OPTIKA®
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Teaching Guide

Ver. 1.0.0

Cod. 5335

THE PRINCIPLE OF DIGITAL IMAGING

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LIST OF MATERIAL INCLUDED

N.	Description	Cod.
1	Box	OFF4965
1	Power supply 12V	PS-UNI-12V

MATERIAL NOT SUPPLIED BUT REQUIRED

- Digital tester: 5196 o 5197

<u>NOTICE</u>

The small differences between the characteristics of the pieces making the collection and the relative drawings are justified by technological upgrade.

INTRODUCTION

Over the last few decades, technology of optics and electronics, materials and the 'digital' world in general has reached high levels, offering consumers and owners of laptops, smartphones, tablets, PCs, televisions, etc. the possibility of watching films and images and/or interacting with them through graphic colour interfaces 'produced' by high-performance screens.

What is physically involved in a digital image?

Before answering this question, it is necessary to examine a few key concepts.

THEORICAL BASIS

1. THE LIGHT

One cannot fail to mention light and its dual nature when talking about images and colours. This wonderful and mysterious natural phenomenon, observed under certain conditions, behaves as a flow of discrete (i.e., 'distinguishable' from each other) individual particles called photons or light quanta, according to Planck's law, each having *Energy*

$$Energy = h\nu$$

where $h = 6{,}626 \times 10^{-34}\,Js$
is the Planck's constant and ν is the frequency (Herz), the definition of is given below.
Observed under other conditions, however, light can behave like a *non-mechanical, transverse* wave. The first term refers to the fact that this type of wave does not require a 'mechanical' medium to propagate through space (such as air, water, etc.). This means that light is able to propagate even in vacuum (otherwise, the light emitted by the Sun would never reach the Earth).
A wave is *transverse* when the direction of propagation in space is *perpendicular* (i.e. 'transverse' or 'normal') to the direction it oscillates.
To clarify this concept without going too deep into details that are outside the scope of this experiment, consider the light as a *continuous* flow of energy that travels along a certain direction in space. The direction is indicated by the direction and spatial orientation of a fictitious *vector*, usually denoted **K**.

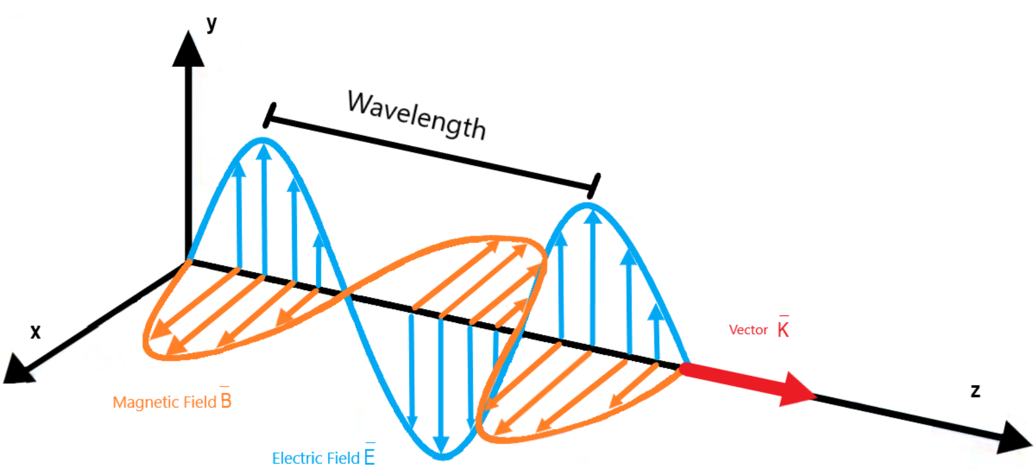
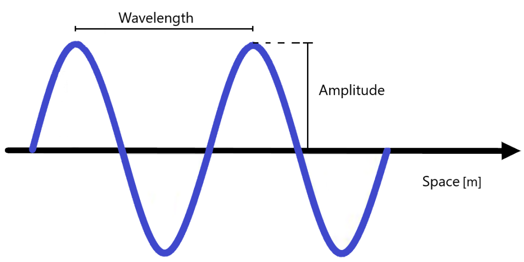


Fig. 1 Representation of an electromagnetic wave

The energy transported by light is the result of an *electric field* **E** and a *magnetic field* **B** that oscillate, one perpendicular to the other and both perpendicular to the direction followed by the vector **K**. The continuous oscillation (and thus variation in time) of the field **E** and the field **B** generates the energy that represents the essence of the light wave. In physics, light is described as an *electromagnetic wave*.
Going back to the previously mentioned concept of transverse wave, the reason for assigning this definition to light now seems clearer: the electric and magnetic fields, which are responsible for the 'creation' of the wave itself, oscillate along planes perpendicular to the direction described by the vector **K**, the one along which the wave propagates. Lastly, it should be noted that the electric and magnetic fields oscillate in phase: if **E** assumes, for example, the value 0 at a certain instant of time or its maximum value, **B** also assumes the value 0 or its maximum value at that same instant of time.

