

# UNIT 3 ELECTRONICS & PHOTONICS

Quick notes on Unit 3 Electronics and Photonics-v3

*Luxvis*

<b>2-CORE</b>	<b>Study design 2009 – 2012: Unit 3: Electronics and photonics</b>
	apply the concepts of current, resistance, <b>potential difference</b> (voltage drop) and power to the operation of electronic circuits comprising diodes, <b>resistors</b> , <b>thermistors</b> and photonic transducers including light dependent resistors (LDR), photodiodes and light emitting diodes (LED), ( $V=IR$ , $P=VI$ );
	<b>Calculate</b> the effective resistance of circuits comprising parallel and series resistance and unloaded voltage dividers;
	describe energy transfers and transformations in opto-electronic devices;
	describe the transfer of information in analogue form (not including the technical aspects of modulation and demodulation) using: <ul style="list-style-type: none"> <li>i) light intensity modulation, i.e. changing the intensity of the carrier wave to replicate the amplitude variation of the information signal so that the signal may propagate more efficiently;</li> <li>ii) demodulation, i.e. the separation of the information signal from the carrier wave;</li> </ul>
	<b>design, investigate and analyse</b> circuits for particular purposes using technical specifications related to <b>potential difference</b> (voltage drop), current, resistance, power, <b>temperature</b> and illumination for electronic components such as diodes, <b>resistors</b> , <b>thermistors</b> , light dependent resistors (LDR), photodiodes and light emitting diodes (LED);
	<b>analyse</b> voltage characteristics of amplifiers including linear voltage gain ( $\frac{\Delta V_{out}}{\Delta V_{in}}$ ) and clipping;
	<b>identify and apply safe and responsible practices when conducting investigations</b> involving electrical, electronic and photonic equipment.

Background on Electricity

Basic Facts

### Quick Review on electricity

- Net movement of charge in 1 direction for a current to exist
- Conventional current = movement of positive charges from the + terminal to the – terminal
- Electric Current = measure of rate of flow of charge

$$I = \frac{Q}{t}, \text{ where } Q = \text{quantity of charge (measured in Coulombs, C), } t = \text{time in seconds}$$

Now 1C is equal to the amount of charge carried by  $6.24 \times 10^{18}$  electrons.

The charge on a single electron is  $1.6 \times 10^{-19}$  C (now the charge possessed by an electron is the smallest free charge possible- all other charges are whole number multiples of this value)

Charge is a fundamental quantity of nature. There are in atoms positively charged protons and negatively charged electrons. When an object becomes charged it either gains or loses electrons. The unit for charge is the Coulomb which was based on the amount of charge to produce a force of

repulsion between like charges of 1.0 Newton. When the electron was discovered, it was found that the Coulomb was an enormous amount of charge, at least in terms of electrons. One Coulomb of charge consists of  $6.25 \times 10^{18}$  electrons or the other way round, the charge on one electron is  $1.6 \times 10^{-19}$  Coulomb.

Current is the rate at which electric charge flows through a wire. It is calculated as the amount of charge passing a point every second. It has the units of Coulomb/Second or its own unit of the Ampere. The formula for this definition is therefore Current (I) = Charge (Q) / Time (t),  $I = Q / t$ , which is usually remembered as  $Q = It$ .

Batteries supply energy to charge to travel around the circuit through the resistances. The voltage, or EMF (electromotive force), of a battery is a measure of how much energy, in joules, the battery gives to each coulomb of charge that leaves the terminals. In other words a 9 volt battery gives 9 joules of energy to one Coulomb of charge, 18 joules to two Coulombs, etc.

That is, the energy supplied by the battery = the EMF (Voltage) of the battery x the Amount of charge leaving.

$$W = V Q$$

Using the definition of current, this becomes:

$$W = V I t$$

All this supplied energy is used up as the charge goes through the resistances in the circuit. The energy lost in a resistance will have the same expression with “V” being the potential difference or voltage drop across the resistance.

**Question 1:** Find I if 10 Coulombs of charge pass a point in 5 seconds?

Solution:

$$Q = 10C \quad t = 5 \text{ seconds}$$

$$I = \frac{Q}{t}$$

$$I = \frac{10}{5} = 2$$

**Question 2:** How much charge pass through a load if current of 3A flows for 5 minutes and 20 seconds

Solution:

$$I = 3, \quad t = (5 \times 60 + 20) = 320 \text{ sec}$$

$$Q = I \times t$$

$$Q = 3 \times 320$$

$$Q = 960$$

**Question 3:** Convert 450 mA into amperes

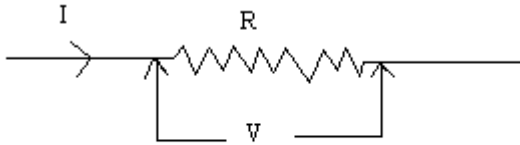
Solution:

$$\frac{450}{1000} = 0.45 \text{ A}$$

Ohms law

Georg Simon Ohm (1787-1854), a German physicist, discovered Ohm's law in 1826. This is an experimental law, valid for both alternating current (ac) and direct current (dc) circuits.

When you pass an electric current ( $I$ ) through a resistance ( $R$ ) there will be an electric potential difference ( $V$ ) created across the resistance.

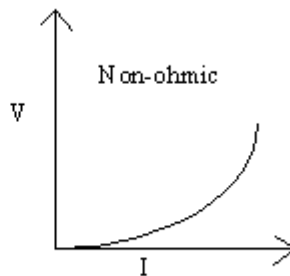
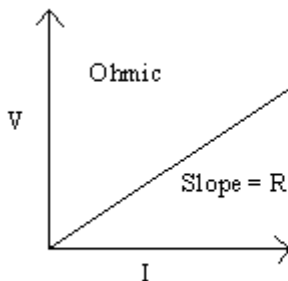


Ohm's law gives a relationship between  $V$ ,  $I$  and  $R$  as follows.

$$V = IR$$



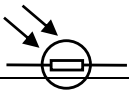
For ohmic resistances,  $V$  versus  $I$  is a linear relationship, and they have a constant resistance. Resistance can be calculated using the Ohm's law,  $R = V/I$ . The slope of the  $V$  versus  $I$ , line will also give the resistance,  $R$ .



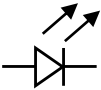
For non-ohmic resistances,  $V$  versus  $I$  is a non-linear relationship, and they have a varying resistance. The resistance at a particular point can be calculated using Ohm's law,  $R = V/I$ , where  $V$  and  $I$  are the voltage and current at that point.

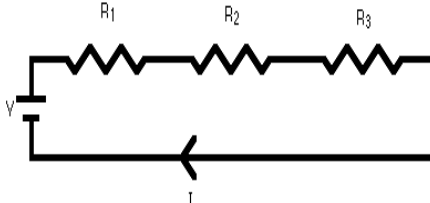
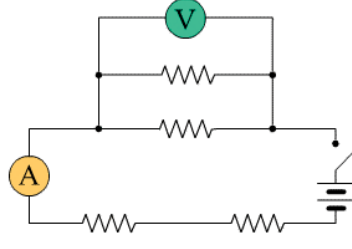
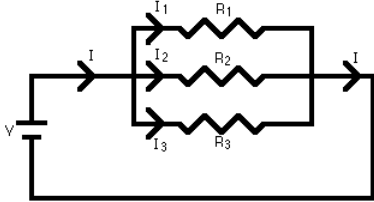








Common Formulas and explanations

Basic Formula	Explanation of symbols	Example
$I$	Current measured in amperes, conventional direction is from + positive terminal to - negative terminal of battery	
$V$	Actually it should be the $\Delta V$ the change of voltage, that is why it is called the potential difference	
$I = \frac{Q}{t}$	$I$ - current measured in amperes $Q$ - charge (measured in coulomb, C) $t$ - time (measured in seconds)	If 12C of charge pass a point in 3 sec find the current flowing? $I = \frac{Q}{t} = \frac{12}{3} = 4$ amps
1 C is equivalent to	Therefore 1 electron carries	How many electrons does 0.6C equal

