



PRINCIPLES OF LIGHTING LEVEL 3

CP2273

Inspiring The Next
Generation Of Engineers

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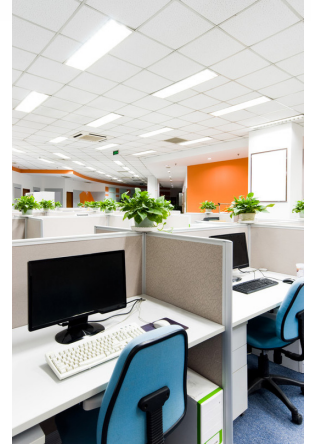
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Introduction

Why is good lighting important?

Lighting is important to the health and safety of people using the area.

Poor lighting causes effects like eyestrain, migraine and headaches, increasing absence through sickness and reducing productivity. Good lighting allows people to spot and avoid hazards.



The task - to light a given room to the required level, by determining:

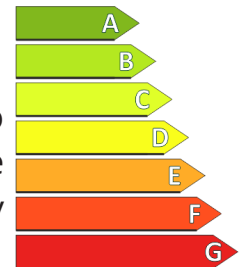
- How many luminaires (electric lights) are required ;
- Of what power rating;
- And positioned where.

It is not simply a matter of asking “How bright is a light bulb?” That is rather like asking “how long is a piece of string?”

It depends...

The solution involves consideration of issues like:

- **Energy efficiency;**
- **Spectral response;**
- Dimensions of the room;
- Activities that take place in the room.
- **Energy efficiency** - how much of the electrical energy supplied to the luminaire goes into generating light. (More precisely, the issue is the **luminous efficacy** of the luminaire - how much of the energy supplied goes in to generating visible light.)



This depends on the type of luminaire used. The table gives typical values:

Technology	Luminous efficacy in lumen/watt
Filament incandescent	5 - 10
Halogen incandescent	10 - 20
Compact fluorescent	45 - 70
Linear fluorescent	50 - 100
LED	80 - 150

Introduction

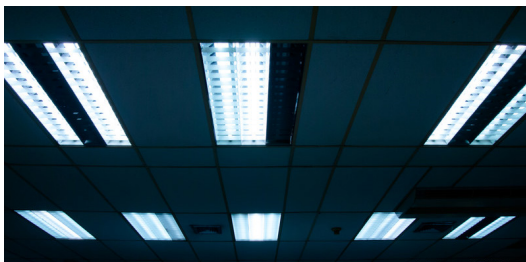
As the table shows, luminaires use one of three common types of light source.

Some, known as **incandescent sources**, rely on heating up material until it gets so hot it glows. The colour of the light produced depends on the temperature of the material.



Fluorescent lights generate ultraviolet radiation initially - invisible to us. However, this is absorbed by a coating on the inside of the lamp which then re-transmits visible light.

The precise colour depends on the substances in the coating.

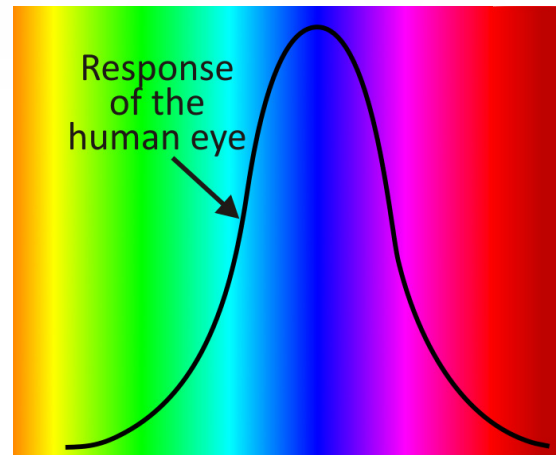


LED lights involve more complex physics, beyond the scope of this course. They generate light without the need for high temperature by passing electric current through semiconductor crystals. The colour of the light produced depends on the chemical composition of the semiconductor crystals. They are used to display data as well as to provide general lighting.



Introduction

- **Spectral response** - How much of the energy is in the visible part of the spectrum. The diagram illustrates what we mean by the visible spectrum. It means the colours of light that our eyes respond to - we see green light the best!
- **Dimensions** of the room - The higher the ceiling, the further the light from a particular luminaire spreads out and the weaker it gets.



Technology	Luminous efficacy in lumen/watt	Average illuminance in lux
General movement	Entrances and corridors	20
Movement in hazardous areas	Construction sites, Loading bays	50
Work requiring low level of detail	Kitchens, General factory work	100
Work requiring medium level of detail	Offices and workshops	200
Work requiring fine detail	Drawing offices, Small components assembly line	500

- **Activities** that take place in the room - The table lists recommended lighting levels, in lux, for a number of different situations.

Introduction

We have used some concepts and units that may be unfamiliar.

Here is a glossary:

The concepts:

- **Flux** - something that flows.
- **Radiant flux** - energy that flows in the form of electromagnetic radiation.
- **Luminous flux** - energy that flows as light, i.e. produces the sensation of sight in our eyes. Often used as an objective measure of the "useable" light emitted from a source, it is measured in lumens.
- **Illuminance** - the total luminous flux hitting (illuminating) a unit of surface area. It is a measure of how much 'useable' light strikes a surface. Illuminance is measured in lux or lumens per square metre.
- **Luminance** - measures the amount of light reflected off a surface - the 'brightness' of an object. Luminance is measured in candelas per square metre.

The units:

- **Lumen (lm)**: measures how much light the source produces - the total amount of light energy, regardless of direction. It is used to measure energy efficiency, using a lumens-per-watt formula. In the lighting industry the result is called 'luminous efficacy'.
- **Lux (lx)**: equals one lumen per square metre. Used in conjunction with distance, it allows us to calculate whether a luminaire delivers adequate light intensity for specific applications.
- **Candela (cd)**: shows how well a light source enables humans to see objects. It measures how well the light produced stimulates our vision. Whereas the **radiant intensity** measures the total energy radiated in the full visible spectrum, the candela looks at how much energy is emitted at the peak response frequency, 540 x 10¹² Hz, green light. It is not the same measure as the lumen however, as it does not indicate the total light energy but how bright the source appears. A laser, for example, is highly focused into a very narrow beam and will have a low lumen value, as the total light energy given off (in all directions) is small. However, it will have a very high 'brightness', in candela.