Having described the wave nature of light, we can now talk about the quantities that characterise a wave in general:



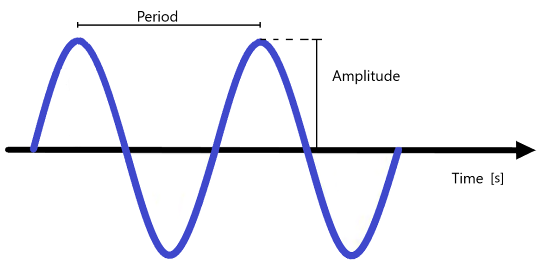


Fig.2 Wave observed in space

Fig.3 Observed wave over time

- having fixed a certain instant in time, the spatial distance between two consecutive maxima (or more generally, between two consecutively assumed equal values) is called the *wavelength* λ and is expressed in metres;
- observing the wave from a fixed position in space, the interval of time T, that passes between two consecutive maxima, (or more generally, between two equal values taken consecutively) is called the *period* of the wave;
- is denoted by

$$\nu = \frac{1}{T}$$

the *frequency* of the wave, defined as the inverse of the period and expressed in *Hz*;

- using the above quantities, we can derive the speed of the wave, or in this case the *speed of light c* (In the case of light travelling in a vacuum)

$$c = \frac{\lambda}{T}$$

and since frequency ν is the inverse of period T we can write

$$c = \lambda \nu$$

Where you can see the direct link between frequency and wavelength

- Finally, we define the *amplitude* of the wave as the value (or range of values) assumed by the wave at a given instant of time and point in space. In the case of light, simplifying, the amplitude is proportional to the values assumed by the oscillating electric field **E**. In practice, we introduce the concept of light intensity as that quantity that depends on **E** and indicates the amount of energy that light is transporting in the unit of time and area. To summarise:
-

Light intensity $\propto$ *Transported energy* $\propto$ **E** *oscillating*

- A l*ight beam* is defined as a set of light waves travelling in the same direction (their vectors **K** are parallel to each other and have the same direction). A light beam composed of light waves with the same wavelength, for example λ_1, is known as monochromatic. If a perfectly *monochromatic* light beam is considered, the total intensity, and thus the energy transported per unit time and per unit area, is the sum of the individual intensities of each light wave composing it (all with wavelength λ_1).

In general, a light beam can contain several light rays with different wavelengths, which form the so-called *spectrum*.

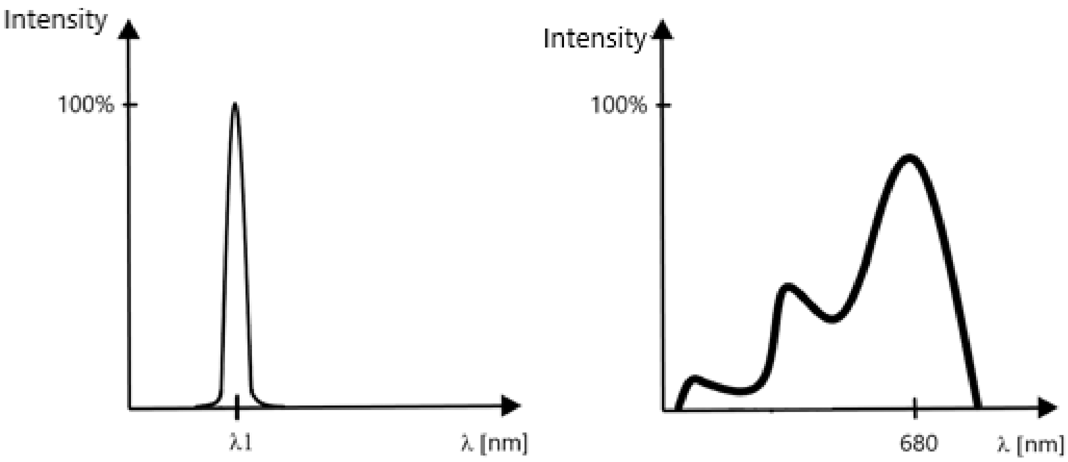


Fig. 4-5 Spectra of a monochromatic (4) and generic (5) beam

The graphs above show the spectra of a monochromatic beam (left) and a generic beam containing multiple wavelengths of light (right).
Taking the graph of the monochromatic beam as an example, it is shown that almost all the intensity (and therefore also energy) is given by light waves having wavelengths λ_1 (the shape of the spectrum is very close to that of a vertical line centred at λ_1).

If we look at the graph of the generic light beam, we can see that different wavelengths contribute different percentages to the total intensity. For example, the maximum of the spectrum is found at λ_0. Consequently, if we assume that λ_0=680nm, the entire light beam will appear to tend to red.

2. ADDITIVE COLOUR SYNTHESIS

Our eye on average is able to perceive a wavelength range between 380nm and 780nm, which is why the set of wavelengths that fall within this range is called *visible light or the visible spectrum.* The visible spectrum can be divided into 7 sub-intervals identified with the 7 well-known colours of the rainbow.

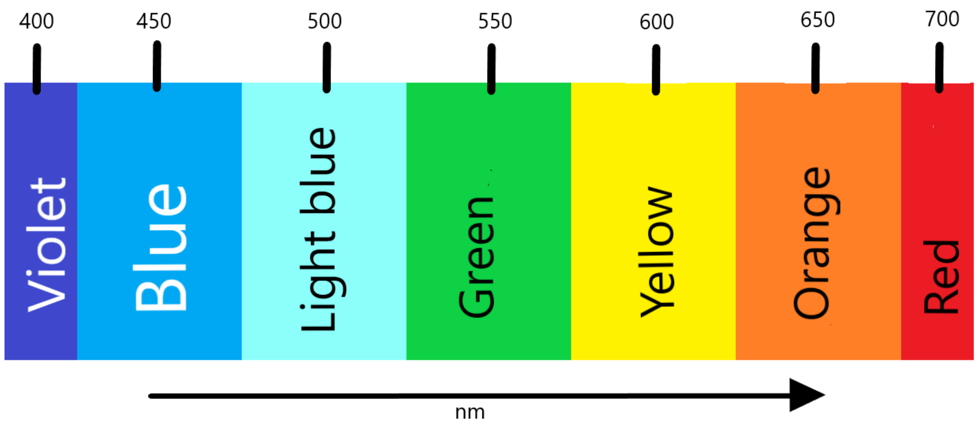


Fig. 6 Classification of the intervals of the visible spectrum into colours

What we commonly call 'colours' are nothing more than the result of the work our brain does after receptors located in our retinas are stimulated by beams of light. Objects, depending on their physical characteristics, are able to absorb certain frequencies (and therefore wavelengths) that hit them while reflecting the other ones. In this way, the petals of a dandelion appear yellow because, when hit by beams of light, they absorb the wavelengths of the visible spectrum excluding the yellow ones, which are reflected (or re-emitted) back to our eyes.

