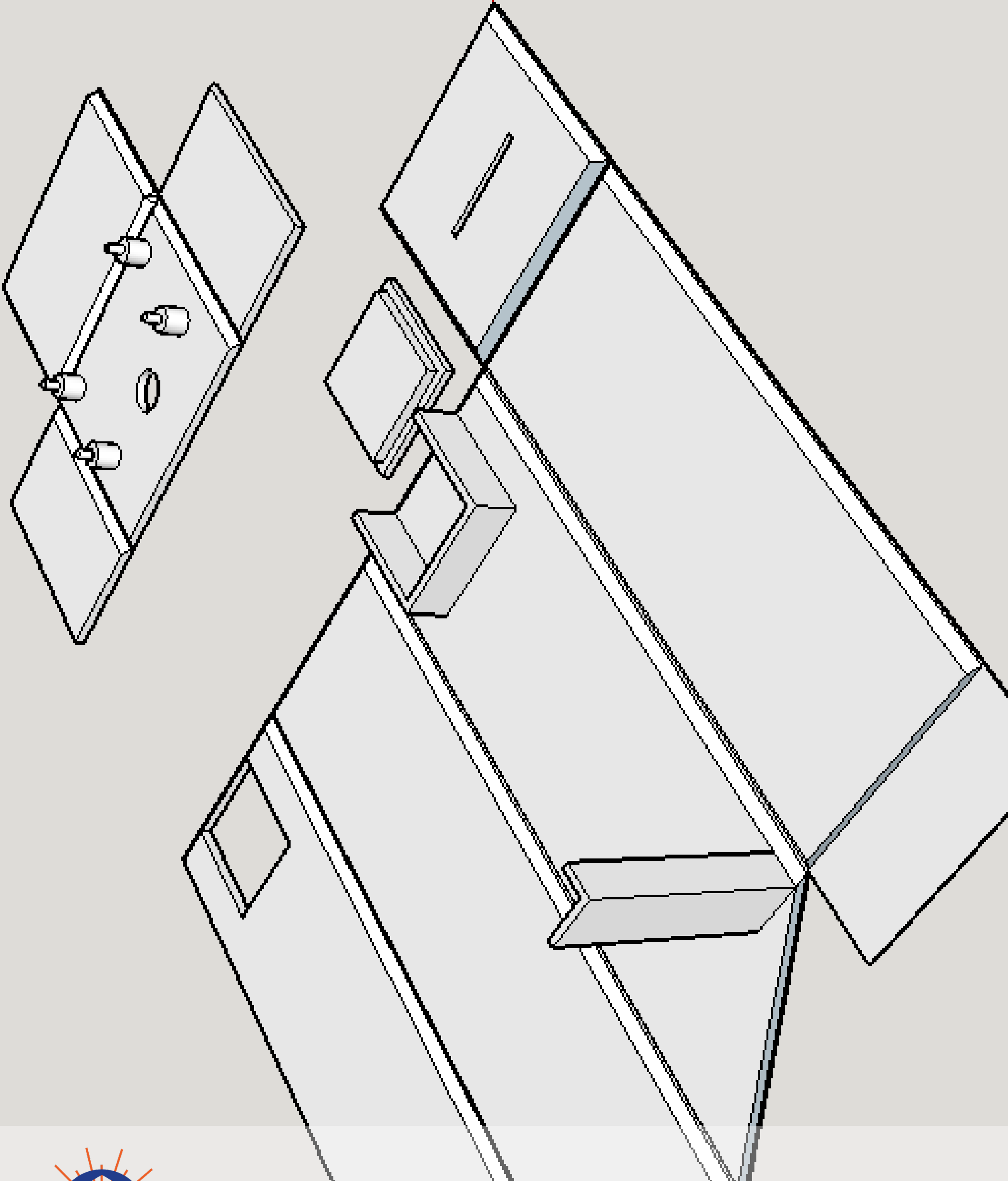

PHABLABS 4.0

PHOTONICS WORKSHOP

# BASIC SPECTROMETER

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## PROPERTIES OF THIS WORKSHOP

### SUMMARY:

Spectrometry allows us to see what colours of light are present in our source, the students will create a simple spectrometer from 3D-printed material, a diffraction grating and some cellotape.