$6.24 \times 10^{18}$ electrons carrying the same charge	$\frac{1}{6.24 \times 10^{18}} = 1.6 \times 10^{-19} \text{ C}$	too? $0.6 \times 6.24 \times 10^{18} = 3.744 \times 10^{18}$
$V = I \times R$	This is called Ohm's law V – voltage (measured in volts) I – current (measured in amps) R- resistance (measured in ohms)	If the current is 2 amps and the resistance is 300 ohms, what is the voltage difference across the element? $V = I \times R = 2 \times 300 = 600 \text{ Volts}$
$W = Q \times V$	W- work done or energy used up-measured in Joules Q -charge (measured in coulomb ,C) V- Voltage difference (actually potential difference, measured in volts)	If the charges that passes is 1.1C and the V is 200V then the work done is $W = Q \times V = 1.1 \times 200 = 220 \text{ J}$
$W = V \times I \times t$	W- work done or energy used up-measured in Joules	
$P = \frac{W}{t}$	P- Power measured in Watts , W W- work done or energy used up-measured in Joules t- time measured in seconds	
$P = \frac{V^2}{R}$	P- Power measured in Watts , W V- Voltage difference (actually potential difference, measured in volts) R- resistance (measured in ohms)	
$P = V \times I$	P- Power measured in Watts , W I – current (measured in amps)	
$P = \frac{V^2 \times t}{R}$	P- Power measured in Watts , W V- Voltage difference (actually potential difference, measured in volts) R- resistance (measured in ohms)	
<b>Series Circuit</b>		
$R_T = R_1 + R_2 + R_3$	To find the total resistance add all the resistors together	
	Current remains the same throughout the circuit provided it is a pure series circuit, but voltage is different	
	Voltage is different for each resistor. Adding up the voltage lost across each resistors gives us the total voltage supplied to the circuit.	
<b>Parallel Circuit</b>		
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	Voltage remain constant for all resistors but the current changes- opposite to the series circuit	
<b>Various Diagrams</b>		
	Battery	
	Resistor- to restrict the flow of current. They may be connected either way round. Resistance is measured in ohms	
	LDR-light dependent resistor- a thermistor An LDR is an input transducer (sensor) which converts bright light to resistance. Its resistance decreases as the brightness of light falling on it	

	increases	
	<p>Junction diode</p> <p>Diodes allow electricity flow in only one direction. The arrow of the circuit symbol shows the direction in which current can flow. </p>	<p>Ordinary diodes can be split into two types signal diodes , which pass small currents and rectifier diodes which can pass large currents.</p> <p>Diodes must be connected the correct way- cathode (-) is marked by a line painted on the body.</p>
	<p>Light emitting diode</p> <p>LEDs emit light when an electric current passes through them.</p> <p>Must be connected correctly</p> <p>Anode (+) is the longer lead</p> <p>Cathode (-) is the shorter lead symbol , k,</p>	<p>An LED must have a resistor connected in series to limit the current through the LED otherwise it will burn out almost instantly.</p>
<b>Simple definitions</b>		
Open circuit	Open circuit means no connection. It is usually used to describe a break in some part of a circuit	
Short circuit	A short circuit is a connection of very low resistance such as a wire which is very low and provides a very easy path for current to take. For example if the leads of a battery touch one another they create a very low resistance connection across the battery. Current will flow through this short circuit instead of going through the circuit. It may cause a fire since the wires will become hot with a large current flowing.	
Voltage	<ul style="list-style-type: none"> <li>• Voltage is a measure of the energy carried by the charge ( it is the energy per unit charge)</li> <li>• Its proper name is the potential difference but it is not often used</li> <li>• The voltage is normally supplied by something either a battery or a power source</li> <li>• Voltage is normally measured across a component and it is measured in volts.</li> <li>• A voltmeter measures volts and it is connected in parallel</li> <li>• So voltage is the difference between two points, but in physics we normally refer to the voltage at a point meaning the potential difference between that point and a reference point which we call 0 volts, normally the negative terminal of the battery.</li> <li>• You might find it useful to think of voltage the same way we think of gravitational potential energy. The zero point is the ground and all heights are measured from that point, something similar happens in electronics.</li> <li>• So voltage attempts to make a current flow and current will flow if the circuit is complete. Voltage sometimes has been liked to a force, but it really is no force. So it is possible to have voltage without current but current cannot flow without voltage.</li> </ul>	
Current	<ul style="list-style-type: none"> <li>• Current is the rate of flow of charges</li> <li>• Current is not used up, what flows into a component must flow out of it.</li> <li>• Current is measured in amperes</li> <li>• It is measured using an ammeter and it must be connected in series.</li> <li>• We normally have small currents such mA –milliamps , 1000mA =1A</li> </ul>	
Millimeters	Millimeters are very useful instruments which are used to test various circuits. By switching the meter we can have either a voltmeter, ammeter or ohmmeter. There are normally different settings for each.	

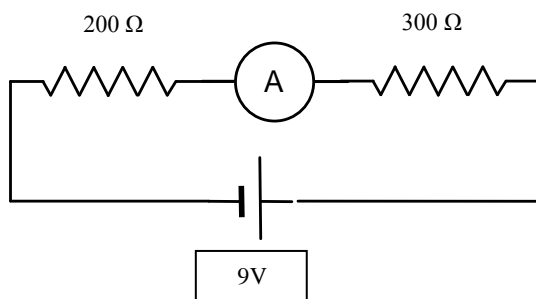
	<p><b>Series</b></p> $V_{\text{total}} = V_1 + V_2 + V_3 \dots$ $I_{\text{total}} = I_1 = I_2 = I_3 \dots$ $R_{\text{total}} = R_1 + R_2 + R_3 \dots$   <p><b>Combination circuit</b></p>	<p><b>Parallel</b></p> $V_{\text{total}} = V_1 = V_2 = V_3 \dots$ $I_{\text{total}} = I_1 + I_2 + I_3 \dots$ $1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3 \dots$  <p>  Voltmeter is connected parallel.   Ammeter is connected in series.   resistor   switch,  batteries,   capacitor (stores energy) </p>
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### Circuit analysis

**Question 1:** Find the total resistance if the following resistors are joined together **in series** and then **in parallel**

- 400 ohms + 300 ohms
- 400 ohms + 100 ohms
- 2 k $\Omega$  + 10 k $\Omega$
- 12.3 k $\Omega$  + 23 k $\Omega$  + 0.34k $\Omega$

**Question 2:** Analyse the following circuit below and then answer underneath



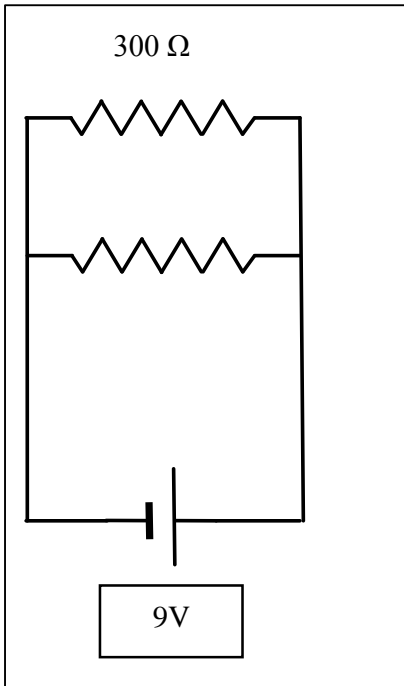
- Find the total resistance for this circuit
- Find the current flowing through circuit
- What is the voltage lost across the 200 ohm resistor?
- What is the voltage lost across the 300 ohm resistor?
- Do the two voltages lost across the resistors equal the voltage supply by the battery?

**Question 3:** Using Ohms law complete the following table

Voltage ( V )	Current ( in amps )	Resistance ( in ohms )
25	5mA	R
3.3	250mA	R
V	2.34	24k $\Omega$

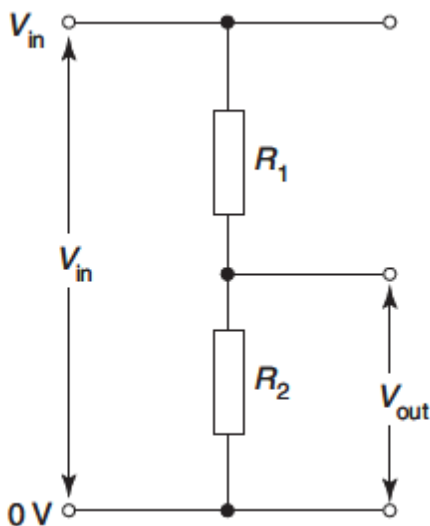
V	12	200Ω
100	2	R
12	3mA	R

**Question 4: Parallel Circuits Quick Question**



1. What is the voltage across each resistor, assuming that both resistors have the same resistance?
2. What is the current in each resistor?
3. How much power is used up by the 300 ohm resistor?
4. Simplify the circuit into a simpler circuit

**Voltage dividers**



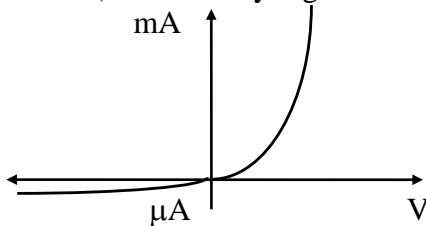
$$V_{out} = \frac{R_2 V_{in}}{R_1 + R_2}$$

What is the big deal about a voltage divider?

Nothing special is just provides us a way of restricting how much voltage and be extension how much current goes through a particular component.