When beams of light more or less different in terms of both intensity and wavelengths (or more generally, in terms of spectrum) reach the eyes, it is possible to perceive vast ranges of colours and shades.
The sensation of *white* light, for example, occurs when the detected light beam contains, theoretically, all the wavelengths of the visible range, mentioned at the beginning of this paragraph, distributed more or less uniformly. In practice, it is sufficient to mix, in the right proportions, portions of the spectra classified as green, red and blue.

The absence of light on the other hand (zero intensity) is equivalent to the feeling of *black*.

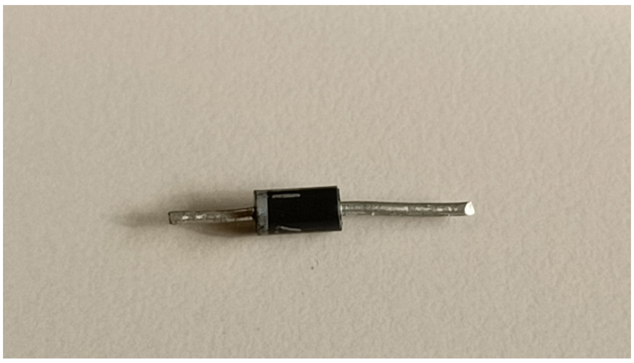
The term additive synthesis refers to a model that describes the blending of colours by 'imitating' the behaviour of the human eye, whose starting point is precisely black (absence of colour).
Red, green and blue are known as *primary colours* because combining them two by two results in magenta, yellow and cyan, defined as *secondary colours*, and combining all three results in white, as mentioned above. When talking about primary colours and their chromatic addition, the acronym RGB (red, green, blue) is used and also the term 'additive synthesis model RGB' is used.

3. LIGHT EMITTING DIODE (LED)

As their name implies, leds are *light-emitting diodes*.

Fig.7 LED generic

In general, a *diode* is an electronic component with two terminals (anode and cathode) made of *semi-conductor* materials that is widely used in the production of electronic circuits.



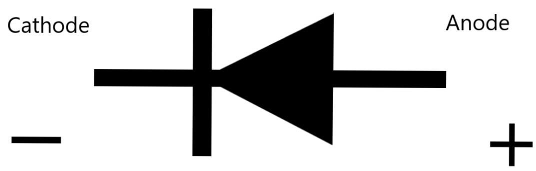


Fig.8-9 Classic diode (8) and its electronic symbol (9)

The main function of the diode is to allow current to flow between its ends in a single direction: this occurs whenever a voltage, greater than or equal to a threshold value V_S characteristic of the individual diode, is applied (usually very small compared to the general voltage applied to a circuit).

Consider the following circuit diagrams:

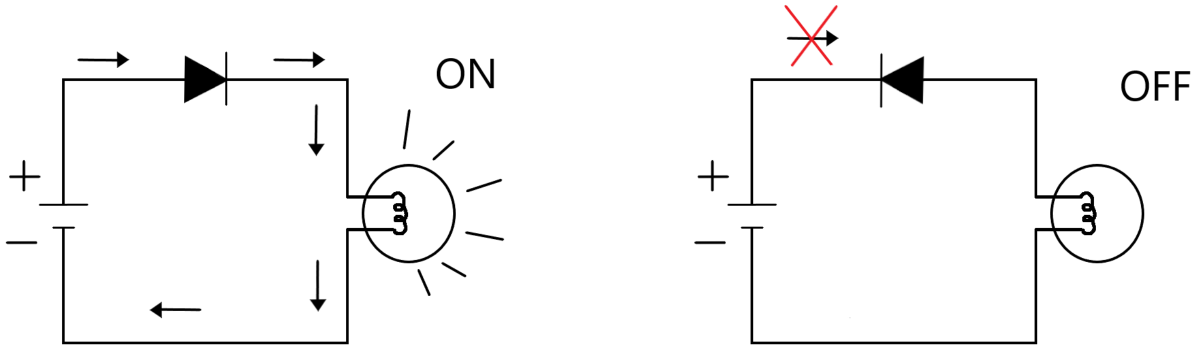


Fig. 10-11 Circuit with one bulb and one diode in direct (10) and reverse (11) configuration

Assuming a voltage V is applied by a generator and can be increased and decreased at will, no current flows through the diode until V reaches and exceeds the threshold value V_S. In this case, the diode is said to be in *direct polarisation*, upper diagram.
If one attempted to insert the diode into the circuit in the opposite direction as in the lower diagram, even if V exceeded the V_S threshold, the current would not flow through the diode and would be blocked by the diode. This configuration is known as *reverse polarisation*, and very high values of V can result in the breakdown of the electronic component.
One can conclude by saying that the diode acts as a unidirectional current switch.