### TARGET AUDIENCE:

Students (14-18 years old)

### SUGGESTED TIME PLANNING: (Total: 2h)

| Timing in minutes | activity |
|---|---|
| 0 - 20 | Understanding the concepts of 'Diffraction, Interference & diffraction grating experiment' |
| 20 - 35 | Construction of the 3-D printed spectrometer with diffraction grating |
| 35 - 85 | Imaging of different light sources and calibration using images |

### TOOLS:

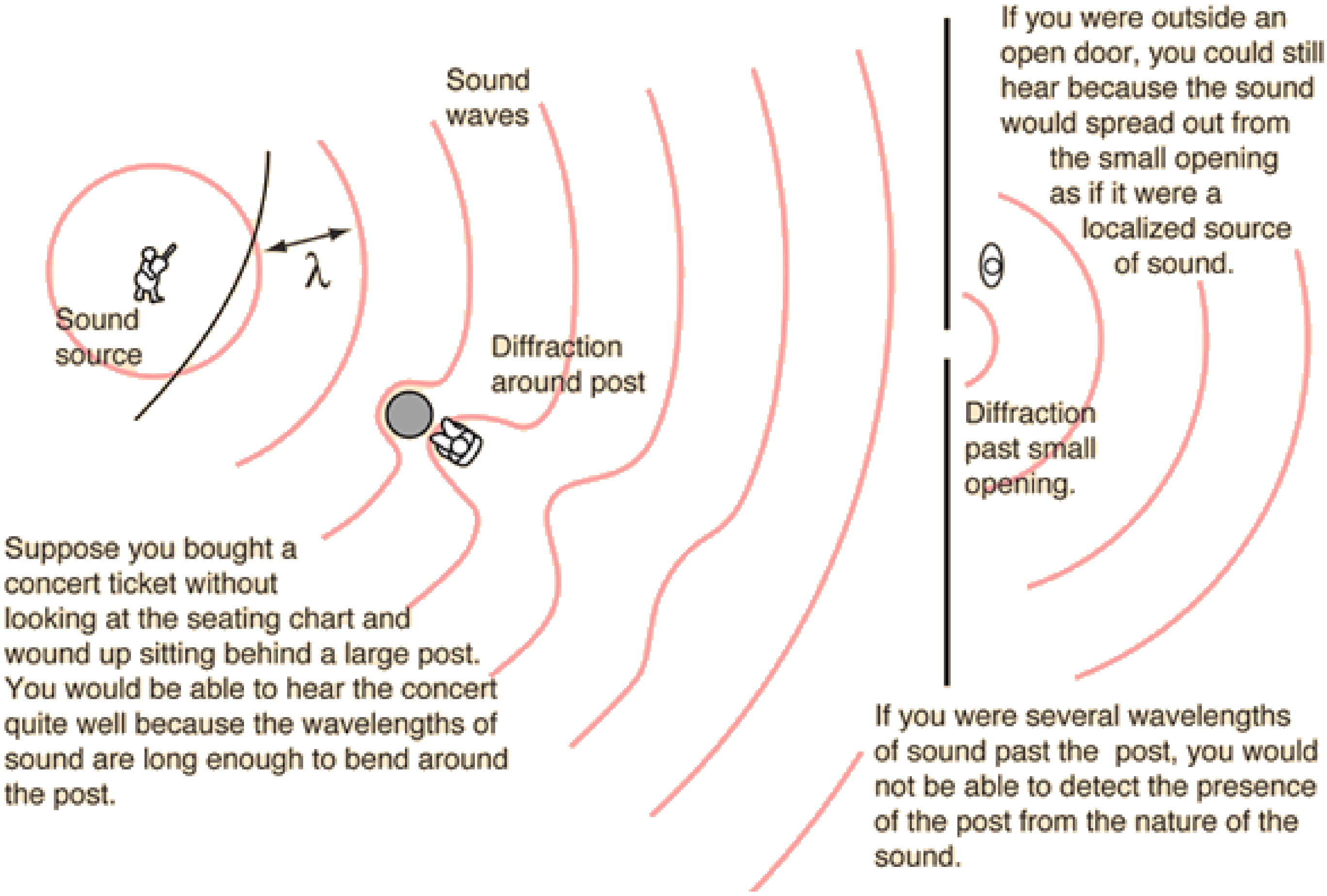
3D printer

### ESTIMATED COST:

€20

## Step 1: Interference and diffraction

Interference and diffraction of waves not only produces interesting visual effects by interaction of waves in nature, they can be harnessed as a powerful tools for the study and measurement of tiny objects. Although the phenomenon has been known about for centuries, it is of special interest today. More and more technology relies on micro-- and nanometer--sized particles – too small to be seen by a normal microscope. By understanding diffraction and the interference of light waves and using them smartly, not only can we peek into this microscopic world, we can even manipulate objects in it.




To gain an intuition about light diffraction, where our wavelength is in the nanoscale, we can look at our experiences with sound involve diffraction. The fact that you can hear sounds around corners and around barriers involves both diffraction and reflection of sound. Diffraction in such cases helps the sound to "bend around" the obstacles.

Light too can bend when it around corner, we have have designed a spectrometer to exploit this feature using a diffraction grating.

## Step 2: Parts list

Collect all materials for each participant.

### Included:

### Photonics Parts:

Diffraction grating