WORKSHEETS



WORKSHEETS

Worksheet 1 - Measuring Light

Light meters are present in a wide range of applications.



Some are embedded in cameras, allowing them to set exposure times automatically.

Some allow cars to turn on headlights automatically when it gets dark. Some control street lighting, security lights or domestic lamps.

The one included with the equipment for this module indicates the light intensity in lux (lumen / square metre.)

Over to you

- Examine the light meter. Notice the external light sensor and the control dial.

Usually, when taking readings, the sensor is turned so that light hits it vertically.

The display shows the number '1' when the light intensity is too bright for the range chosen. Turn the dial clockwise until a proper reading is shown.

- Move around taking light measurements as you go. Complete the table given in the Student Handbook, reproduced below to help you.

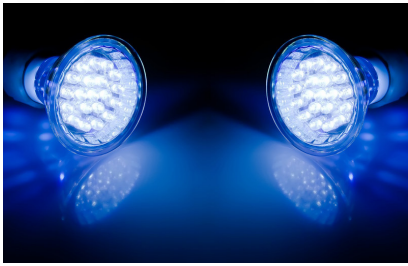


Location	Light level in lux
Outdoors - bright sunshine	
Outdoors - shade	
Room - near window	
Room - near luminaire	
Room - shade	
Room - dark corner	

- Compare your readings with those given in the table on page 5. Are the locations you tested suitable for any of these kinds of activity? Answer the questions in the Student Handbook.

WORKSHEETS

Worksheet 2 - Energy Efficiency



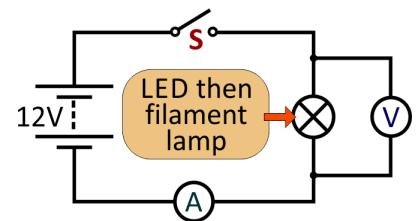
Electrical energy costs money!

Why waste it heating the surroundings when what you really want is a light source!

This investigation looks at whether LED lighting is more energy efficient than an incandescent light.

Over to you

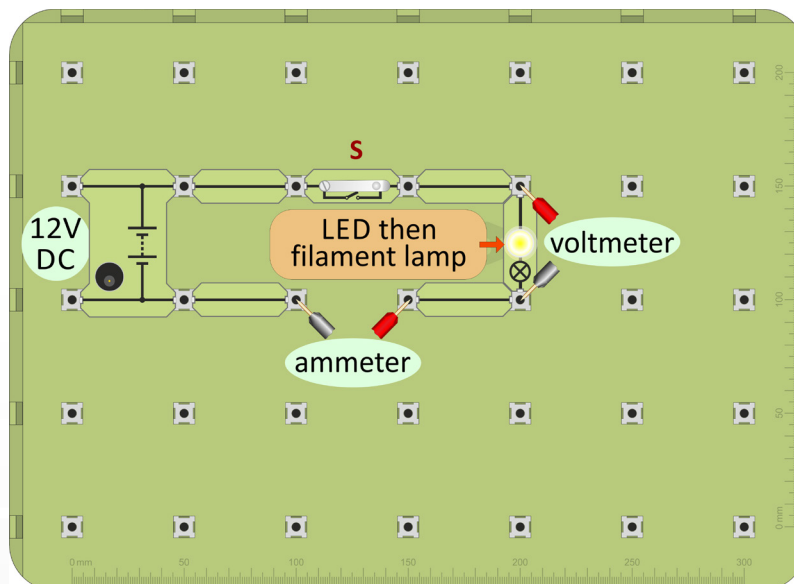
- Build the circuit shown opposite, using the LED lamp. A possible layout is shown at the bottom of the page.
- Connect the 12V DC power supply and switch it on.
- Close switch S.



The LED bulbs are extremely bright.

Do not stare at them for long periods of time!

- Hold the LED lamp in between finger and thumb. Do you detect any rise in temperature?
- Measure the current through the LED lamp and the voltage across it.
- Hold the meter's light sensor 10cm above the lamp and measure the light intensity from the lamp.
- Record them in the table given in the Student Handbook, reproduced below to help you.
- Now, swap the LED lamp for the 12V filament lamp and repeat the procedure.
- Once again, record the measurements in the Student Handbook.
- Complete the calculations using these measurements and answer the questions.



WORKSHEETS

Worksheet 3 - The Effect of Distance



The Sun is pretty bright when we see it at its best, and we are 150 million kilometres away!