The behaviour of the diode is due to the nature of the *semiconductor* materials that compose it (silicon, germanium, indium phosphide, etc.): a typical example is that of silicon whose atoms have a total of 14 electrons, 4 of which are on the outermost electronic orbital (valence electrons).

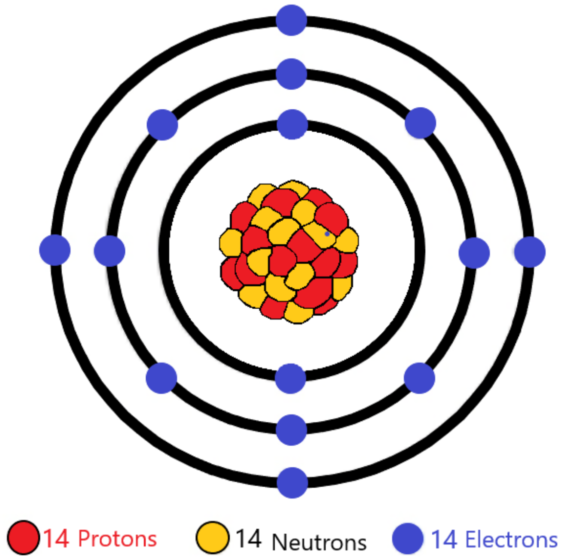


Fig. 12 Orbital representation of the silicon atom

The silicon atoms form *covalent* bonds with each other by sharing 4 valence electrons each. As a result, the outermost atomic orbitals (valence atomic orbitals) are completely occupied by 8 electrons ($4e^-+4e^-$).

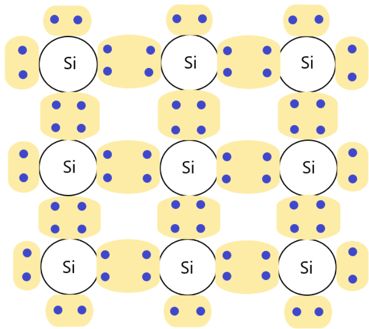


Fig. 13 Pure Silicon Layer. As can be seen from the silicon atom in the centre of the diagram, the valence atomic orbitals are completely occupied by 8 electrons due to the covalent bonds formed between neighbouring atoms.

In this configuration (Fig. 13), a hypothetical pure silicon layer is electrically inert. In fact, remember that the electrons e^- are the individual negative charges that make up the electric current. Whenever a voltage is applied, within a conductive material, in fact, the electric current is the result of the continuous passage of electrons (or transition) from one valence electron orbital of an atom to another. If all the atomic valence orbitals are filled, the transition cannot take place and no electric current can be generated.

The construction of a diode therefore involves some silicon atoms being replaced by other types of atoms (an operation called *doping*), so that some outer atomic orbitals within the material are no longer fully occupied

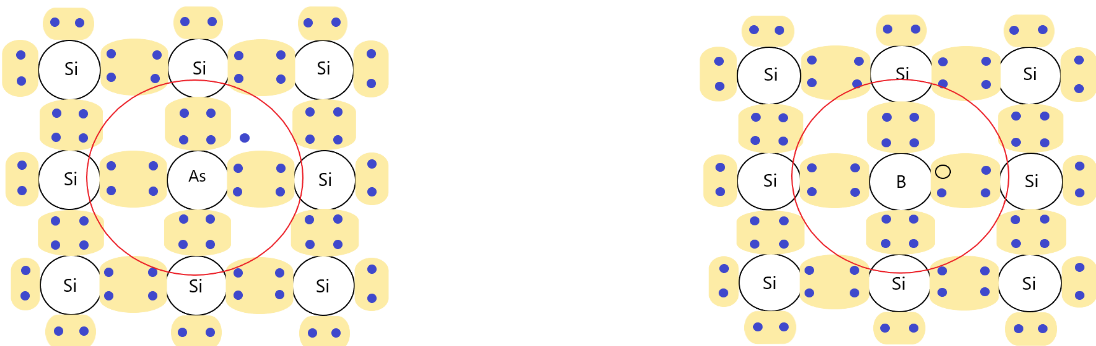


Fig. 14-15 Arsenic-doped silicon (N layer) on the left; boron-doped on the right (P layer). Within the parts circled in red, it is possible to see locally an excess negative charge for the N layer and a minus negative charge (equivalent to an extra positive charge or gap) for the P layer.

Typically, a first layer of silicon called “**N**” or “**Negative**” is doped with atoms (e.g. arsenic) such that locally one negative charge (i.e. one electron) will be in excess, while a second layer called “**P**” or “**Positive**” is doped with atoms (e.g. boron locally resulting in one less negative charge (Fig. 14 and 15). In the latter case, the absence of a negative charge is equivalent to the presence of a positive charge or **gap**.

