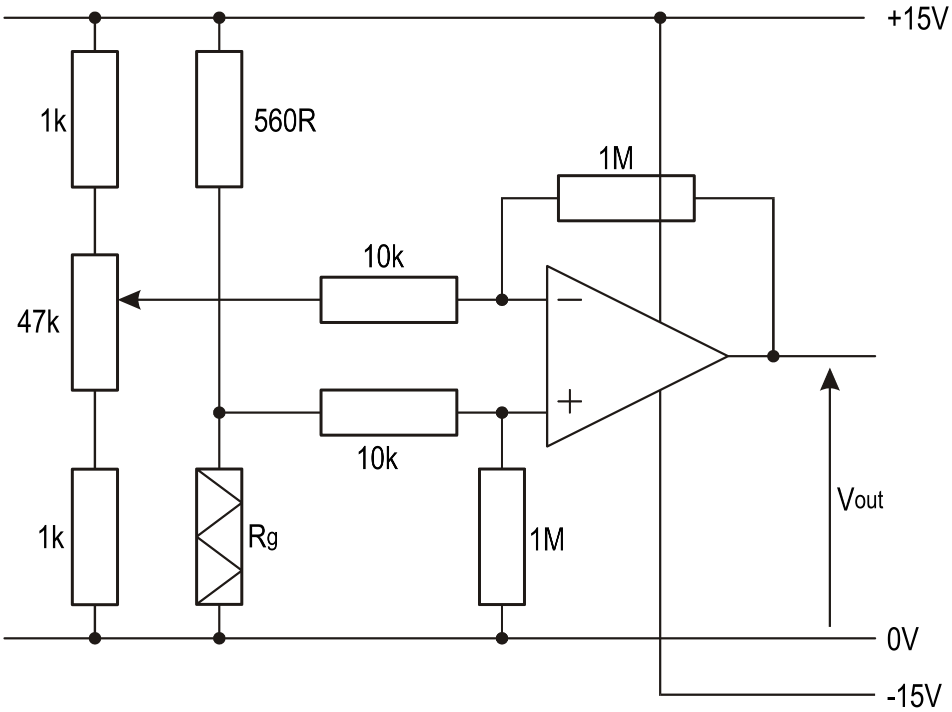
Measurement of Load

Strain gauges can be used to investigate the load on particular members of a construction. The resistance of a strain gauge depends on whether it is under tension or compression. The diagram below shows a single strain gauge bonded to the upper face of a metal strip.

It will also however depend on temperature.



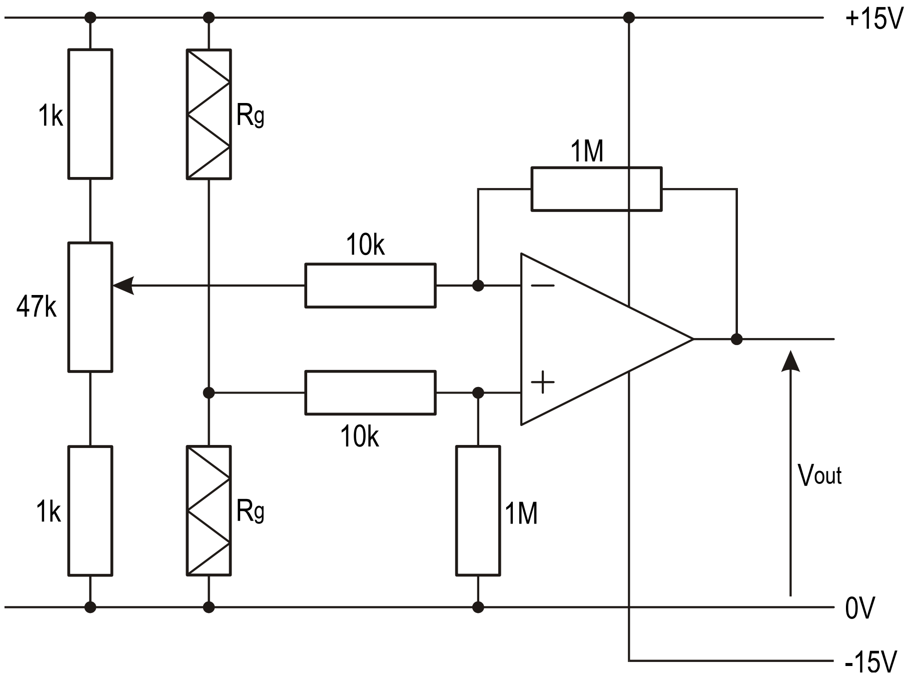
As loads are placed on the strip, it bends, stretches the strain gauge which in turn changes resistance. This change in resistance can be amplified using a differential op. amp. Circuit as shown below.