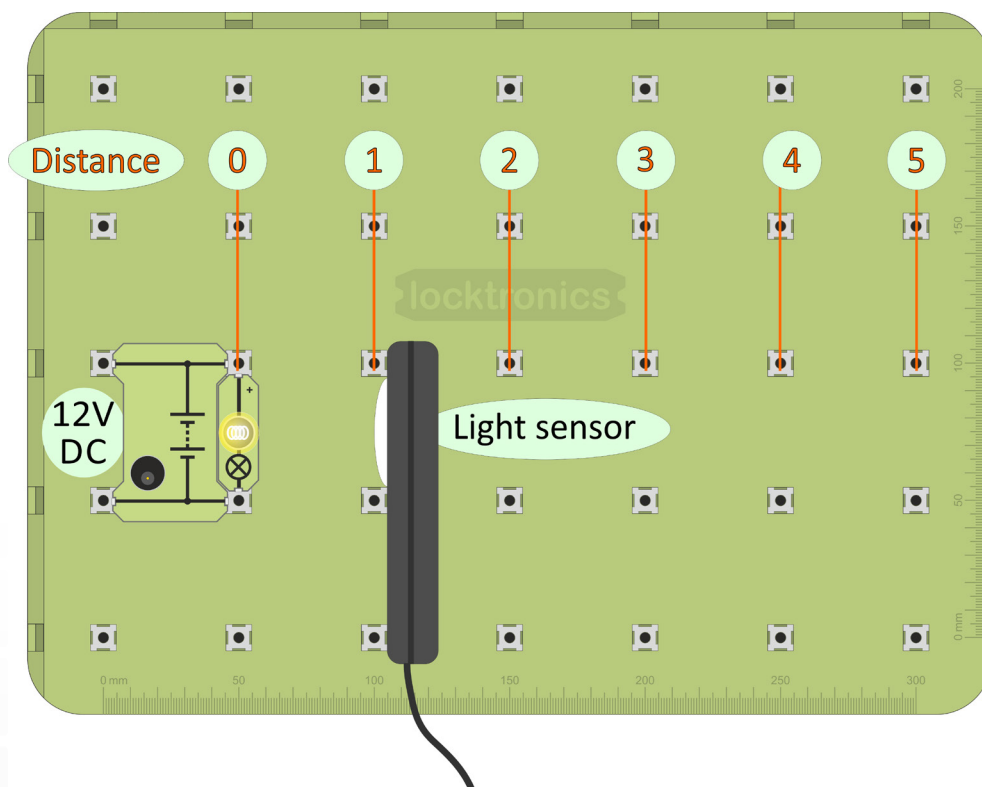
How bright would it appear from the surface of Mercury (only 40% of that distance from the Sun) or from Jupiter, over five times as far away from the Sun?

The results of this next investigation will help to answer these questions.

Over to you

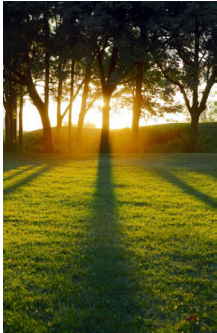
This investigation is best carried out in subdued lighting, in a room with drawn blinds, or even under a bench. It uses the pillars on the baseboards as indicators of distance from the light source: they are spaced 50mm apart.

- Build the circuit shown below and switch on the power supply.
- Place the light sensor so that it rests up against the pillars at distance '1' from the light source. Twist the sensor a little and notice the maximum reading obtained.
- Record this reading in the table in the Student Handbook.
- Repeat this procedure with the light sensor at the other positions shown in the layout below. Each time, record the light intensity in the Student handbook table.



WORKSHEETS

Worksheet 4 - The Effect of Angle



Even on a hot, sunny summer day, the temperature starts to drop as the sun sinks in the sky. It is not further from the earth. It has not cooled down. Light from it spreads over a larger area and so has a smaller warming effect.

For places on the equator, the sun is directly overhead at mid-day no matter what time of year. As a result, there is little variation between seasons.

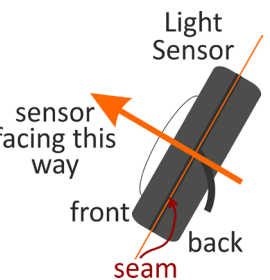
Photovoltaic solar panels produce maximum output when the sun is directly above them.

Over to you

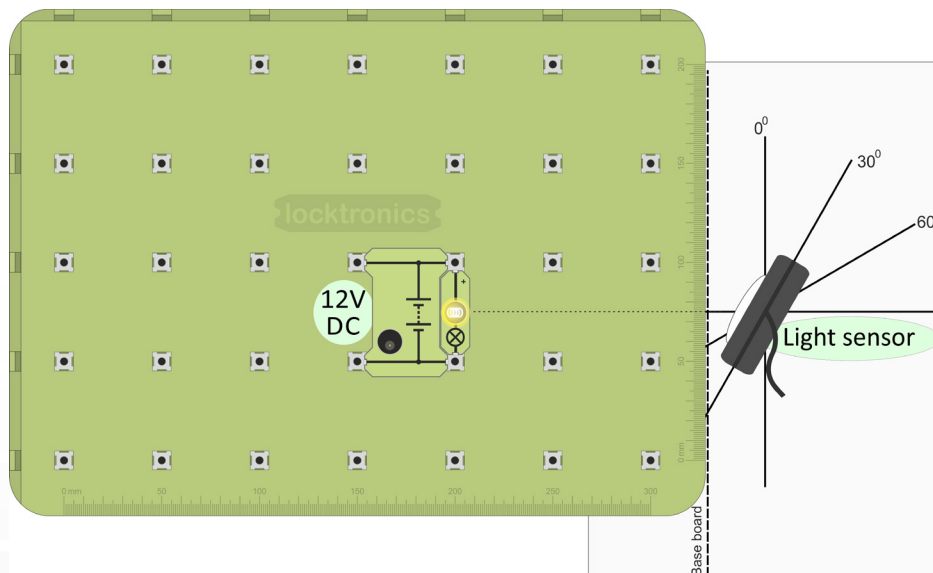
This investigation is also best carried out in subdued lighting.