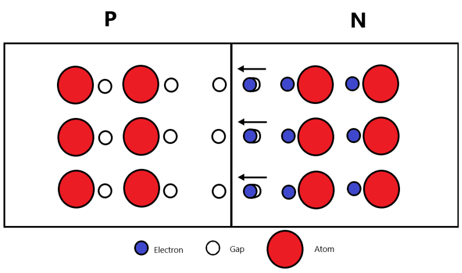


Fig.16.1

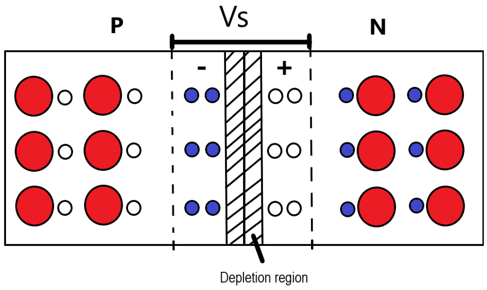


Fig. 16.2

The N-layer and P-layer thus obtained are subsequently joined together (Fig. 16.1): near the junction, some of the excess electrons of the N-layer **spontaneously** go to occupy the neighbouring gaps of the P-layer, electrically neutralising this thin portion of material. This creates a thin central zone, called the *depletion* region, which is electrically neutral (Fig. 16.2). In turn, electrons migrating from the N-layer to the P-layer leave behind gaps. Simplifying, these gaps are attracted by the same electrons that are migrating into the P-zone and migrate in turn into the vicinity of the junction due to the electrical Coulomb force. In a very short time, a thin layer of electrically neutral zone is formed with a layer of negative charges on one side and a layer of gaps (positive charges) on the other. The Coulomb force of attraction between these two charged layers causes a potential barrier to appear, which prevents the rest of the negative charges in the N layer from flowing into the P layer and thus generating an electric current.

At this point, the diode is ready for use.

The potential barrier corresponds to the minimum threshold voltage V_s mentioned before. If the diode is placed in the circuit in direct polarisation and a voltage greater than or equal to V_s is applied to it, a current will flow through it. Conversely, if the diode is placed in reverse polarisation, the negative charges and gaps will move away from the junction, preventing the formation of current.
When an electron makes the transition from one atomic orbital to another, it 'loses' energy that is converted into a photon of light that is emitted externally. This effect is known as electroluminescence, and the colour of the emitted light, and thus the wavelength, corresponds to the energy of the emitted photons (remember Planck's law mentioned above).
If the diode is constructed as in Fig. 8, no emitted light beam will be see as the photons will remain confined within the diode's armature. If, on the other hand, the planned construction is of the type shown in Fig. 7, the light is emitted outwards from the diode, which is then called an led:

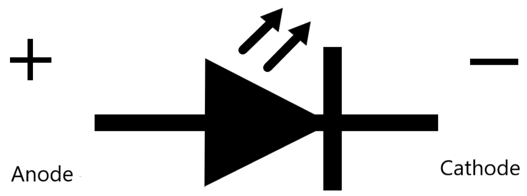


Fig. 17 Simbolo elettronico del LED

Conventional leds usually emit only one type of light (white, for example), whereas RGB leds contain three different leds of three different colours: Red (R), Green (G), (Blue)

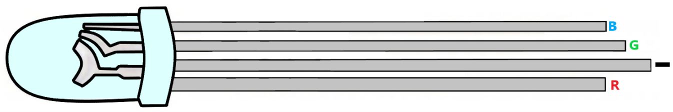


Fig. 18 RGB leds with input tracks to supply the red (R), green (G) and blue (B) leds and an output track - (or cathode)

RGB leds follow the rules of additive colour synthesis. By increasing or decreasing the brightness (or intensity, or energy) of the three colours, practically all colours of the visible spectrum can be created. The brightness of the led depends on the voltage to which it is subjected.

In the case of this instrument, the voltage is adjusted by acting on electronic components, widely used in circuits, called potentiometers

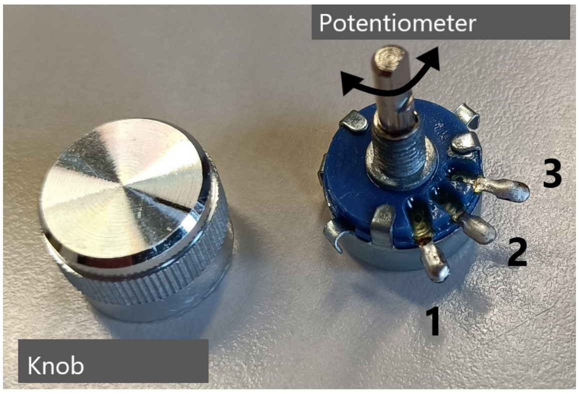


Fig. 19-20 Generic potentiometer with knob

In essence, the potentiometer is a variable resistor: turning its knob (Fig. 19) changes its internal resistance and consequently decreases or increases the voltage applied to the circuit.
A generic diagram of a potentiometer is shown below:

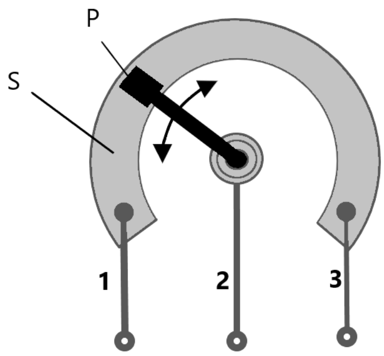


Fig. 21 Three-terminal potentiometer diagram

Referring to Fig. 21, a potentiometer usually has three terminals here named as 1, 2 and 3.

Assume that terminal 1 is connected to a fixed voltage, terminal 2 is connected to a portion of a circuit and terminal 3 to another portion. When the knob of the potentiometer is rotated, a pin P, which is connected directly with terminal 2, swipe along a circular crown of low-conductive and resistive material. Consider S as the portion of the circular segment of resistive material between terminal 1 and pin P.
If pin P is turned clockwise, the length of S increases and consequently the output voltage from terminal 2 will more strongly attenuated due to the greater resistance encountered along the path inside the potentiometer. In fact, the greater the length of S, the greater the resistance provided by the potentiometer.
We can thus speak of an ‘analogue’ type of regulation, in which one acts directly on the characteristics of the circuit itself or on parts of it (a varying resistor, as in this example).
There is also a ‘digital’ method to vary the voltage, called PWM (Pulse Width Modulation).
At this point, we can return to the question posed in the introduction:

What is physically behind a digital image?