Construct the circuit as shown in the previous page. Adjust the variable resistor so the voltmeter reads zero when no load is applied to the metal strip.

Determine if the voltage output is proportional to the load applied to the strip.

Since the resistance of the gauge also depends on temperature, any temperature change will be "recorded" as a change in load. In order to overcome this, it is normal to use two strain gauges in a voltage divider circuit.



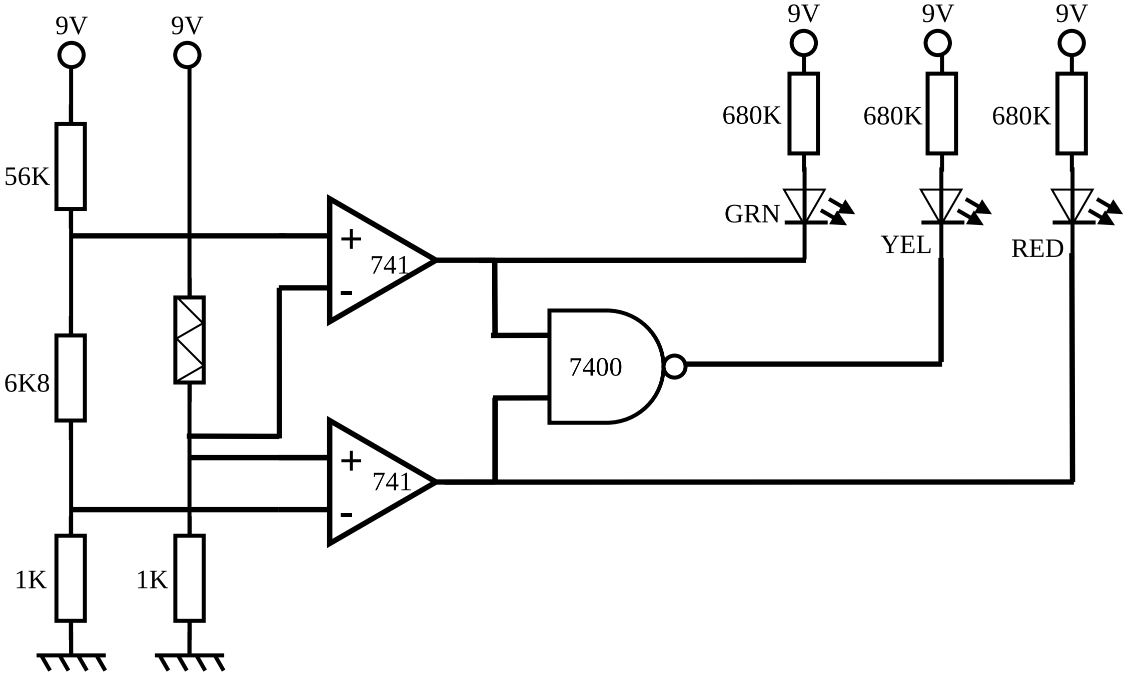
Assuming both gauges remain at the same temperature, they will both change resistance by the same amount and therefore the circuit will remain in balance.

Further, if the second gauge is placed beneath the strip, as load is added, the first gauge will be under tension while the second will be in compression. This will have a doubling effect.

Task 37

A new cocktail bar is opening in Aberdeen. As they are expecting this to be extremely popular they want something to help their waiters and waitresses to realise when customers are nearly finished their drinks.