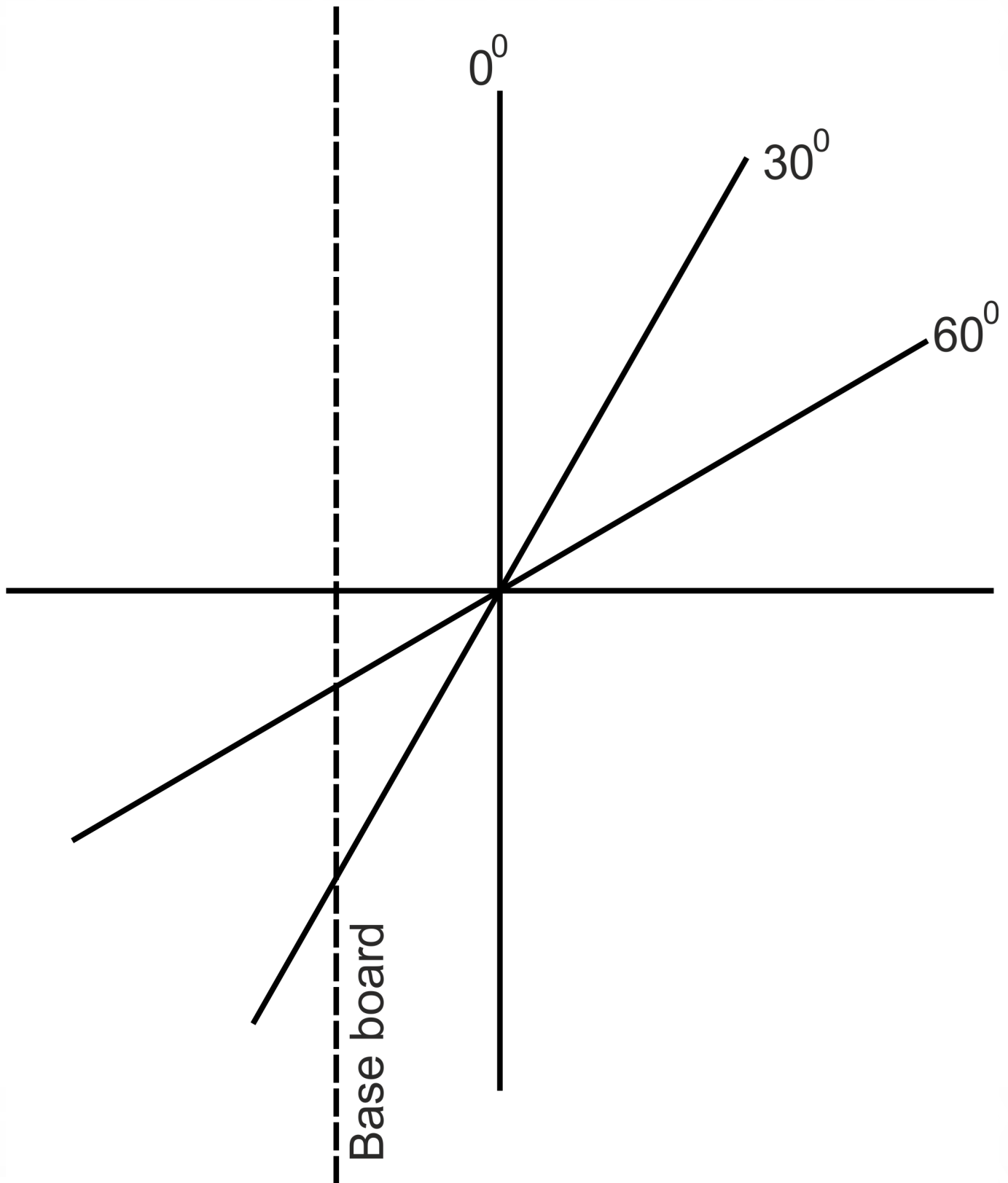
It uses a sheet of paper on which are printed lines at angles of 0° , 30° and 60° and a guide line for the position of the baseboard.

On the light sensor, the seam between the front and back mouldings is used to set the direction in which it is facing.



- Build the circuit shown below and switch on the power supply.
- Place the sheet of paper as shown, so that the base board sits on the dotted line and the centre line is aligned with the centre of the LED lamp.
- Place the light sensor so that it is vertical with the seam lined up with the 0° line. Twist the sensor a little and memorise the maximum reading obtained.
- Rotate the sensor until the seam lines up along the 30° line.
- Do the same for the 60° line.
- Record all readings in the Student Handbook.





WORKSHEETS

Worksheet 5 - The Effects of Reflectors



Generating unwanted light is a waste of money!

The task - to direct the light to where it is needed and remove it from other areas.

Luminaires often use reflectors to modify the light distribution. In some cases, this is to achieve a focussed beam. In others, it is to achieve a spread of light over an extended work area.

This worksheet explores the effect of a reflector on the distribution and intensity of light from a LED lamp. The precise design of the investigation is left open to allow students to practice the skills involved in investigating a light installation.

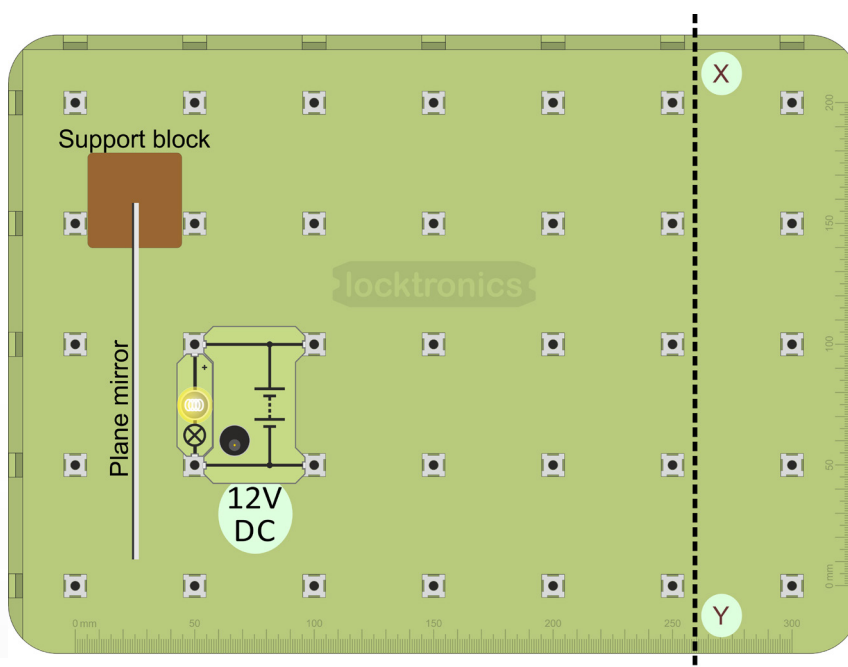
Over to you

The challenge:

Investigate the spread of light from the LED lamp with the reflector in place and then without it.