Essentially, the principle of a digital image lies in the physical characteristics of RGB leds and the additive colour theory associated with them.

4. THE PIXELS

The pixel (short for ‘picture element’) is the smallest unit into which a digital image can be split.
An image that is produced on a screen in its entirety is obtained by the juxtaposition of many pixels, and in the computer science this is referred to as a bitmap image. In other words, comparing the image to a puzzle, a pixel would represent a single piece of it.
In fact, to quantify the resolution of digital device screens, the total number of pixels used is usually indicated. In general, it can be said that the more pixels used, the finer the detail of the images they will compose.

What is a pixel?

Essentially, a pixel is composed of at least three sub-units (or ‘sub-pixels’), which are nothing more than three coloured leds placed close together: one red, one green and one blue.
In fact, there are various combinations and configurations for these led sub-pixels, but the principle behind the operation of a pixel and the production of digital images does not change.
In order to be able to compose any kind of image, each pixel must be able to assume potentially any kind of colouring. For this purpose, the 3 sub-pixel leds behave as a single RGB unit that will follow the rules of additive colour synthesis. For each individual pixel, the digital device will vary the intensity of each of the red, green and blue led sub-pixels to create a single colour obtained by mixing the three emitted light beams.
Being very close together, the three light emitters corresponding to the various sub-pixels will give the perception that it is the single pixel as a whole that is being illuminated. The pixels are aligned in such a way as to form a rectangular grid, and their size, density and juxtaposition lead to the perception of a single final image on the screen.

5. COLOUR CODING

As described in the preceding paragraphs, each pixel assumes a specific colouration as a result of the mixing of three coloured beams (red, green and blue) emitted by the sub-pixel leds composing it. The intensity of each sub-pixel led must be adjusted according to the final colour desired. For this reason, in the digital-computer field, numerical values are assigned to the Red, Green and Blue component of each pixel between **0** and **255**. The digital system therefore modulates the intensity of each led according to the number assigned to it, which in fact corresponds to an energy level. The value **0** corresponds to zero intensity (sub-pixel led off), while **255** corresponds to maximum intensity.

By convention, each pixel is assigned a code of three numbers:

(R, G, B)

The first value refers to the red sub-pixel, the second to green and the third to blue.
So, to summarise, if you want to colour a pixel a certain colour, you need to assign it a tern of values between 0 and 255.
In computer science, a bit is defined as the fundamental unit to which two values can be assigned: 0 or 1.
They form the basis of binary language (i.e., that language which consists of representing numbers through repeated sequences of 0 and 1) and a byte is defined as a sequence of 8 bits:

10100010

In the example given, the number in the binary system 10100010 represents the number 162 in the decimal system..

In the binary system, the 8-digit number (byte, as mentioned above) 00000000 corresponds to the value 0 in the decimal system and the number 11111111 corresponds to the value 255 in the decimal system.

This means that, with 8 being fixed as the number of digits available, a byte can correspond to any integer between 0 and 255 inclusive, for a total of 256 possible values.

In fact, using permutations with mathematical repetition, the total number of sequences (and therefore final values) that can be obtained using the 2 digits 0 and 1 out of 8 available places is:

$$2^8=256$$

It is therefore possible to have 256 gradations of intensity for each sub-pixel led.
If each pixel thus contains 3 sub-pixel light components, the total number of colours obtainable is given by the combination of all possible light gradations for each sub-pixel led:

$$2^8 \cdot 2^8 \cdot 2^8 = 256^3 = 16.777.216$$

R G B

Conventional panels have 24-bit RGB images, i.e. 8 bits are used for each sub-pixel, as in the case just hi-ghlighted. However, this does not mean that all 16.77 million colours produced are well perceived by the eye, first of all because the human eye can 'only' distinguish up to about 10 million different colours. Furthermore, simplifying, the bit colour management does not correspond to a colour range that reflects the real perception of the human eye, which for example is more inclined to perceive green shades than blue ones.

In any case, the end result is the creation of an enormous number of possible digital images.

INSTRUMENT ELECTRICAL CIRCUIT

Part of the instrument's electrical circuit is shown schematically below, with appropriate simplifications:

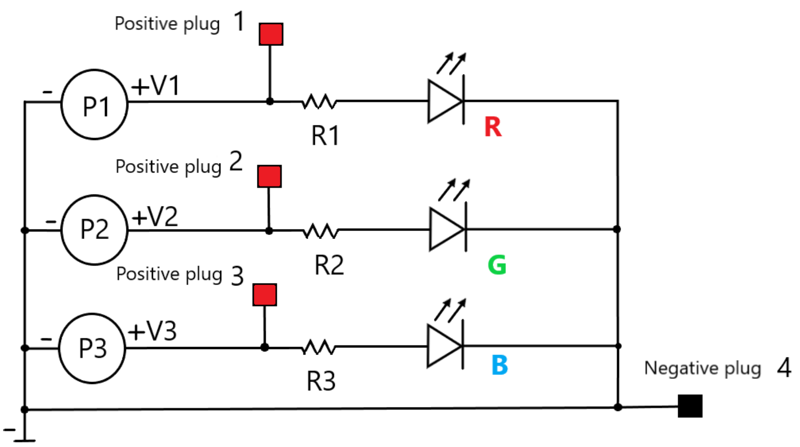


Fig. 22

- **R, G, B** indicate the Red, Green and Blue leds;
- R1, R2, and R3 denote the resistor in series with the Red, Green, and Blue leds respectively;
- P1, P2 and P3 are the potentiometers that adjust the voltage to the Red, Green and Blue leds respectively;
- +V1, +V2 and +V3 are the voltage values output by the three potentiometers that supply the corresponding resistor R and led pair;
- Socket 4 is the black socket into which the negative test lead of the tester should be inserted
- Socket 1, Socket 2 and Bu Socket shing 3 are the red sockets into which the tester's positive test lead should be inserted.