## DIODES-LEDS-THERMISTORS

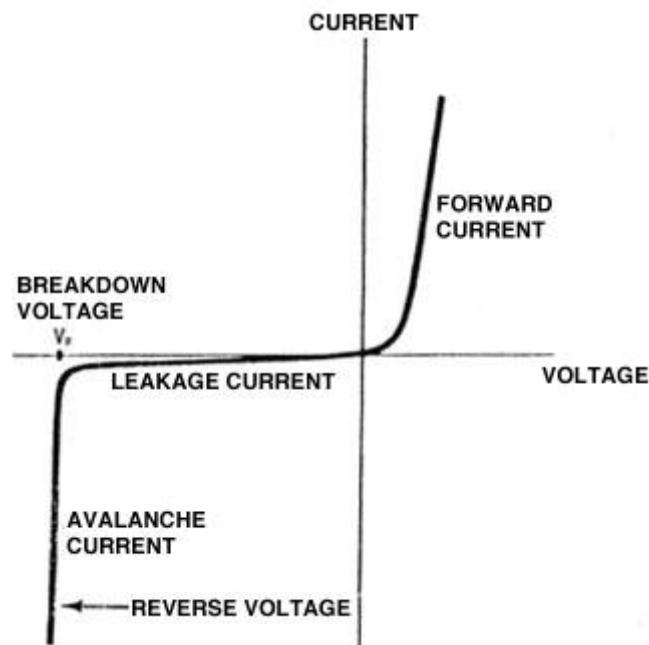
**Diodes** have a unique graph that indicates that they easily conduct (have a very low resistance) in one direction called forward bias, and will only allow microamps in the other direction called reverse bias (an extremely high resistance). This is useful in changing AC into DC.



When a non-linear device is operating in a circuit, its resistance is the voltage across it divided by the current through it, rather than the value of the gradient of the non-linear graph at the point.

Diodes become conducting at about 0.7 V and the voltage drop across a diode stays at this value for further increases in the current. So in order to protect the diode from overheating and blowing, a protective resistor is placed in series with the diode to limit the current.

A typical exam question is to calculate the current in a circuit with a diode and a known resistor connected across a 9 V battery.



## Function

Diodes allow electricity to flow in only one direction. The arrow of the circuit symbol shows the direction in which the current can flow. Diodes are the electrical version of a valve and early diodes were actually called valves.

## Forward Voltage Drop

Electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the forward voltage drop and is about 0.7V for all normal diodes which are made from silicon. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (current-voltage graph).

## Reverse Voltage

When a reverse voltage is applied a perfect diode does not conduct, but all real diodes leak a very tiny current of a few  $\mu\text{A}$  or less. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction. However, all diodes have a **maximum reverse voltage** (usually 50V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction, this is called **breakdown**.

Ordinary diodes can be split into two types:

**Signal diodes** which pass small currents of 100mA or less and **Rectifier diodes** which can pass large currents.

In addition there are **LED'S** and Zener diodes .

**Light Emitting Diodes (LEDs)** are diodes that emit light when a current pass through them. Their graphs is similar to that of an ordinary diode, but they need a voltage in excess of 1.7 V to conduct and emit light.

Photodiodes are diodes used in the reverse bias mode that is the left half of the above graph in the 3<sup>rd</sup> quadrant. In this mode the leakage current is very small, but in the design of a photodiode the effect of light shining on the device is to increase this leakage current in a linear way, that is the leakage current is directly proportional to the light intensity. This makes the photodiode a very effective transducer, that is, a device that converts changes in a physical quantity, in this case the light intensity, into a voltage.

**Light Dependent Resistors (LDRs)** are resistors that are made of semi-conductor material. This means that when light shines on the material more electrons are made available to contribute to a current driven by a voltage. The effect of this is that the resistance of the device decreases with light intensity. LDRs are therefore useful transducers. The graphs of resistance versus light intensity are usually represented as log-log graphs, so care needs to be taken in reading the scales.

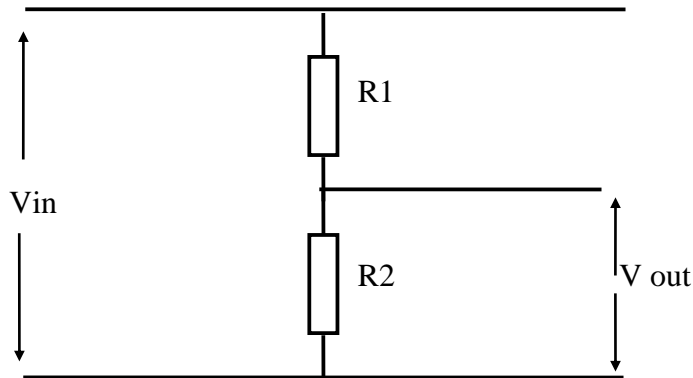
**Thermistors** are resistors that are also made of semi-conductor material. Their resistance decreases with a rise in temperature. The resistance scale for their graphs usually has a log scale. Positive coefficient thermistors whose resistances increases as temperature increases. Negative coefficient thermistors there resistance decreases as temperature increases.

When current is graphed against voltage for most conductors, a straight line is obtained. This is reflected in Ohm's Law. However for most materials a non-linear graph is obtained. Such devices include such semiconductor devices as thermistors, LDRs and diodes, and light globes.

Voltage dividers are circuits made of passive components such as resistors, variable resistors or non-linear devices, such as LDR's. They are input/output devices that are designed to give a variable DC voltage that can range from a maximum value set by the DC power supply to zero. They are often used with transducers such as LDRs and thermistors as one of the components.

A typical voltage divider circuit is drawn below.

The output voltage is  $V_{out} = \frac{R_2 V_{in}}{R_1 + R_2}$



Note: The labeling of the diagram and the above formula need to match. That is, Vout is across R2

The information contained in the characteristic curves for LEDs, photodiodes and LDRs can be used to determine the behaviour in voltage divider circuits.

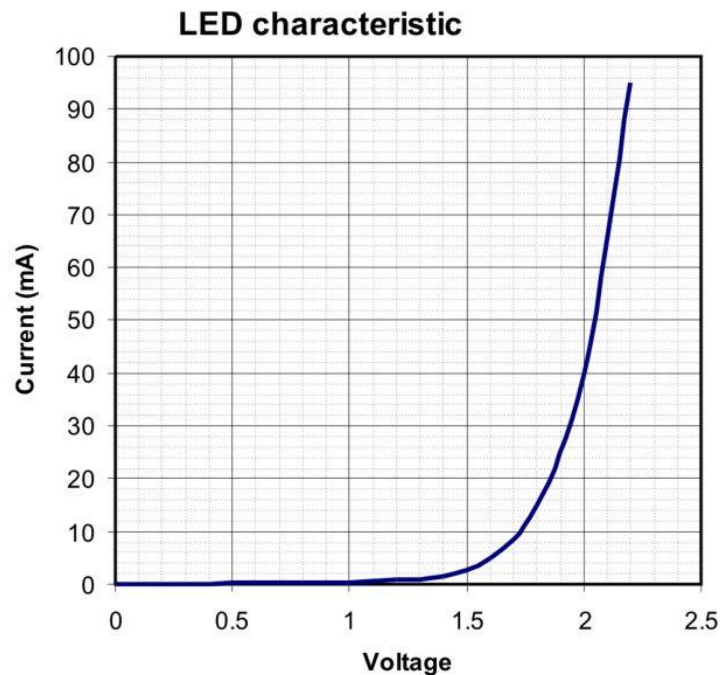
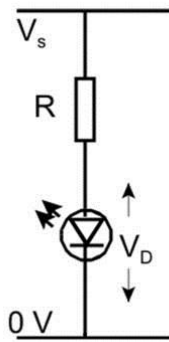
LDRs, thermistors and photodiodes are input transducers. The LDR and the thermistor characteristic curves indicate the resistance at different brightnesses and temperatures respectively. The characteristic curve for the photodiode gives the value of the reverse current for a particular illumination.

LEDs are output transducers. In this case the curve indicates the voltage at which the LED conducts.