This investigation is best carried out in subdued lighting. The target area is along the line marked 'X Y' on the layout.

- Build the circuit shown below, with the LED lamp at the position shown and switch on the power supply.
- Place the light sensor at various positions along the line 'X Y' and measure the light intensity.
- Remove the reflector and repeat the procedure.
- Describe your findings in the Student Handbook.



WORKSHEETS

Worksheet 6 - Challenge 1



A lighting engineer must be able to design an installation to provide the required level of illumination with the minimum of installation and running costs.

The design must take into account the height of the luminaires above the work surface and the activities that will take place, as the table on page 5 shows.

Over to you

- Build the circuit shown below, with all sixteen LED lamps.
- Switch on the power supply.

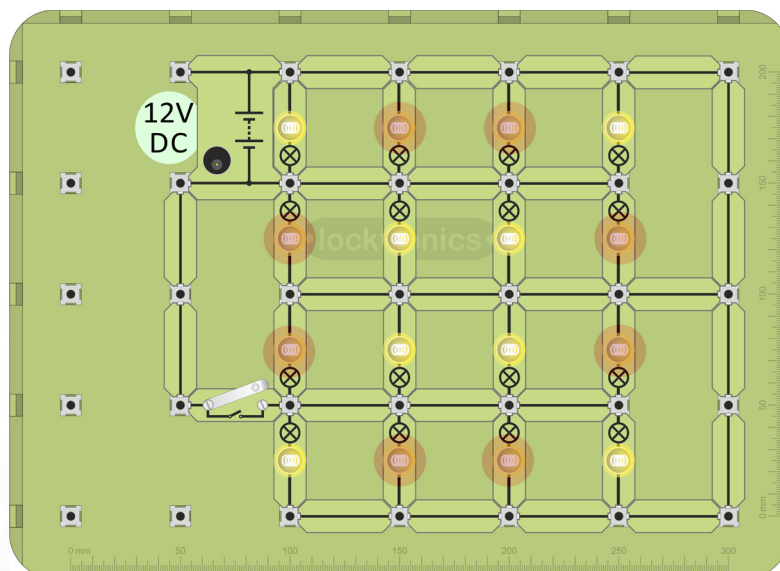
The challenge:

Investigate the following questions:

- At what distance from the LED lamps does the intensity drop to 100 lux, adequate lighting for work involving a low level of detail?
- At that distance, over what area does the light intensity remain above 50 lux?
- Do twice the number of LED lamps produce twice the brightness?
- Describe your findings in the Student Handbook.

Notes:

- The investigations are best carried out in subdued lighting;
- Take care not to short circuit the power supply;
- Take care to ensure that each LED lamp receives the full 12V;
- To halve the number of LED lamps while retaining a relatively uniform beam, remove the ones that are marked with a red circle;
- It may be better to work 'upside-down' with the luminaire pointing up at the light sensor.



WORKSHEETS

Worksheet 7 - Challenge 2



The correct level of illumination and spread is an important element of health and safety.

The challenge here is to design and test a lighting installation for a factory workstation.

Over to you

A workstation is used to solder printed circuit boards. It requires adequate lighting. Your task is to design that lighting.

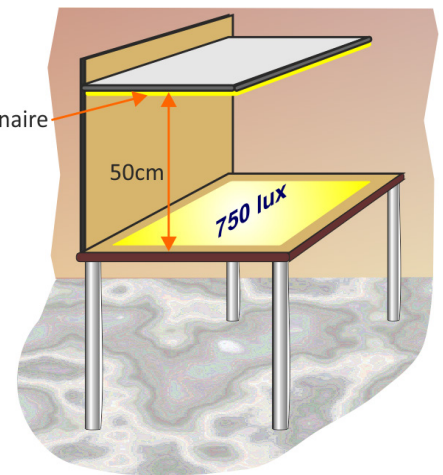
The design brief:

A lighting installation must deliver a minimum of 750 lux over an area 50cm by 35cm at the work surface. The luminaire is positioned at a height of 50cm above the work surface.

Notes:

Test the design in subdued lighting

- A good design:
- Delivers the design brief;
- Using a minimum number of LED lamps, to cut down installation and running costs;
- Take care not to short circuit the power supply;
- Take care to ensure that each LED lamp receives the full 12V;
- The design should not use a reflector (though in real life, it probably would);
- It may be better to work 'upside-down' with the luminaire pointing up at the light sensor.



Use the template in the Student Handbook to show your design.

Describe how you tested it and include the test results.



APPENDIX



Appendix 1 - Measuring Voltage



The picture shows one form of multimeter. It has a wide range of uses -which varies from model to model - but usually includes measuring AC and DC voltage and current

When using a multimeter, before you switch it on:

- Take care to plug the probes into the correct sockets;
- Select the correct range.

('Auto-ranging' versions select the best range automatically.)

Voltage:

- Is a measure of the force pushing the electrons around the circuit;
- Measures energy lost or gained as an electron moves through part of a circuit
- Is measured with a voltmeter connected in parallel with the component.

The circuit symbol for a voltmeter is shown in the diagram.



Using a multimeter to measure voltage:

Multimeters can measure both AC and DC.

The following symbols distinguish between them:

- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**V**' socket.
- Select the 20V DC range by turning the dial to the '**20**' mark next to the '**V** 

AC	
DC	



- Plug the wires into the sockets at the ends of the component under investigation.
- Switch on the multimeter when you are ready to take a reading.
- A '-' sign in front of the reading means that the meter wires are connected the wrong way round. Swap them over to get rid of it!

Appendix 2 - Measuring Current



When using a multimeter to measure current, plug the probes into the '**A**' and '**COM**' sockets, or equivalents.