INSTRUMENT OPERATION

Description

Code 5335 is intended as a tool for learning, experimenting and carrying out measurements on what lies behind the creation of digital images on screens, focusing precisely on their fundamental unit: the pixel. In particular, the main objective is to understand, also quantitatively, the connection between the purely digital aspects of pixel colouring and the physical quantities involved.

In fact, inside part no. 5335 there is an RGB led whose coloured leds (Red, Green and Blue) can be individually set in intensity through the action of three knob-potentiometers. A semi-transparent frosted layer placed above the RGB led facilitates the mixing of the three coloured beams emitted to obtain a single colour, simulating the behaviour of a pixel on a screen.
Four bushing inserts allow measurement of the set voltage values for each led-resistance pair (Fig. 22).

To begin, place the instrument on a flat surface.
Connect the power supply to the connector at the back of the instrument.

NOTE: During the course of each experiment, in order to have a good perception of the colours obtained, it is advisable to observe the illuminating surface frontally from a distance that does not annoy or fatigue the eyes (40cm at least).

EXPERIENCE 1

Materials needed: 1 BOX. 5335; 1 Power supply.

It has previously been discussed how the mixing of red, green and blue light can produce a wide range of colours. The result also depends on the intensity of light that is delivered by each led and the sensitivity of the observing eye. Referring to Fig. 22, resistors R1, 2 and 3 have been factory-calibrated so that the intensity emitted by each led does not overpower the others. Consequently, by setting the maximum light intensity on each, the result is as close as possible to a white light beam.

- Switch on the instrument by pushing the ON/OFF power button adjacent to the power connector.
- Adjust the three potentiometers to maximum power to confirm what has just been said.
- Repeat the experiment by resetting the power of each led to zero, thus obtaining the condition of complete absence of light.

- o What colour do we associate with complete absence of light?
- o If the internal and external colour of the construction material of the instrument had been yellow, teal or similar, would the observed phenomenon have changed?

- o What colour does a switched-off digital screen look like? Why that colour?

- o Return to the previous questions by considering the case of the maximum intensity set on each led.

EXPERIENCE 2

Materials needed: 1 BOX. 5335; 1 Power supply; 1 Digital tester (not supplied)

Observe Fig. 22 and in particular consider one of the three branches of the circuit comprising resistor and green led (**G**), e.g.

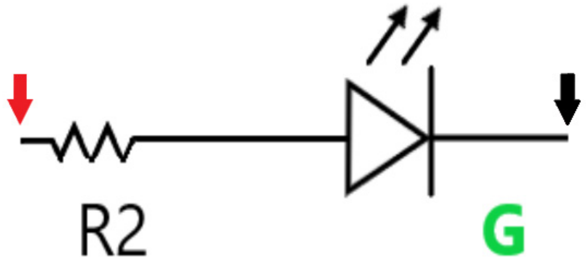


Fig. 23

The red and black arrows in Fig. 23 correspond respectively to the contact points of Socket 2 and Socket 4 in Fig. 22.
By inserting the positive cable into socket 2 and the negative cable of a tester into socket 4, it is possible to measure the voltage to which R2 and the green led are subjected when the potentiometer, which in this example is P2, is rotated.

For construction reasons, the characteristics of the three coloured RGB leds differ in terms of the maximum voltage applicable at their ends, output, maximum luminous intensity, etc.
It should also be remembered that leds are a special type of diode and therefore, once inserted into a circuit in direct polarisation, require a minimum voltage value to be exceeded at their ends in order to allow current to flow (and to produce light, accordingly). This threshold value differs between leds of different colours, as in this case.

The three fixed resistors R placed in series with the RGB leds serve precisely to prevent the leds from being overloaded in terms of voltage, thus preventing them from 'breaking' or burning out, and to modulate their maximum light intensity.

For this reason, it is necessary to measure the minimum threshold voltage value such that each led, placed in series with its associated resistor, begins to emit light visibly.
- Insert the positive cable into socket 2 and the negative cable of a tester set to 20 Volt scale into socket 4.
- Turn all potentiometers to the minimum value.
- Press the ON/OFF button on the rear of the instrument.
- Slowly turn potentiometer P2 until the green led starts to emit light.
- Mark the voltage value read on the tester as the minimum voltage value for the green led to light up or threshold voltage $V_{Threshold}$.
- Turn the potentiometer as far as it will go to obtain the maximum green light intensity and mark the voltage value read on the tester as the maximum voltage value to which the green led and resistor R2 are subjected.
- Repeat the previous steps for the other two coloured leds.

/	R	G	B
$V_{Threshold}$ (Volt)			
V_{max} (Volt)			

- What can be seen when looking at the three maximum values measured? Is there consistency with the circuit depicted in Fig. 22?
- Are the minimum (or threshold) switch-on values identical or can they vary depending on the led?

EXPERIENCE 3

Materials needed: 1 BOX. 5335; 1 Power supply; 1 Digital tester (not supplied)

The adjustment of the intensity level of each coloured led is crucial to obtain a specific final colour, derived from the mixing of the three light beams.