Typical Questions

Question 1:

An LED which has the characteristics shown in this graph below and is to be used in the circuit below in which both  $V_s$  and  $R$  can be varied. For this LED the switch on voltage ( $V_D$ ) is 1.7 volt which produces a current of 10 mA at which point the LED will just glow dimly. Let us say that the diode operates brightly at 40 mA, but will fail if the current exceeds 90 mA for too long



Initially the  $V_s = 6V$  answer the following questions

**Question 1: If 40 mA goes through the led what is the voltage across it?**

Solution

Looking at the graph all we need to do is find how much voltage is across the led when a current of 40 mA flows through it. The answer is 2V

**Question 2: If the power supply is set to  $V_s = 6V$ . What value is required for the resistor so that the LED operates at 40 mA?**

Solution

Well in the previous question we found that the voltage across the led is 2V. Now look at the circuit it is a series circuit, which means that the voltage across the resistor and the voltage across the led must add up to the supply voltage of 6V

Therefore the resistor must have a voltage of  $6 - 2 = 4V$

So the voltage through the resistor is 4V and the current through it is 40mA, therefore using Ohm's law we can work out the value of the resistor

$$R = \frac{V}{I} = \frac{4}{\frac{40}{1000}} = 100\Omega$$

Do not forget to change mA into A by dividing by 1000

**Question 3: What is the minimum value of resistor that could be used without damaging the led?**

### Solution

A few steps will be required here:

1. What is the maximum current that the led can stand? **90mA**
2. Now we need to find the voltage across the led when the current is 90mA- so we need to read it off the graph carefully-**2.2V**
3. Now we know that the supply voltage is 6V, so if we subtract 2.2V , we will get the voltage across the resistor: **6-2.2 = 3.8 V**
4. So we now know the voltage across the resistor ( 3.8V) and the current flowing through it ( 90mA),

we use ohm's law and once again we can find the resistance.  $R = \frac{V}{I} = \frac{3.8}{\frac{90}{1000}} = 42.2\Omega$

**Question 4: If a current of 20mA is flowing and the resistance is 200  $\Omega$  , what is the supply voltage?**

### Solution

We have been told the current which is 20mA, so we can find the voltage across the led from the graph. Looking at the graph we see that the voltage drop across is the led is **1.85 V**

Next we can find the voltage lost across the resistor by using ohm's law:  $V = IR = \frac{20}{1000} \times 200 = 4 \text{ V}$

Now we add the two voltages and we get  $4 + 1.85 = 5.85 \text{ V}$  as the supply voltage

**Question 5: If the voltage drop across the resistor is 4.6 V and 2.1 V across the led, what are the supply voltage and the resistance of R now?**

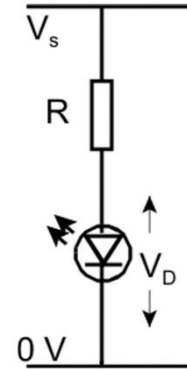
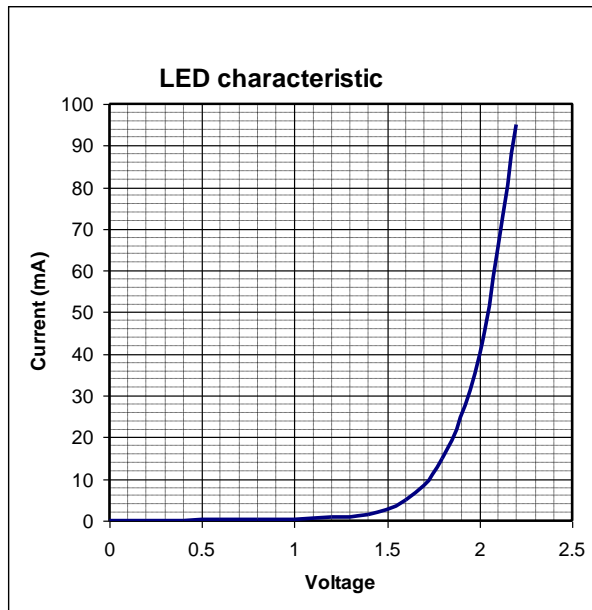
### Solution

1. Supply voltage is simply the addition of the voltage, since this is a series circuit, so **4.6 + 2.1 =6.7 V**
2. Now we need to find the resistance of the resistor: we have the voltage across it but what about the current across the resistor?
3. We need to find the current that flows through the led and that will be the current flowing through the resistor also
4. Looking at the graph we see what the current is for a voltage of 2.1 V- current is 65 mA
5. Now using ohms law we find the resistance  $R = \frac{V}{I} = \frac{4.6}{65\text{mA}} = 70.8$

**Question 6: When 40mA goes through the diode what is its resistance? Assuming the resistor is 200 ohms what would the supply voltage be know? ( student to try)**

An LED which has the characteristics shown in this graph is to be used in the circuit below in which both  $V_s$

and  $R$  can be varied. For this LED the switch on voltage ( $V_D$ ) is 1.7 volt which produces a current of 10 mA at which point the LED will just glow dimly. Let us say that the diode operates best at 60 mA, but will fail if the current exceeds 80 mA for too long.



- Initially the power supply is set at  $V_s = 6\text{ V}$ . What value is required for the resistor so that the LED operates at 60 mA?
- In a similar way, find the minimum value of the resistor that could be used without damaging the LED.
- If a current of 20 mA is flowing and the resistor is  $400\ \Omega$ , what is the supply voltage?
- If we find a voltage across the  $200\ \Omega$  resistor of 2.0 V what is the supply voltage and will the LED be glowing?
- If there is a voltage drop of 6.5 V across the resistor ( $R$  is not  $200\ \Omega$  this time) and 2.1 V across the LED, what is the supply voltage and the resistance of  $R$ ?
- If the supply voltage is 8 V and  $R$  is  $300\ \Omega$ , what will be the current in the LED?

#### Answers

It is easy to make mistakes in converting between units. Make sure you know how to do this!

Note that  $1\ \mu\text{A} = 0.001\ \text{mA}$ ,  $10\ \mu\text{A} = 0.010\ \text{mA}$ ,  $100\ \mu\text{A} = 0.100\ \text{mA}$  and  $1000\ \mu\text{A} = 1\ \text{mA}$  etc. (If you use three decimal places the  $0.\underline{123}\ \text{mA}$  represent the  $\underline{123}\ \mu\text{A}$ , etc. – but be careful about the number of zeros!)

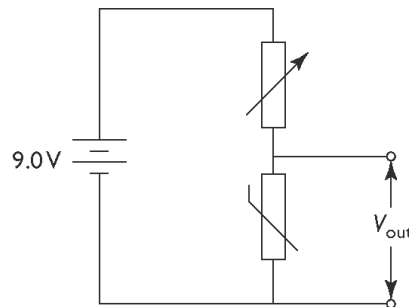
#### LED Test

- $V_R = 6 - 2.1 = 3.9\ \text{V}$  and so  $R = 3.9/0.060 = 65\ \Omega$
- $V_R = 3.85\ \text{V}$ , So  $R = 3.85/0.080 = 48\ \Omega$

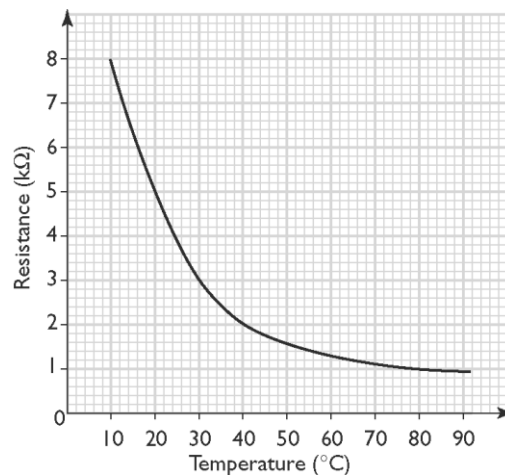
3.  $V_R = 8 \text{ V}$  &  $V_D = 1.85 \text{ V}$  so  $V_S = 9.85 \text{ V}$   
 4.  $I = 2/0.2 = 10 \text{ mA}$  and so  $V_D = 1.7 \text{ V}$  (or  $1.75 \text{ V}$ ) so  $V_S = 2.0 + 1.7 = 3.7 \text{ V}$   
 5.  $V_S = 6.5 + 2.1 = 8.6 \text{ V}$  so from graph  $I = 65 \text{ mA}$  (or  $60 \rightarrow 70 \text{ mA}$ ) so  $R = 6.5/65 = 100 \Omega$  [ $6.5/65 = 0.100\text{k}\Omega = 100 \Omega$ ] or  $93 \rightarrow 108 \Omega$  depending on current taken from graph.  
 6. At  $V_D = 2.0 \text{ V}$ ,  $I = (8 - 2)/0.3 = 20 \text{ mA} \rightarrow V_D = 1.85$   
 At  $V_D = 1.85 \text{ V}$ ,  $I = 6.15/0.3 = 20.5 \text{ mA} \rightarrow V_D = 1.85$  so  $20.5 \text{ mA}$  is the answer.

### Thermistor Question

A voltage divider circuit is set up as shown in the following diagram.



The thermistor has the characteristic curve shown below.