40 pieces

Other parts you need for doing this workshop:
-Different kinds of light sources: laserpointers, mercury lamp, sodium lamp
-A3 paper
-pens
-protractors, rulers
-Computer with imageJ and java installed
-Camera/smartphone

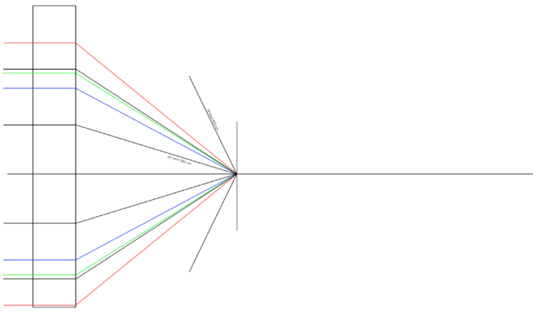
The photonics parts can be bought by EYESTvzw.
The electronic parts can be bought by Fablabfactory.

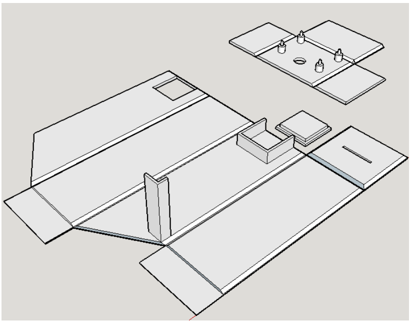
## Step 3:

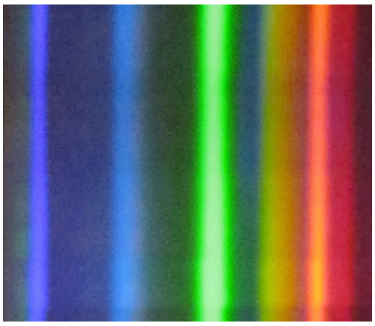
This workshop is based on the science of spectroscopy. The participants will construct a basic spectrometer through which they can look using their eye and then attach a smart phone to acquire images. These images will then be imported to a computer and the participants will learn how to calibrate their spectrometer and generate spectra for various light sources and transmissive media. During the workshop, the participants will perform the following tasks:

1. Design and assemble a simple diffraction experiment using a laser pointer and diffraction grating. They will learn about diffraction and the diffraction equation. They will plot the angle of diffraction for a red and green laser to illustrate the angular dependence on wavelength.
2. 3D print a miniature spectrometer through which they can look or attach to their smart phone or camera.
3. Acquire some images of various light sources and samples such as a sodium light, mercury light, LED light bulbs, daylight and examine the difference in their spectral lines.
4. Import the images to a computer and learn how to calibrate their spectrometer using open source image analysis software (ImageJ)
5. Create a macro using ImageJ to crop, average, plot graph and output spectral data.