Then select the correct range, either from the '**A~**' section, for AC current or the '**A**' section, for DC current.

Finally, switch on. 

Current:

- Measures the number of electrons passing any point in the circuit each second;
- Measures the rate of flow of electrical charge in the circuit;
- Is measured with an ammeter connected in series with the component.

The circuit symbol for a ammeter is shown in the diagram.



Using a multimeter to measure current:

- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**mA**' socket.
- Select the 200mA DC range by turning the dial to the '200m' mark next to the '**A**'  'symbol. (Again, it is best to set the meter on a higher range to begin with. Then Break the circuit where you want to measure the current, by removing a link, and then plug the two multimeter leads in its place.
- Switch on the multimeter when you are ready to take a reading.
- A possible problem: The ammeter range is protected by a fuse located inside the body of the multimeter. This may have 'blown', in which case the ammeter will not work. Report any problems to your instructor so that it can be checked.

Appendix 3 - Measuring Resistance



When using a multimeter to measure resistance, the component must be removed from the circuit first!

Once again, before you switch on:

- Take care to plug the probes into the correct sockets, the 'Ω' and 'COM' sockets;
- Select the correct range.

Resistance

- Is a hindrance to the flow of electrons around the circuit;
- Removes energy from each electron as it moves through the resistor;
- Converts this energy into heat;
- Is measured in units called 'ohms' (symbol - 'Ω') or kilohms (kΩ), using an ohmmeter.
(1 kilohm = 1 000 ohms.)



Resistance

- Plug one wire into the black 'COM' socket.
- Plug another into the red 'Ω' socket.
- Turn the dial to select a resistance range, such as 200kΩ. (Once again, it is good practice to set the meter on a range higher than the reading you are expecting and then refine it to a lower range.)
- Make sure that the component under investigation is not connected to any other.
- Plug the wires into the sockets at the ends of the component.
- Switch on the multimeter when you are ready to take a reading.



STUDENT HANDBOOK



Student Handbook

Introduction

Lighting is important to the health and safety of people using the area.

Poor lighting causes effects like eyestrain, migraine and headaches, increasing absence through sickness and reducing productivity. Good lighting allows people to spot and avoid hazards.

The solution involves consideration of issues like:

- Energy efficiency;
- Spectral response;
- Dimensions of the workspace;
- Activities that take place in it.

Energy efficiency, (better called **luminous efficacy**), measures how much of the electrical energy supplied goes into generating visible light. It depends on the type of luminaire used.

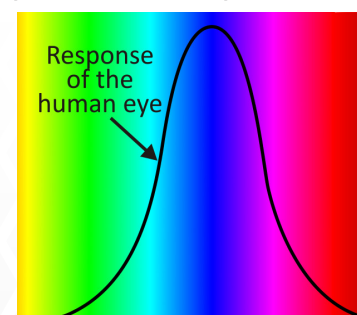
Technology	Luminous efficacy in lumen/watt
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LED	80 - 150

Incandescent lights rely on heating up material until it gets so hot that it glows. The colour of the light produced depends on the temperature of the material.

Fluorescent lights generate ultraviolet radiation initially - invisible to us. However, this is absorbed by a coating on the inside of the lamp which then re-transmits visible light. The precise colour depends on the substances in the coating.

LED lights involve more complex physics, beyond the scope of this course. They generate light without the need for high temperature by passing electric current through semiconductor crystals. The colour of the light produced depends on the chemical composition of the semiconductor crystals.

Spectral response, how much of the radiation produced is in the visible part of the spectrum, shows which colours of light our eyes respond to the best.



Student Handbook

Dimensions - the higher the ceiling, the further the light from a particular luminaire spreads out and the weaker it gets.

Activities taking place -

Activity	Typical location	Average illuminance
General movement	Entrances and corridors	20
Movement in hazardous areas	Construction sites, Loading bays	50
Work requiring low level of detail	Kitchens, General factory work	100
Work requiring medium level of detail	Offices and workshops	200
Work requiring fine detail	Drawing offices, Small components assembly line	500

Glossary:

- Flux - something that flows.
- Radiant flux - energy that flows in the form of electromagnetic radiation.
- Luminous flux - energy that flows as light, i.e. produces the sensation of sight in our eyes. A measure of the "useable" light emitted from a source, it is measured in lumens.
- Illuminance - the total luminous flux hitting (illuminating) a unit of surface area. It is a measure of how much 'useable' light strikes a surface and is measured in lux.
- Luminance - measures the amount of light reflected off a surface - the 'brightness' of an object. Luminance is measured in candelas per square metre.
- Lumen: measures the total amount of light energy regardless of direction. It is used to measure energy efficiency, using a 'lumens-per-watt' formula. The result is called 'luminous efficacy'.
- Lux: equals one lumen per square metre. Used in conjunction with distance, it allows us to calculate whether a luminaire delivers adequate light intensity for specific applications.
- Candela: shows how well a light source enables humans to see objects. It measures how well the light produced stimulates our vision. Whereas the radiant intensity measures the total energy radiated in the full visible spectrum, the candela measures how much energy is emitted at the peak response frequency, 540×10^{12} Hz, green light.

Student Handbook

Worksheet 1 - Measuring light

Here are the readings taken with the light meter:

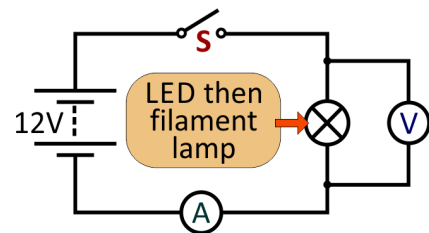
Location	Light level in lux
Outdoors - bright sunshine	
Outdoors - shade	
Room - near window	
Room - near luminaire	
Room - shade	
Room - dark corner	

Use the table on page 5 to answer the following:

- Which location is suitable for doing detailed work? _____
- Which location is suitable for general factory work?. _____

Worksheet 2 - Energy efficiency

A filament (incandescent) lamp and a LED lamp were set up to produce the same light output.