<p>Question 7</p> <p>What is the temperature when the resistance of the thermistor is <math>5 \text{ k}\Omega</math>?</p>	<p><math>20^\circ\text{C}</math></p> <p>(Read from the graph)</p> <p style="text-align: right;">(1 mark)</p>
<p>Question 8</p> <p>What is the resistance of the thermistor when the temperature is <math>80^\circ\text{C}</math>?</p>	<p><math>1 \text{ k}\Omega</math></p> <p>(Read from the graph)</p> <p style="text-align: right;">(1 mark)</p>

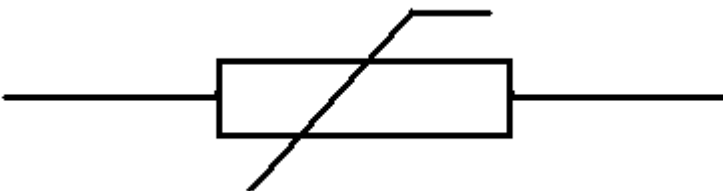
<p>Question 9</p> <p>What is the value of the variable resistor that gives an output voltage of 3.0 V when the temperature is 80°C?</p>	$V_{\text{out}} = \frac{R_2 V_{\text{in}}}{R_1 + R_2}$ $3.0 \text{ V} = \frac{1 \text{ k}\Omega \times 9.0 \text{ V}}{R_1 + 1 \text{ k}\Omega}$ $3R_1 + 3 = 9$ $R_1 = 2 \text{ k}\Omega$ <p style="text-align: right;">(2 marks)</p>
<p>Question 10</p> <p>What happens to the value of the output voltage as the temperature falls and the variable resistor remains at a fixed value? Explain your answer.</p>	<p>As the temperature falls, the resistance of the thermistor increases.</p> <p>This reduces the current through the variable resistor and reduces the voltage drop across it.</p> <p>The voltage drop across the thermistor therefore increases, as does <math>V_{\text{out}}</math>.</p> <p style="text-align: right;">(3 marks)</p>

### Thermistor resistance increases when the temperature decreases

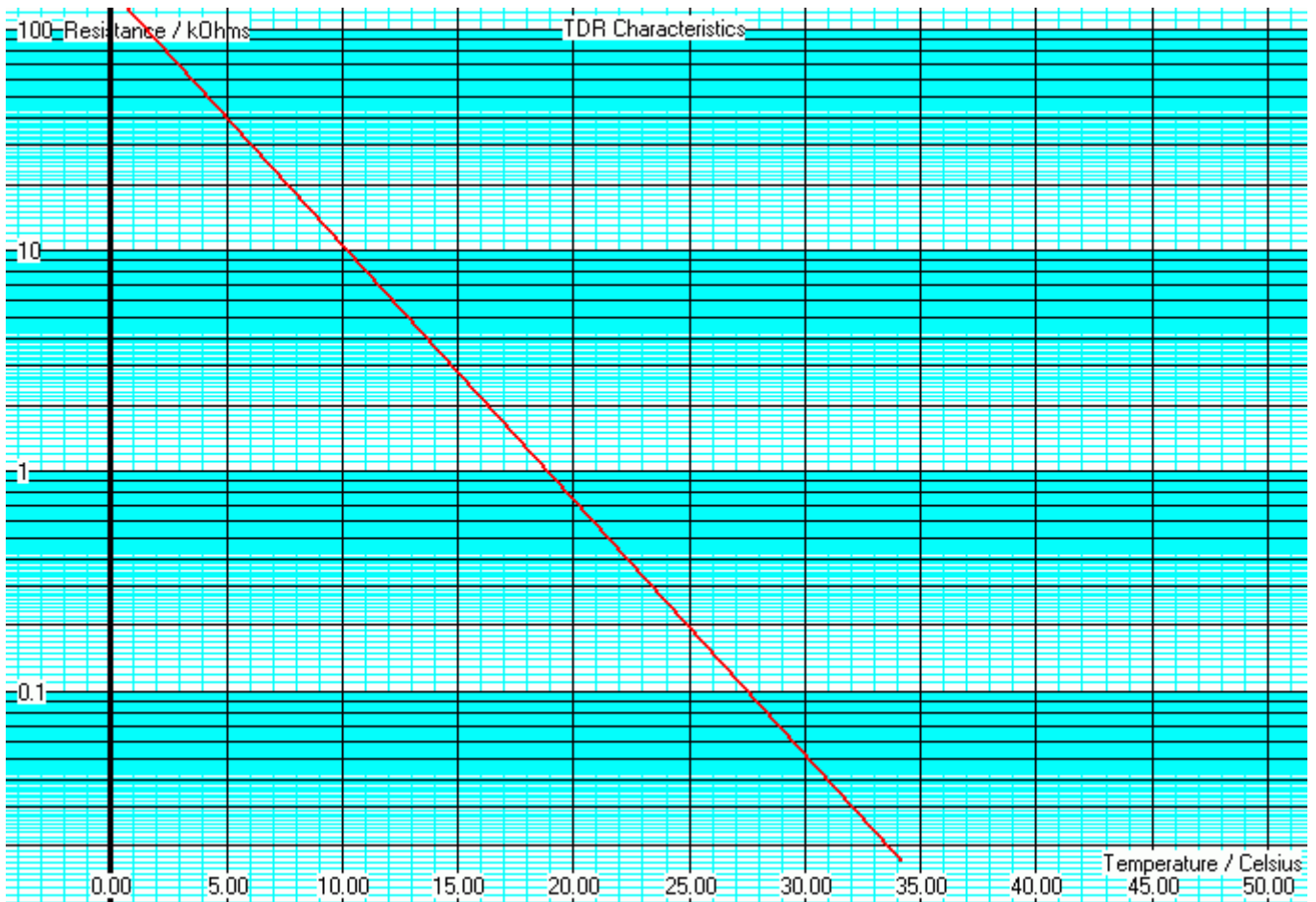
- Thermistors are used to measure temperature.
- They are fairly slow to react.
- Measurement circuits must be designed with care because the current flowing in the TDR must not significantly heat it up.

Negative Temperature Coefficient thermistors reduce their resistance in response to increasing temperatures.

Devices like incandescent bulbs increase their resistance as the temperature rises. (Positive temperature coefficient).



The resistance changes over such a large range that normal graphs are not useful. Log graphs solve the problem. Here is an example.



- At 5° the resistance is 40kΩ
- At 25° the resistance is 200Ω
- When the resistance is 3kΩ the temperature is just under 15°
- When the resistance is 50Ω the temperature is 30°

The series resistor value should be similar to the thermistor resistance at the temperature we are trying to detect.

For example in a refrigerator, the cooling pump might come on if the temperature rises above 5 Celsius. From the graph above, the thermistor resistance is about 40kΩ. A 40kΩ series resistor could be used. In a 12 volt circuit, at 5°, the current flowing would be ...

$$I = V / R$$

$$I = 12 / 80 \times 10^3$$

$$I = 0.15 \text{ mA}$$

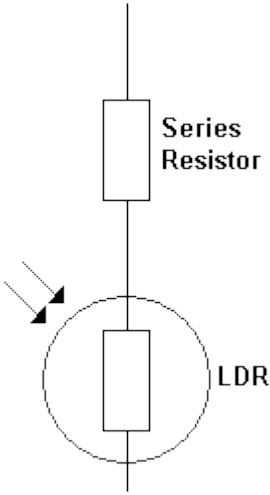

This tiny current would not have much of a heating effect.  
The series resistor is similar in value to the thermistor at 5°

## LIGHT DEPENDENT RESISTOR(LDR) NOTES

- LDRs are used to measure the light level.
- They are slow to react so they are not used with fibre-optic or other optical communications systems.
- They are used in light meters for photography and for systems that turn on lights when it gets dark.
- The LDR is normally used with a fixed resistor. This prevents too much current flowing when the light is very bright. It also converts the varying light level into a varying voltage.

**Designing to Protect the LDR.** The LDR is wired up with a resistor in series. This makes a [voltage divider](#) circuit. The series resistor is chosen to satisfy two design constraints.