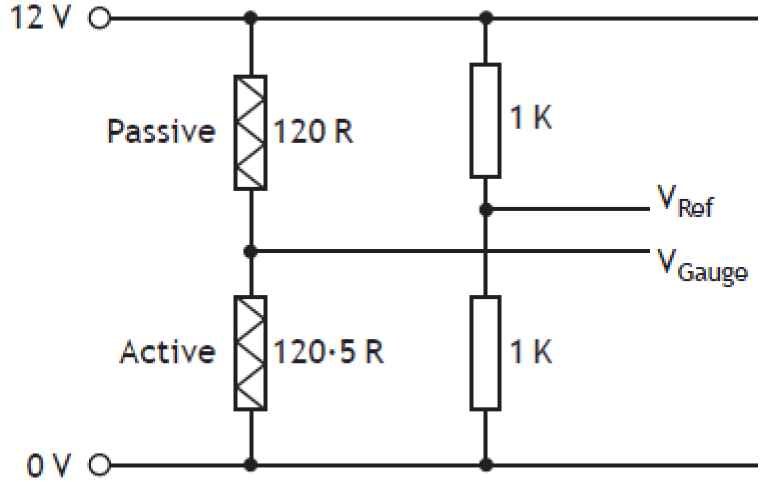
An electrical Engineer has come up with a design to create "glowing" coasters. They will be green when the drink is full, glow yellow when half full, and when empty glow red. The circuit diagram for the electronics is below.



a) Build this circuit using breadboards. Take a photo of your circuit and stick below.

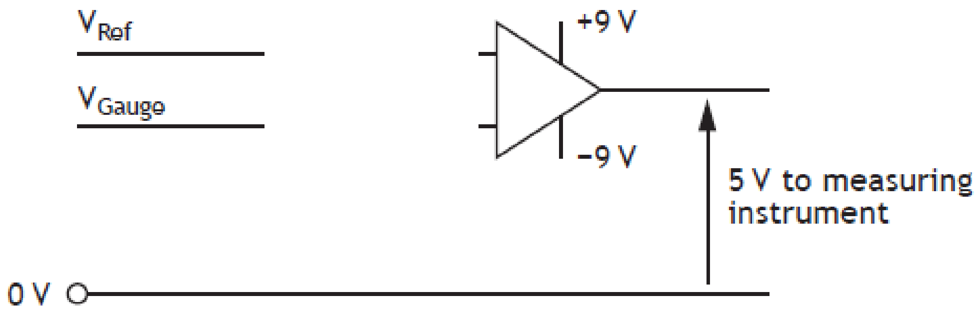
Task 38

The instantaneous load at various points on the bridge is monitored using strain gauges attached to the support cables. When the cable is under maximum permitted strain, the resistance of the active gauge rises to 120·5 Ω and the passive gauge remains at 120 Ω. The sensing part of the circuit at maximum permitted strain is shown below.



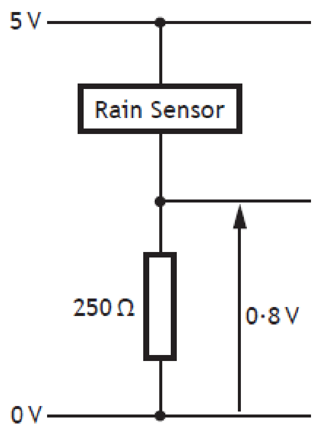
The measuring instrument requires a voltage of 5 V to give a reading showing the maximum permitted strain.

Complete the circuit below, showing all component values, to provide the signal conditioning described. Working should be to six significant figures.



Task 39

A sports centre is building a retractable roof over a synthetic pitch. The roof will open and close depending on the amount of rain that is falling. Part of the input sensing circuit is shown.



a) Calculate the resistance of the rain sensor.

b) An operational amplifier based circuit is used to change voltages to the required values ("Signal conditioning"). The output from the voltage divider has to be increased from +0·8 V to +4 V.

(i) State the name of a suitable op-amp circuit.

(ii) Calculate the required gain.

(iii) Sketch a suitable op-amp circuit diagram showing appropriate resistor values.