At the digital level, the system adjusts the light emitted by the sub-pixel leds according to the three-number code (**R**, **G**, **B**) assigned to each screen pixel.
It was also seen that by convention the value 0 corresponds to zero intensity and 255 to maximum intensity. Thus, the code (0, 0, 0) indicates the absence of light from all sub-pixel leds, resulting in the colour black, while the code (255, 255, 255) refers to the condition whereby the light intensity of all coloured leds is maximum, consequently leading to the perception of the colour white.
All numerical values that can be assigned to each sub-pixel led between 0 and 255 will correspond to a specific light intensity level in reality.

In order to better understand the principle behind each pixel that forms an image on the screen, and thus create a direct link between what is handled digitally and the physical phenomena involved, note that the amount of light emitted by an led increases as the voltage applied to it increases. To a good approximation, **it is possible to create a correspondence between the scale of numerical values between 0 and 255 and the voltage range available for each sub-pixel led.**

$$\frac{Maximum\ voltage\ range}{256} = \frac{Colour\ voltage}{Digital\ value}$$

or in terms of proportion

$$Maximum\ voltage\ range : 256 = Colour\ voltage : Digital\ value$$

The ΔV , is the *maximum range of voltage values* that can be set by turning the potentiometer for each coloured led and is given by the difference between the maximum voltage value and the threshold voltage value measured in **Experiment 2:**

$$\Delta V = V_{max} - V_{threshold}$$

The *Colour voltage* is the voltage to be applied to the individual coloured led (red, green or blue) to adjust the intensity of light emitted to a specific level.
The *Digital value* corresponds to the number between 0 and 255 that a hypothetical digital system would interpret to set a voltage equal to the *Colour voltage* on the coloured led in question.
For simplicity's sake, they will be called

$$V_{dig} = Digital\ value$$

and

$$V^{*} = Colour\ voltage$$

- First, the ΔV V for each coloured led is calculated according to the previous formula

ΔV_R (Volt)	
ΔV_G(Volt)	
ΔV_B(Volt)	

- Once you have chosen the final colour to be obtained, and consequently the V_{dig} or be assigned to each coloured led, you can derive V* to be set for each sub-pixel led

$$V^{*} = \frac{\Delta V}{256} \cdot V_{dig}$$

- Finally, it is necessary to add to V* the lighting threshold value $V_{Threshold}$ for each coloured led in order to have a direct reading of V* using a tester

$$V^{*}{}_{Direct\ reading} = (\frac{\Delta V}{256} \cdot V_{dig}) + V_{Threshold}$$

To give an example, suppose you want to obtain the colour *Salmon Red* which corresponds to the code RGB (210, 103, 82). Consequently, the voltage values to be set, by directly reading the scale on the tester for the three colours, are obtained as follows:

$$V^*_{Red\ direct\ reading} = \frac{\Delta V_R}{256} \cdot 210 + V_{Red\ threshold}$$

$$V^*_{Green\ direct\ reading} = \frac{\Delta V_G}{256} \cdot 103 + V_{Green\ threshold}$$

$$V^*_{Blue\ direct\ reading} = \frac{\Delta V_B}{256} \cdot 82 + V_{Blue\ threshold}$$

- Set the tester reading scale to 20V. Insert the positive lead of the tester into the socket corresponding to the coloured led to be adjusted in intensity and the negative lead into socket 4
- Turn the corresponding potentiometer until the desired value $V^*_{\text{Direct reading}}$ is read on the tester. Set the voltage value that comes closest to the calculated theoretical value according to the measurement accuracy allowed by the tester

- Repeat the steps for each coloured led

A table with some examples of colours with their respective RGB codes is shown below

Color	Description	Code RGB
	Black	0 0 0
	White	255 255 255
	Red	255 0 0
	Lime	0 255 0
	Blue	0 0 255
	Yellow	255 255 0
	Fuchsia	255 0 255
	Aqua	0 255 255
	Grey	128 128 128
	Maroon	128 0 0
	Green	0 128 0
	Navy	0 0 128
	Olive	128 128 0
	Purple	128 0 128
	Silver	192 192 192
	Teal	0 128 128
	Sulphur yellow	240 232 64
	Traffic yellow	248 192 0
	Yellow orange	221 113 0
	Red orange	190 74 34

Color	Description	Code RGB
	Vermillion	194 51 28
	Coral red	169 54 41
	Rose	207 77 90
	Salmon red	210 103 82
	Rasberry red	176 19 59
	Blue lilac	124 99 153
	Signal violet	138 66 128
	Magenta	192 53 115
	Sky blue	0 115 175
	Traffic blue	0 81 140
	Night blue	34 40 86
	Turquoise green	0 103 77
	Yellow green	77 156 53
	Mint green	0 110 59
	Pastel turquoise	114 170 168
	Black grey	47 51 53
	Light grey	193 197 192
	Copper brown	140 72 50
	Orange brown	164 89 45

NOTE: Depending on the person's visual sensitivity, the distance from which the person observes, the digital screen or the paper and ink used to represent the final colour samples obtained with the code 5335, the characteristics of the ground material for mixing the light beams, the precision of the voltage set for each colour channel and many other factors, **the similarity between the colour emitted by the instrument and the expected colour may vary.**

The main purpose of the experiment is to understand and experience the physical characteristics behind the pixel and thus the physical principle that allows the realisation of digital images on screen

- Why is it necessary to consider the threshold voltage $V_{Threshold}$ when calculating the voltage values to apply to each coloured led? What would happen if it were not considered?
- It may happen during the experience to see colour shades that are not completely uniform. What could be one of the main causes? Does observing the light emitted from a greater distance improve the situation? Why? Hint: Look up the typical size of a pixel and compare it with the size of the circular light window of instrument no. 5335.