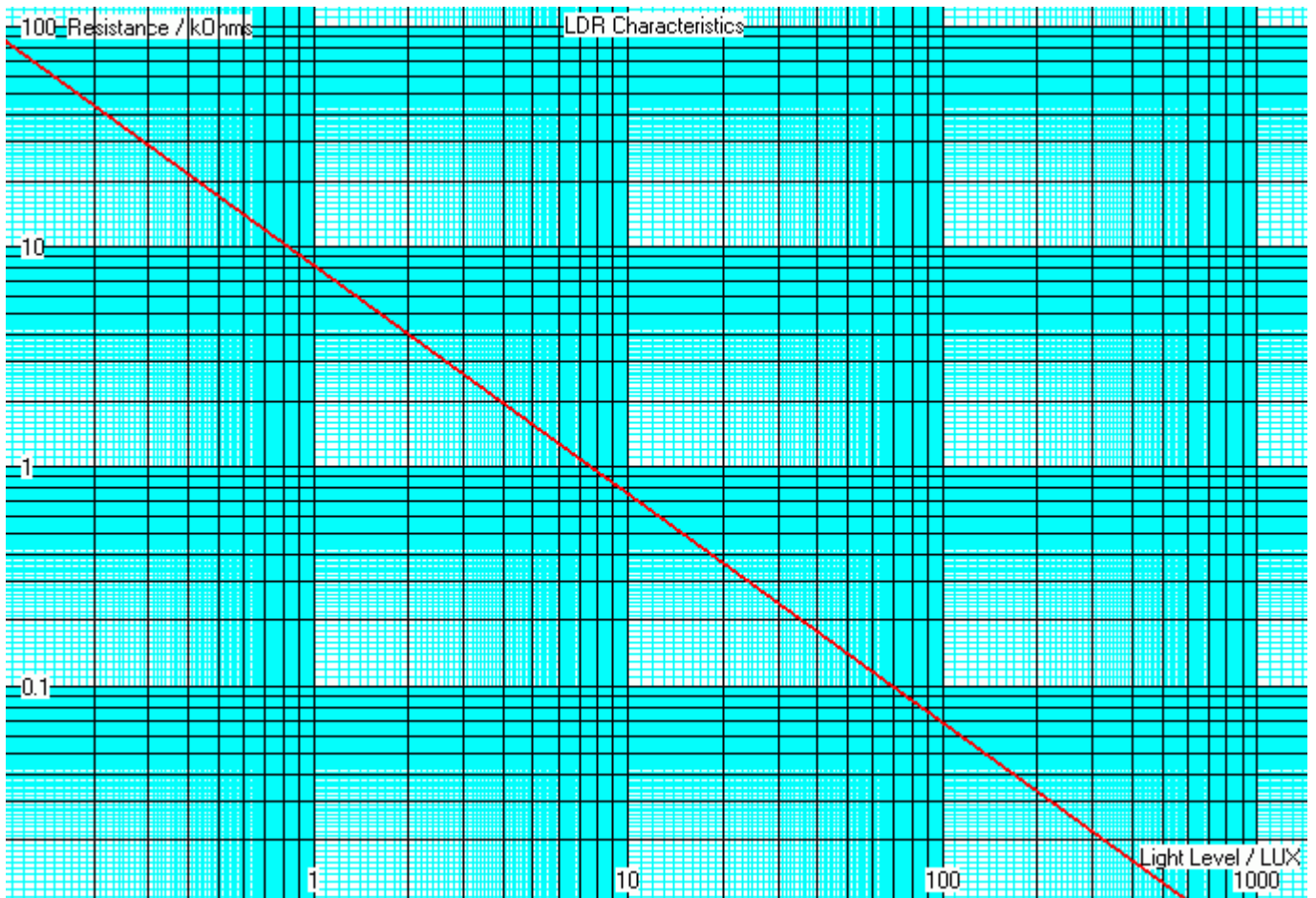
1. When the light is bright and the LDR resistance drops close to zero, the other resistor **MUST** ensure that the LDR current remains below a safe limit.
2. It is also **desirable** if the LDR resistance and the series resistance are approximately equal at the light level you are trying to detect.

 <p>The diagram illustrates a series circuit. At the top is a rectangular component labeled 'Series Resistor'. Below it is another rectangular component labeled 'LDR', which is enclosed in a dashed circle. Two arrows point towards the LDR from the left, representing incident light.</p>	 <p>A photograph of a physical LDR component. It is a circular, semi-transparent package with a grid of orange resistive traces on its top surface. Two thin wires extend from the sides of the package.</p>
How connect in circuit	Actual picture of an LDR

### **LDR Resistance decreases with increasing light intensity.**

Light Dependent Resistors (LDR) are made from a semiconductor. In the dark, this semiconductor has very few free carriers so the LDR has a high resistance. When photons of light hit the semiconductor, they add enough energy to dislodge carriers which can then flow. This reduces the resistance.

As the light level changes, the resistance of the LDR changes over a huge range. This is difficult to plot onto normal graph paper so [logarithmic](#) graphs are used.



- If the resistance is 20kΩ, the light level is about 0.42 Lux.
- If the resistance is 3kΩ, the light level is 20 lux.
- If the light level is 3 lux, the resistance is 2.7kΩ.
- If the light level is 600 lux, the resistance is about 10Ω which is close to zero.

### Calculating the series resistor value.

For this LDR, the absolute maximum current is 50mA.

In bright light, assume the LDR resistance drops to zero.

If the LDR is in a 12 volt circuit, the series resistor must be at least ...

$$R = V / I$$

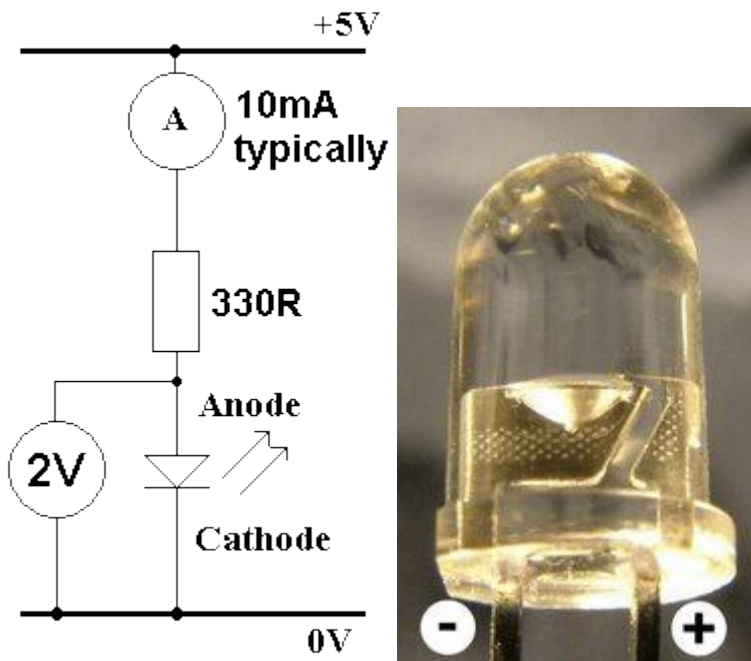
$$R = 12 / 50 \times 10^{-3}$$

$$R = 240\Omega$$

240Ω is the minimum safe resistance.

## More notes on LEDs

In the circuit below, the resistor limits the current through the LED to a safe level. A typical LED current is 10mA.



- Typical LEDs have about 2 Volts across them when lit but this varies from 1.6 to 3.5 Volts (depending on the colour and type of LED).
- A typical absolute maximum forward current is 20 mA. They are more often run at 10mA to give a wide safety margin. Some new ultra bright LEDs need a lot more current.
- LEDs are much more efficient and reliable than light bulbs.
- LEDs are replacing bulbs in many applications like traffic lights and car brake lights.
- Bicycles use LED lighting for longer battery life.
- Efficient LED torches are for sale too.
- Infrared LED light pulses are used to carry data from remote controls to the TV, DVD player or other device being controlled.
- LEDs are used in fibre optic links.
- LEDs are even being used for domestic lighting because of their high efficiency and low heat generation.
- LEDs are replacing cold-cathode lights for computer and TV flat screen back-lighting.
- Contraflow road works lights now use LEDs. These can be battery powered. The older bulb lights needed a small diesel generator.

## Resistance Calculation

The circuit above has a 5 Volt supply. There are 2 Volts across the LED. The remaining 3 Volts are across the resistor. Using Ohm's law ...

$$R = V / I$$

$$R = 3 / 10\text{mA}$$

$$R = 3 / 0.01$$

$$R = 300R$$

Allowing a small safety margin, 330R was chosen allowing just under 10mA to flow.