The following measurements were taken:

Light source	Light intensity in lux	Voltage in V	Current in mA
LED			
Filament			

Use these in the formula $P = I \times V$ to calculate:

- The power P_1 , dissipated in the incandescent lamp _____
- The power P_2 , dissipated in the LED lamp _____

Which bulb got hotter? _____

Comment on any differences in the light produced by the two sources:

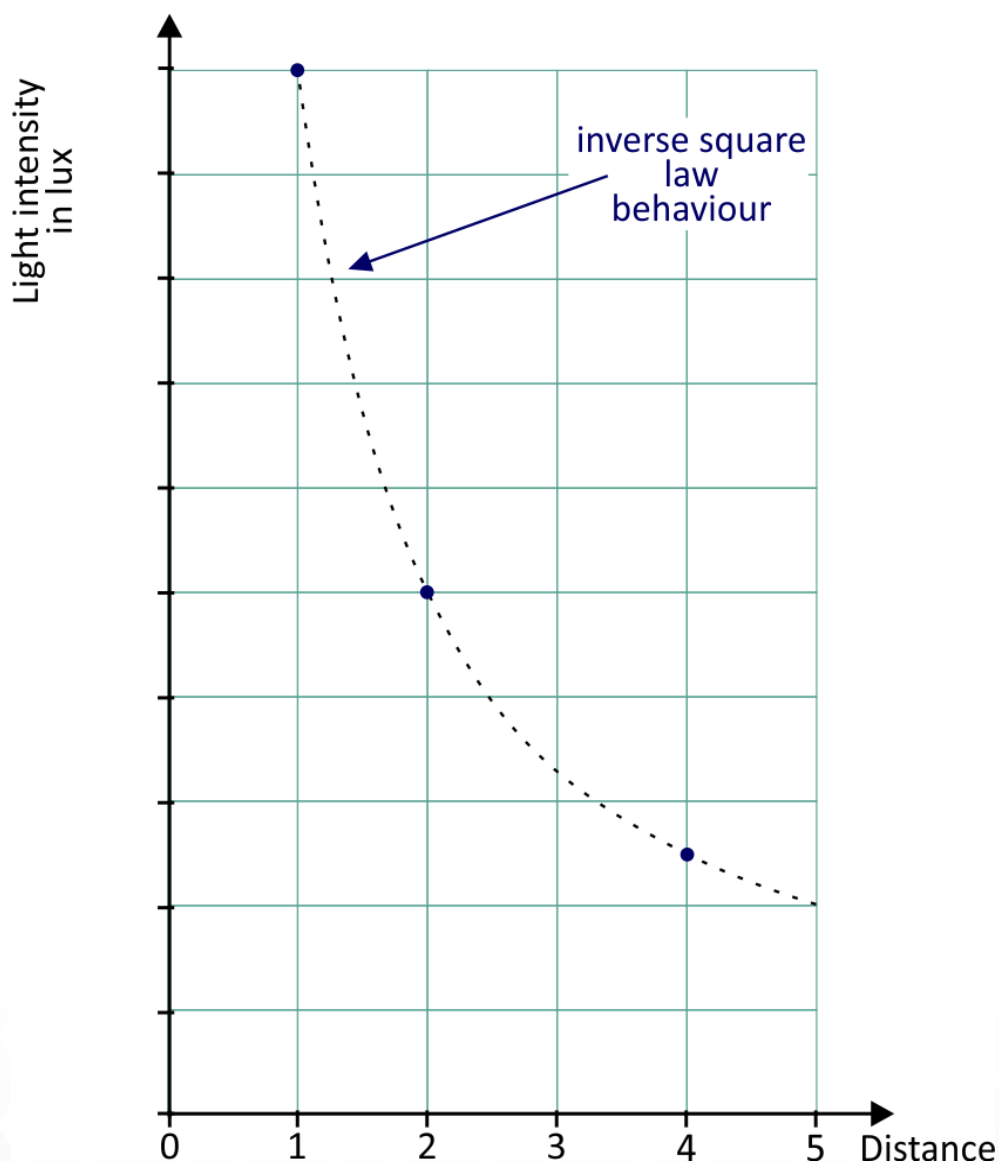
Student Handbook

Worksheet 3 - The effect of distance

The table shows how light intensity falls away with distance from the source.

Plot these results on the axes provided below and compare the resulting curve with the inverse square law behaviour.

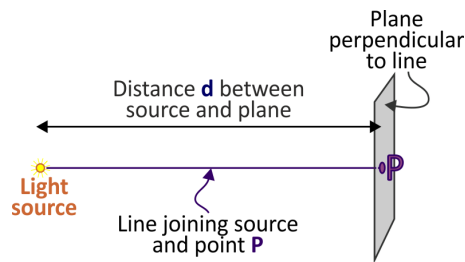
Distance	Light level in lux
1	
2	
3	
4	
5	



Student Handbook

Inverse square law of illumination:

The Illuminance at point P, on a plane at right-angles to the line joining P and a point source of light depends on the **square** of the distance between them and gets smaller as the distance increases.



Mathematically:

Illuminance **E** depends on $1 / d^2$

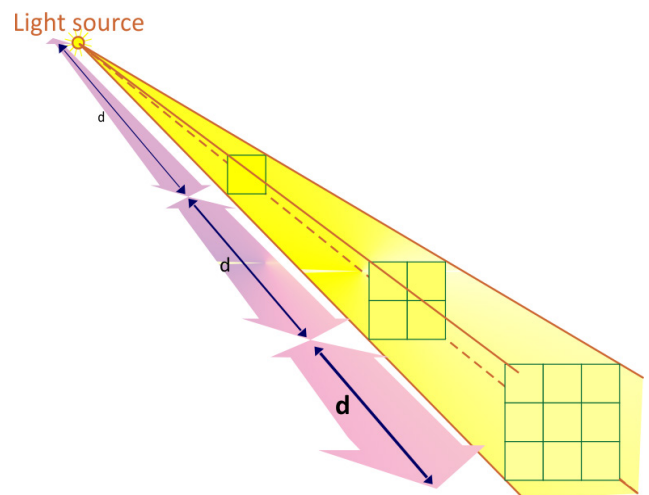
This means that when d is:

- Doubled (2 times bigger), **E** is four times ($= 2^2$) smaller;
- Trebled (3 times bigger), **E** is nine times ($= 3^2$) smaller etc.