Each participant will get to take home
1. A 3D printed spectrometer
2. Colour images of the various light sources and samples acquired using their smart phones
3. Print outs of the various spectra







### Diffraction experiment
Place the A3 sheet of paper on the table.
The laser light will be projected onto this fold.

Draw a central axis line on the sheet of paper. The laser light will be pointed along this direction.
Place the diffraction perpendicular on the central line in the perpendicular orientation and mark its position on the central line.

First using the red laser, point it directly along the central line and through the diffraction grating.
The laser light will produce three spots on the vertical paper. The central spot is the 'straight through' beam from the laser. The outside spots are the diffracted beams. Using a red pen, mark the position of the three spots.
Now replace the red laser with a green / blue laser and again point the laser along the central axis and such that the central spot overlaps with the central mark from the red laser.
Mark the position of the diffracted spots using green / blue link.
Measure the distance between the diffraction grating and the projected spots. Call this distance D.
n l = d sin(theta)
Rearrange for l = l = d sin (theta) / n

n is the order and you will see that only one order is seen with this diffraction grating, n = 1.
L is the wavelength of the light
D is the distance between consecutive lines of the grating = 1 / 1000 (mm)
Take down the sheet of paper and measure the distance between the central spots and the diffracted spots. For each colour measure the distance between both the left and right spots and find the average. Let this distance be y.
Calculate theta = tan-1 (y / D)

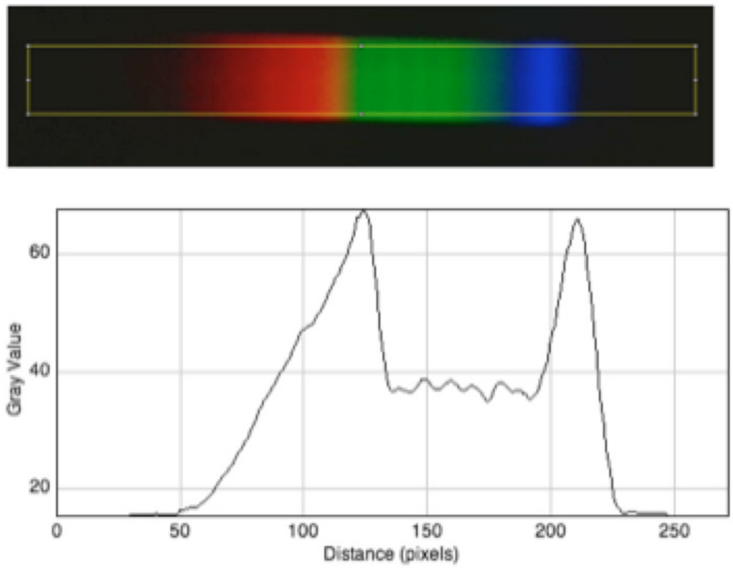
Using the above equation l = d sin (theta) / n
L = 630 nm for red.
For green, l = 560?

A good approximation for the central region of the visible part of the visible spectrum is 545 nm. Calculate the angle of diffraction for this wavelength. = 33°.
This is the reason the spectrometer is angled the way it is.

How do cameras 'see' the light? Will a camera sensor see outside the visible portion of the spectrum? Demonstrate using the IR light emitting diode on a remote control to show that a smart phone camera will easily see this portion of the spectrum.
Show the spectral sensitivity of silicon.

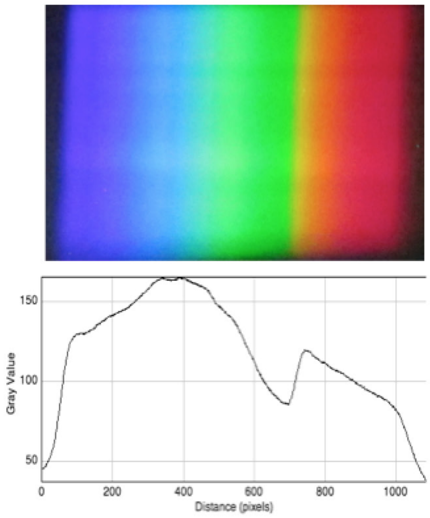
## Step 4:

In addition to the diagram above, a smartphone camera positioned alongside the diffraction grating. Images of the diffraction pattern for each wavelength of light source will be taken. As the wavelength varies, spacing between the order will change. The recorded images will analysed using ImageJ software [https://imagej.net/Downloads](https://imagej.net/Downloads) with the distance between dots measured in pixels. The distance between dots will also be measured using a meter stick.
Since $k\lambda = d\sin(\theta)$, for large distance D we have $\theta = y / D$, the students can estimate the wavelength of the light and graph the relationship between y and k, this will have a different slope for each wavelength of light source.