### Resistor Power Dissipation Calculation

$$\text{Power} = V I$$

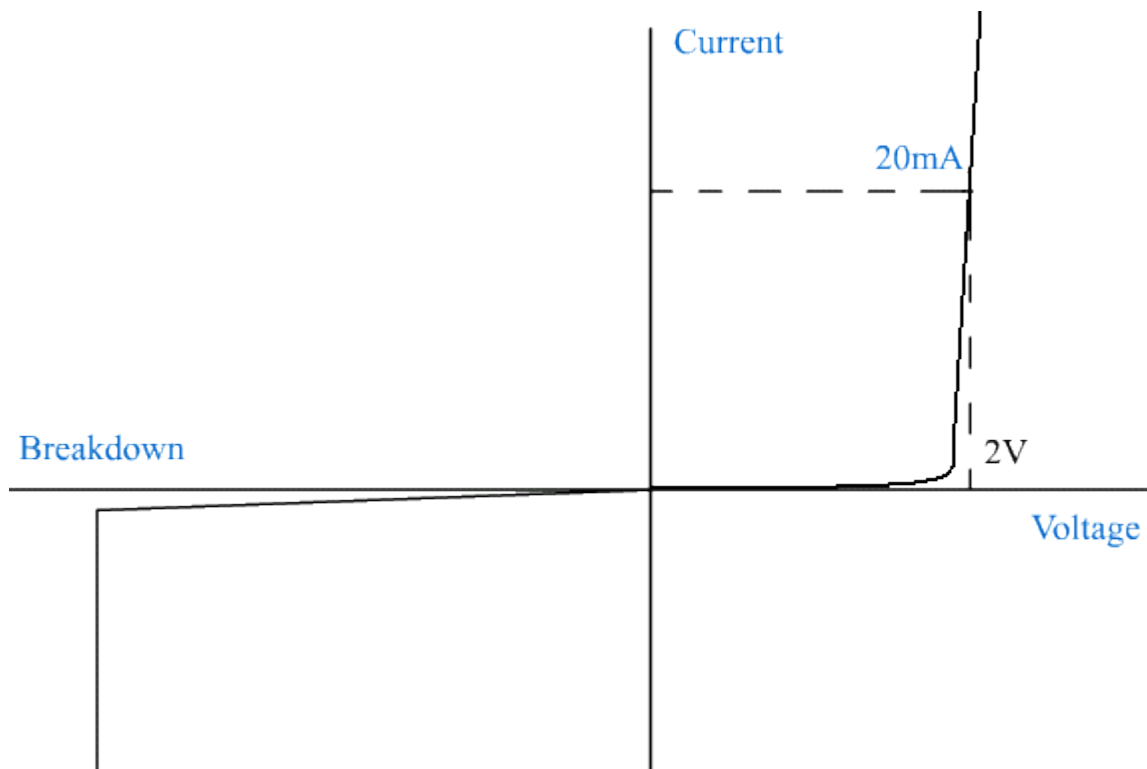
$$\text{Power} = 3 \times 10\text{mA}$$

$$\text{Power} = 3 \times 0.01$$

$$\text{Power} = 0.03 \text{ Watts (30mW)}$$

This is a very low power so any small resistor would be suitable.

The graph below shows the approximate characteristics of an LED. The reverse leakage current has been exaggerated to make it show on the graph. The reverse breakdown voltage is quite low (5 volts approx).



## Amplifiers and clipping

Analyse voltage characteristics of amplifiers including linear gain ( $\Delta V_{out} / \Delta V_{in}$ ) and clipping

### Background on amplifiers

The term *Operational Amplifier* or op amp in short, was coined by John R. Ragazzini in 1947. It denoted a special type of amplifier that could perform a variety of functions like amplification, addition, subtraction, differentiation and integration if the external components were properly selected.

The Operational amplifiers have undergone a lot of development since it was first made. When it was first made, vacuum tubes were used. The problem was that it was too bulky, expensive and used large amounts of power. The first miniaturization of op amp was made through bipolar junction transistor (BJT). A major breakthrough occurred with the development of Integrated Circuit (IC) op amp. They are made by fabricating elements in monolithic form of silicon chip having a size of a pinhead. The first of such a device was developed by Robert J. Widlar in 1960s at Fairchild Semiconductor Corporation. In 1968 Fairchild developed one of the most famous and regularly used op amp  $\mu A741$ . Since, it was developed it has undergone a lot of changes but still is one the most frequently used op amp. Some of other types of amplifiers are  $\mu A324$ ,  $\mu A082$ ,  $\mu A339$ , etc.



Fig.1



Fig.2

Figure 1. shows the first type of op amp  $\mu A741$ . Figure 2. shows the new type of op amp  $\mu A741$  that we use today.

### Fundamentals of amplifiers:

An amplifier is basically a two-port device. The signal externally applied to it is called the input and the one it generated is called the output. The output is a product of gain and the input, here gain is proportionality constant and thus the op amp which has this type of output is called a

linear amplifier and others are called non-linear amplifier. Some types of non linear amplifiers are log/antilog and quadratic amplifiers.

The op amp works in a way similar to the river. The input signal in op amp is received from the source that flows upstream and the output flows downstream through the load. Just like the water of the river flows from the mountains to the sea downstream. Each amplifier is different and it depends on the type of input and output. If the input is a voltage source ( $V_I$ ) and the output is also in the form of a voltage ( $V_O$ ), then the amplifier is called voltage amplifier. In this type of amplifier the input plays a passive role so we model it with just a resistance called input resistance of the amplifier ( $R_i$ ) and the output is modeled with a voltage –controlled voltage source (VCVS) which signifies the dependence on input, output voltage and the series resistance  $R_O$  called as the output resistance.

If the input source is a current source  $I_S$  and the output is also in the form of a current source  $I_O$  then such a type of amplifier is called the current amplifier. If the input of the amplifier is a voltage source  $V_I$  and the output is in the form of a current source  $I_O$  then such a type of amplifier is called transconductance amplifier because its gain is in amperes per volt, which is the dimension for conductance.

Suppose the input of an op amp is taken as a current source  $I_S$  and the output is in the form of a voltage  $V_O$ , such a type of amplifier is called transresistance amplifier.

### Basic types of Op Amp:

The basic types of op amps are noninverting, inverting, summing, and difference amplifiers.

### Non- Inverting Amplifier:

In the non inverting amplifier the voltage source is connected to the positive terminal.

$$V_P = V_{in}$$

The output resistance  $R_2$  is connected in series with input resistance  $R_1$  and the input voltage of the negative terminal is a fraction of out voltage  $V_{out}$ .

$$V_N = (R_1 / R_1 + R_2) V_{out}$$

By definition of amplifiers,

$$V_{out} = a V_D = a(V_P - V_N) = a (V_{in} - (R_1 / R_1 + R_2) V_{out})$$

thus,

$$\text{Gain} = A = (V_{\text{out}} / V_{\text{in}}) = (1 + R_2 / R_1). \text{ As } a \rightarrow \infty,$$

$$\frac{1}{1 + (1 + \frac{R_2}{R_1})/a} \rightarrow 0$$

Since the gain A obtained is positive that mean the output and input are in phase and thus such a type of amplifier is called non-inverting amplifier.

Fig.1 shows the circuit for non-inverting amplifier.

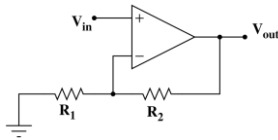


Fig.1

### Inverting Amplifier:

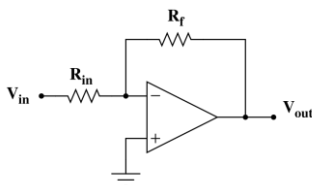
The inverting amplifier has the voltage connected to the negative terminal input through the resistance  $R_{in}$ . By applying Kirchhoff's Voltage law. We get,

$$-V_{in} + R_{in}I_S = 0, V_{out} - R_f I_f = 0$$

$$I_S = \frac{V_{in}}{R_{in}} \text{ and } I_f = \frac{V_{out}}{R_f} = \frac{-V_{in}}{R_{in}} \therefore A = \frac{V_{out}}{V_{in}} = \frac{-R_f}{R_{in}}$$

The negative sign indicates that the output will have  $180^\circ$  of phase shift. Hence such a type of amplifier is called inverting amplifier. It is shown in fig.2.

Fig.2



### Uses of operational amplifiers:

Operational Amplifiers are used in radios and music system to enhance the volume without increase in the consumption of power. In cars the movement of the wiper blades is controlled by the op-amps. In computers op-amps are used in sound control and to increase the flow of memory in order to make it run faster. In airplanes and jets the op-amps are used to attain high speeds by consuming less of power.

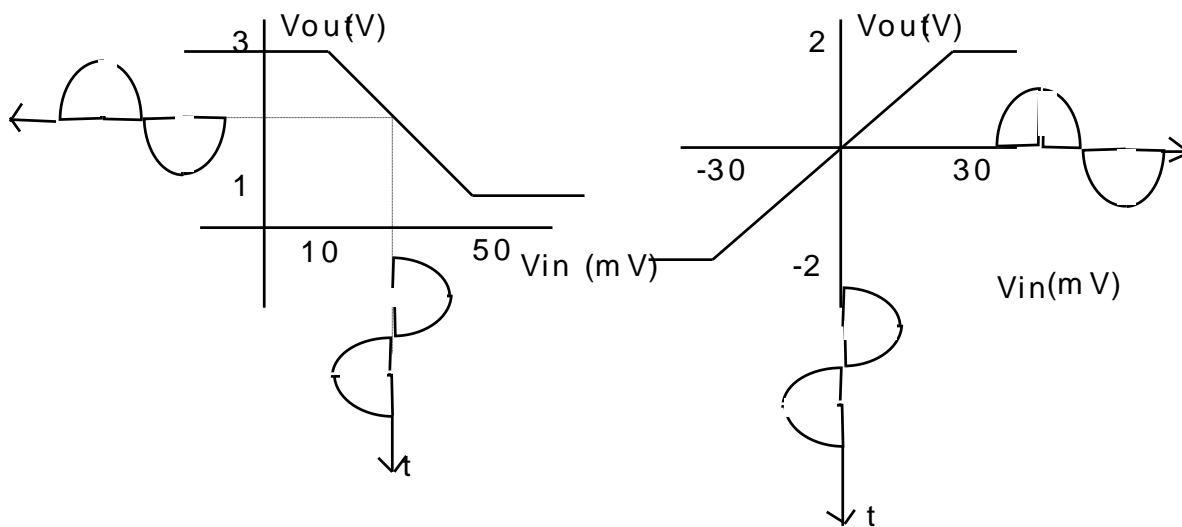


These pictures show the various application of operational amplifiers used in our daily life.