The result comes directly from geometry:

When the distance from the light source doubles, the beam is twice as high and twice as wide, giving it an area four times bigger. The light is now spread over an area four times bigger and so is four times less intense.

The following diagram illustrates this:



Despite appearances, all the squares in the diagram are the same size and the distances marked 'd' are equal!

Student Handbook

Worksheet 4 - The effect of angle

Your measurements:

Angle X	Cosine of angle X	Intensity	Theoretical value
0	1		
30	0.87		
60	0.5		

Lambert's cosine law:

The illuminance at a point is proportional to the cosine of the angle of incidence of the light hitting the surface.

Complete the table by calculating the theoretical values from Lambert's cosine law, using the formula: **Theoretical value = intensity at 00 x cos X**
Compare your measurements with the theoretical values.

What are the sources of error in this experiment?

In optics, angles are usually measured from the 'normal' at the point where the light hits the plane. The normal is a line at right angles to the plane. This terminology is illustrated in the diagram.

This law also results from the geometry of the situation.

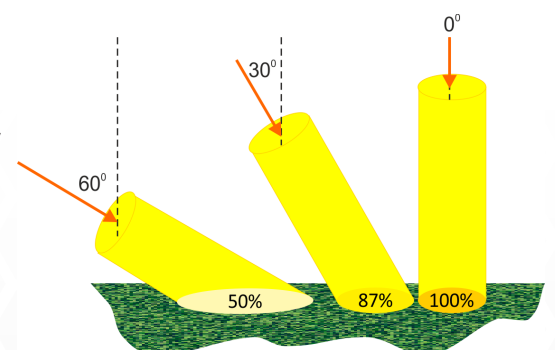
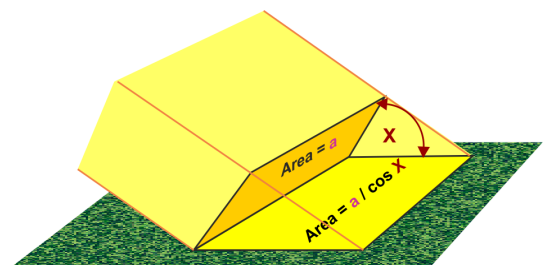
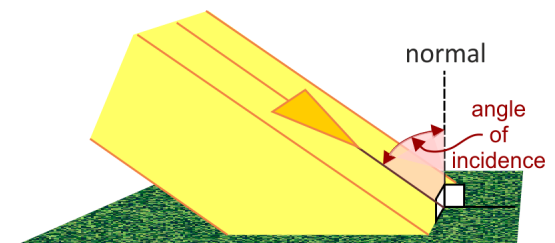
When a beam of light strikes a surface at a shallow angle, it spreads over a bigger area than when it hits it directly (when the angle of incidence = 0°.) The area over which it spreads depends on the angle of incidence, X.

Where the light beam has a cross-sectional area a , the surface illuminated has an area equal to $a / \cos X$.

As a result, the light intensity drops by a factor of $\cos X$.

The next diagram shows the result of this. It uses the relationships:

- $\cos 0^\circ = 1$;
- $\cos 30^\circ = 0.87$;
- $\cos 60^\circ = 0.5$.



Student Handbook

Worksheet 6 - Challenge 1

Question 1:

At what distance from the LED lamps does the intensity drop to 100 lux, adequate lighting for work involving a low level of detail?

Student Handbook

Worksheet 6 - Challenge 1

Question 2:

At that distance, over what area does the light intensity remain above 50 lux?

Student Handbook

Worksheet 6 - Challenge 1

Question 3:

Do twice the number of LED lamps produce twice the brightness?

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Student Handbook

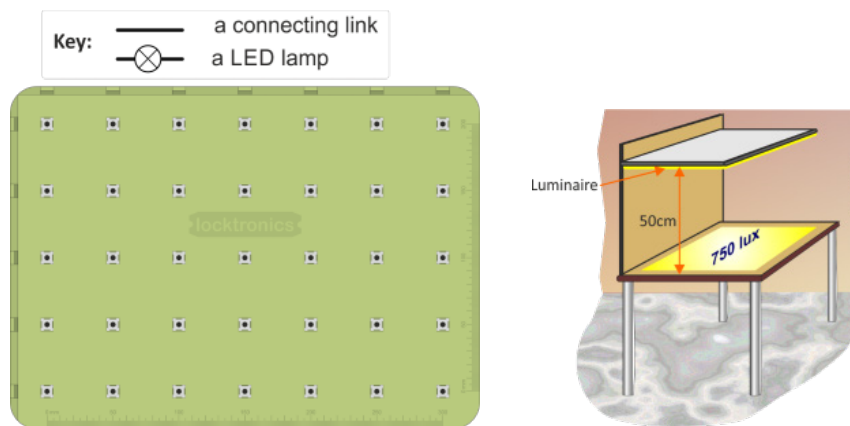
Worksheet 7 - Challenge 2

The design brief:

A lighting installation must deliver a minimum of 750 lux over an area 50cm by 35cm at the surface of a work station. The luminaire is positioned at a height of 50cm above the surface.

Your design:

Use the template to show your final design for the workstation lighting, using the symbols given in the key.



Describe how you tested your design:

Give the results of your measurements:

PRINCIPLES OF LIGHTING LEVEL 3

CP2273

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