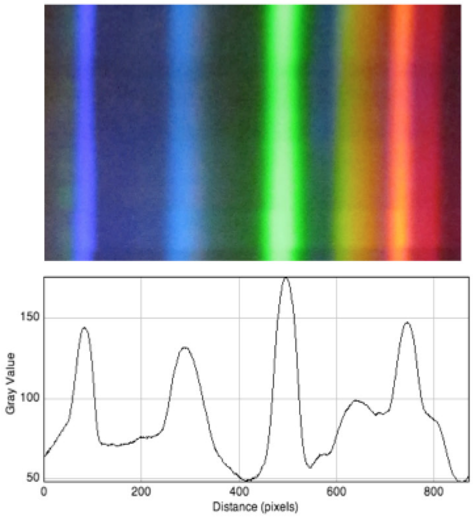



## Spectral images of various spectra

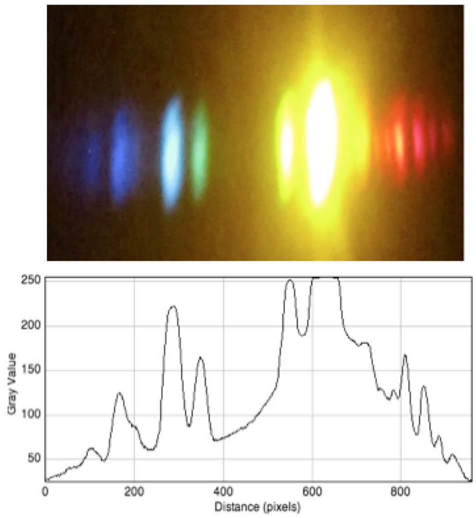
Daylight



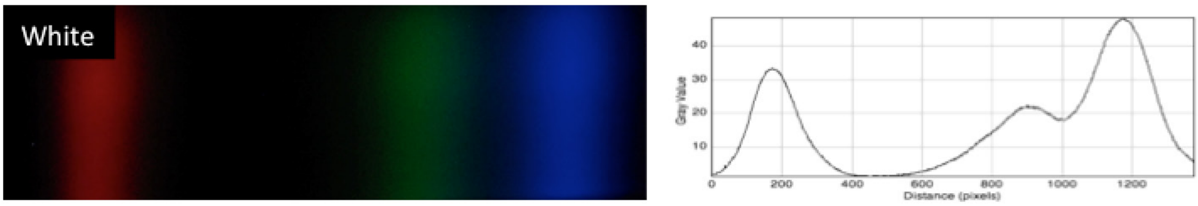

LED lightbulb

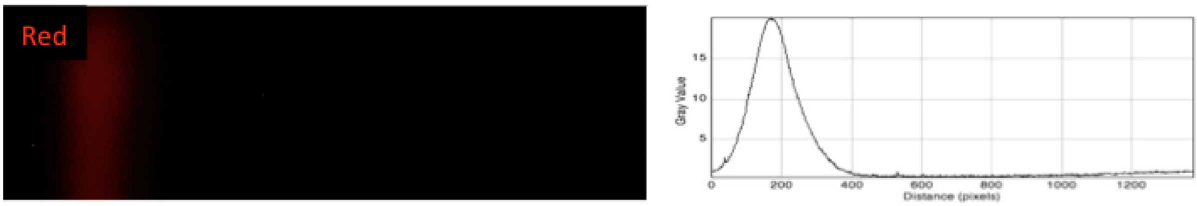


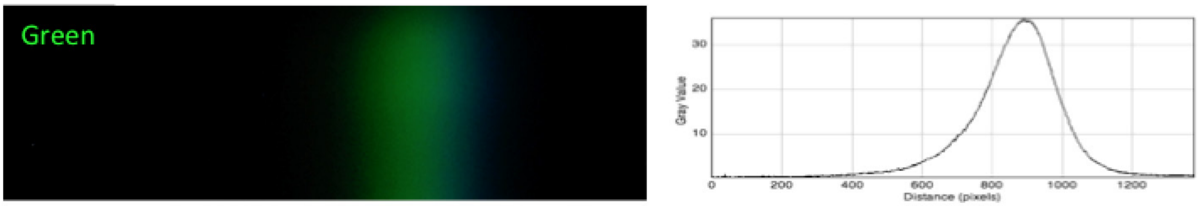

High pressure sodium

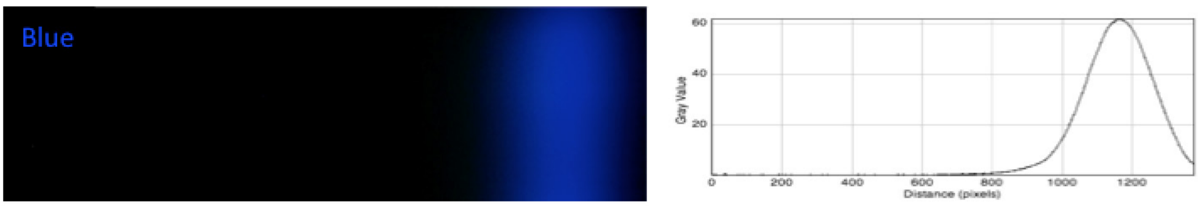


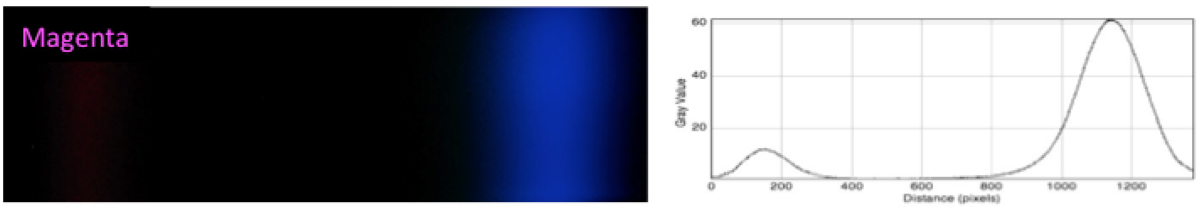

## Spectral images nd profiles of the LED lamp as emits various colours of light




## Instructions for calibrating the spectral lines

Image the spectral line emitted from low pressure sodium. This line is a known wavelength of ? = l1
Image the spectral line emitted from mercury. This line is a known wavelength of ? = l2.
The corresponding pixels are called p1 and p2.
Each pixel corresponds to (p2 – p1 / L2-l1) nm
Say 600 nm – 400 nm = 500 – 100 i.e. 200 nm across 400 pixels i.e. each pixel = 0.5 nm

## Step 6: End result & conclusions

### What we learned?

The participants have learned about the spectral content of different light sources and that we can measure and quantify the wavelengths of light using readily available technology. We learned about how we can use interference and diffraction to create a simple spectrometer and record data from different light sources using our eyes and our phone cameras.

### Concluding thoughts

The spirit of Phablabs 4.0 is to integrate photonics with existing technologies to show that light is fascinating and can be used to gain a physical understanding of our world. By leveraging hacker tech that pervades current Fablabs and Maker projects, we can excite interest and inexplicably link the concepts of technological innovation and photonics in our participants minds.

PHABLABS 4.0

PHABLABS 4.0 is a European project where two major trends are combined into one powerful and ambitious innovation pathway for digitization of European industry:
On the one hand the growing awareness of photonics as an important innovation driver and a key enabling technology towards a better society, and on the other hand the exploding network of vibrant Fab Labs where next-generation practical skills-based learning using KETs is core but where photonics is currently lacking.

www.PHABLABS.eu

This workshop was set up by NUI Galway, Tissue optics & microcirculation imaging department, in close collaboration with Maker Space NUIG.

NUI Galway OÉ Gaillimh

Maker Space

PHOTONICS21

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CNR IFN Istituto di Fotonica e Nanotecnologie TU Delft Delft University of Technology UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE Eyest vzw ECOP European Centres for Outreach in Photonics