### Simple Facts

A voltage amplifier is an input-output device that is designed to take a small varying voltage signal and increase it to a larger varying signal. For the amplifier to perform this task reliably, the output must be an exact replica of the input, only magnified.

The characteristics of a voltage amplifier can be summarised in an Input - Output Voltage graph. There are two types of voltage amplifiers, with slightly different graphs.



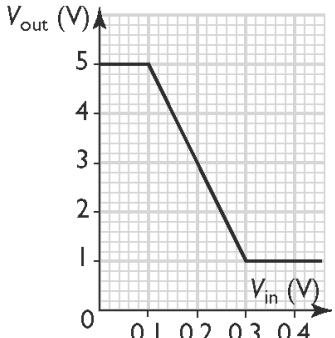
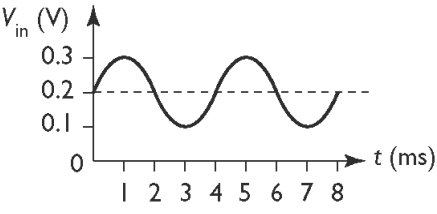
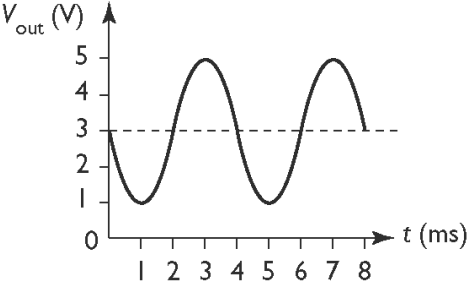
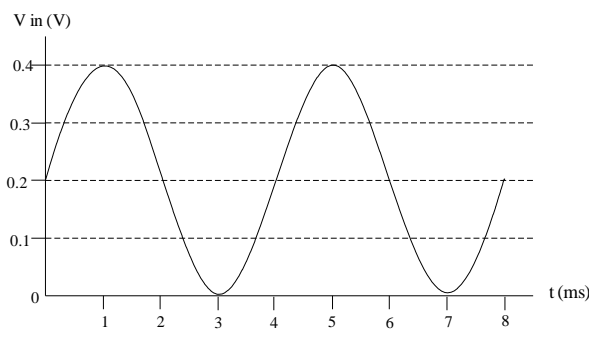
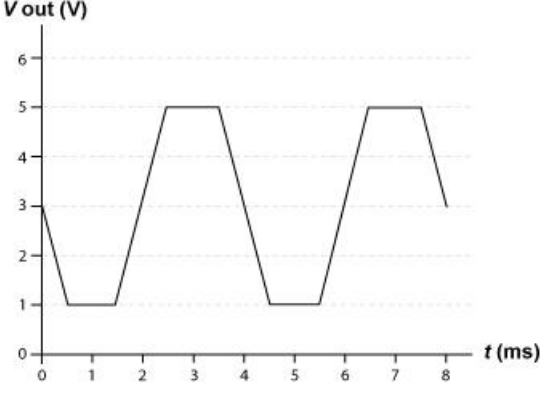
Inverting Amplifier

Non-Inverting Amplifier

1. The voltage amplifier is normally set up or “biased” so that when there is no variation in the input signal the amplifier is sitting at the middle of the inclined line. As the input voltage increases, the amplifier moves along the line in the positive x direction. The output voltage follows.
2. In the case of the Inverting Amplifier, as the input signal increases, the amplifier moves down the line and the output signal decreases. When the input signal decreases, the opposite happens. The fact that the output always does the opposite of the input is the reason for amplifier’s name.

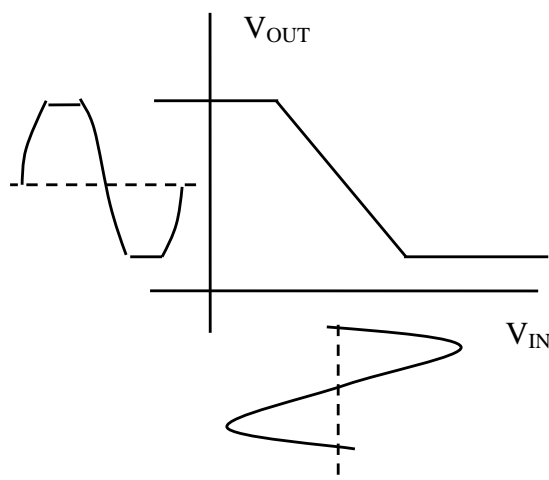
3. With the Non-inverting Amplifier, the reverse is the case. As the input signal increases, the output signal increases.
4. The important feature of a voltage amplifier is how much it amplifies. This amplification is called the “Gain” and is equal to the **gradient of the inclined line**.

Example on amplifiers

<p>A voltage amplifier has the transfer characteristic shown below.</p> 	<p>Q1-What is the linear gain of the amplifier?</p>	<p>The linear gain is the magnitude of the gradient of the linear section of the transfer characteristic.</p> $\text{Gradient} = \frac{-4}{0.2} = -20$ <p>Linear gain is 20.</p>
<p>It is supplied with the input voltage signal shown.</p> 	<p>Q2- Is this amplifier inverting or non-inverting? Justify your answer.</p>	<p>Inverting. An increase in the input voltage produces a decrease in the output voltage. The linear section of the transfer characteristic has a negative gradient.</p>
<p>Q3- Sketch the output voltage signal obtained when the input voltage signal is fed into the amplifier.</p>		
<p>Q4-The input voltage signal is increased in amplitude as shown in the figure below.</p>  <p>Sketch the output voltage signal obtained when the new input voltage signal is fed into the amplifier.</p>		

If the variation in the input voltage is too large the amplifier circuit reaches the extremes of the inclined line. At this point the output voltage cannot change and remains constant.

The effect of the graph of the output voltage is to slice or clip off the top of the graph, hence the name, **Clipping**.



*describe energy transfers and transformations in opto-electronic devices;*

In output transducers or opto-electronic converters such as LEDs the change is from electrical energy to light energy. In input transducers such as photodiodes, phototransistors and LDRs the change is from light energy to electrical energy.

*describe the transfer of information in analogue form (not including the technical aspects of modulation and demodulation) using*

- *light intensity modulation, i.e. changing the intensity of the carrier wave to replicate the amplitude variation of the information signal so that the signal may propagate more efficiently*
- *demodulation, i.e. the separation of the information signal from the carrier wave;*

The intensity of the light might be changed because someone has entered the shop and walked across a light beam, or perhaps the current from a microphone is passing through an LED whose output is fluctuating. This is modulation.

The information can be carried on the light to a receiver, usually a photodiode, that converts the variation in the light beam to a variation in voltage. This is demodulation. The varying voltage can be used to sound a bell indicating that someone is in the shop or to feed into an amplifier, then to speakers.

Summary of Chapter 5-Theory-

You will need to read chapter 5 and summarize how information is transferred in analogue systems paying specific attention to

- light intensity modulation
- demodulation

## Summary

### **Electronics and photonics**

#### Diodes, LEDs, LDRs, thermistors and photodiodes

- Draw the circuits for each with typical voltage and current values.

#### Resistors in Series and Parallel

- Draw circuits

#### Voltage dividers

- Draw diagram with formula
- Clearly distinguish between  $R_1$  and  $R_2$
- Explain effect on output voltage if either the top or bottom resistor is a LDR or a thermistor.

#### Energy transfers and transformations

- Include a written explanation, make it detailed (use text book)

#### Modulating light by changing the intensity and Demodulation

- Include descriptions.
- Do a diagram of signals.

#### Voltage amplifiers

- Draw voltage graphs for both inverting and non-inverting amplifiers.
- Mark in on graph the voltage gain
- Sketch input and output voltage signals for both types of amplifiers, and also for clipping and non-clipping.