

3. The Electromagnetic Spectrum and Visible Spectrum

	Topic	Heinemann		
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Electromagnetic Waves Overview

Light can be considered a transverse electromagnetic wave. Electromagnetic means that there are two parts of the wave – an electric component and a magnetic component.

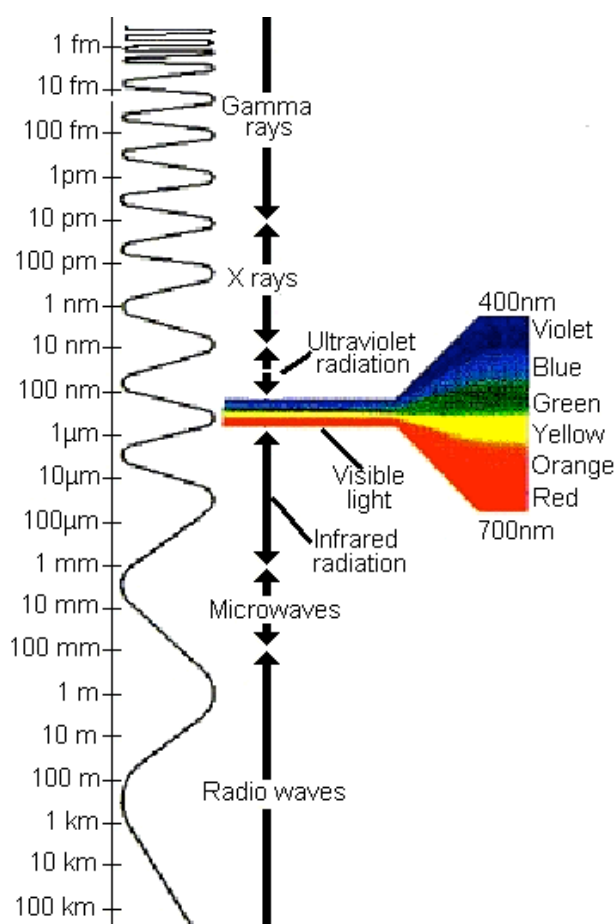
In a vacuum, all **electromagnetic waves** move at the same speed $c = 3 \times 10^8$ m/s. This is known as the speed of light. (In other mediums such as air, water or glass, light and other EM waves move slightly slower.)

All EM waves differ from one another in their wavelength and frequency. The range of wavelengths, as seen right, is from hundreds of kilometres to smaller than the size of the nucleus of an atom.

Visible light has wavelengths between $\sim 4 \times 10^{-7}$ m and $\sim 7 \times 10^{-7}$ m. It makes up a tiny part of the measured EM spectrum.

The longer wavelengths (lower frequency waves) appear red, and the shorter wavelengths (higher frequency waves) appear violet.

Waves with shorter wavelengths (hence higher frequency) have more energy associated with the wave.



Questions

Which of the following colours has the longest wavelength?

- A. Red B. yellow C. blue D. violet

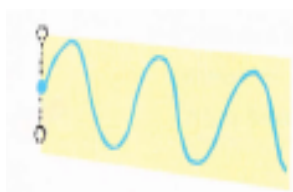
Which of the following colours has the highest frequency?

- A. Red B. yellow C. blue D. violet

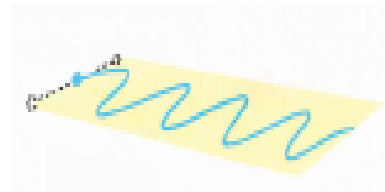
Which of the following has the smallest wavelength?

- A. X-rays B. Gamma rays C. Infrared D. Radio waves

Polarisation of Light



In a beam of light from most sources the light is unpolarised, which means that electromagnetic waves of the light are oscillating in many different directions. So the waves are vertical (shown left), horizontal (shown right), and also every angle in between.



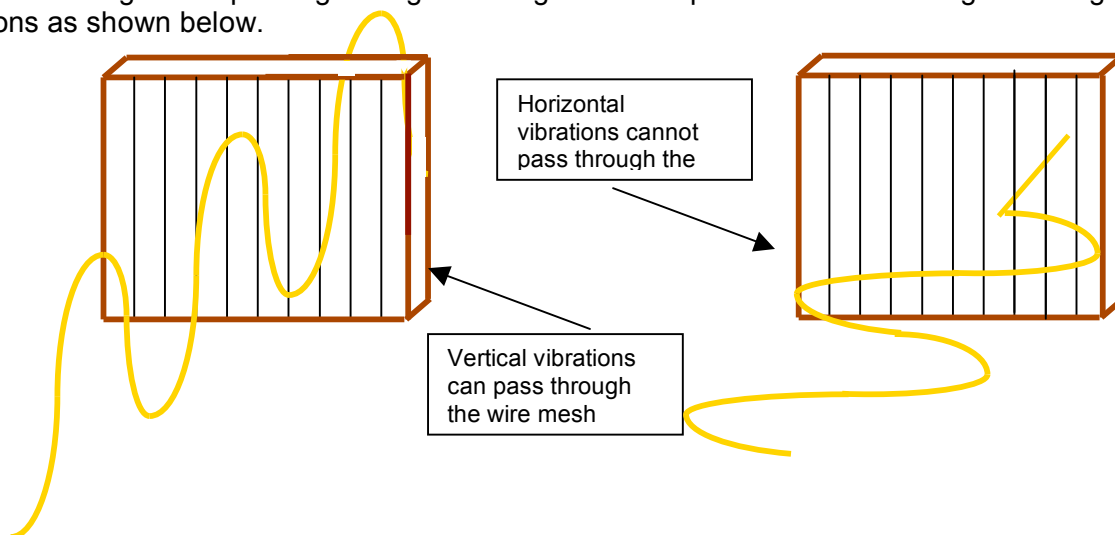
Some sources of light are polarised in a particular direction, such as

- LCD displays (phones, computers and calculators)
- Reflected light from shiny surfaces

It is also possible to block out particular directions of light using polarising filters (and hence create polarised light.)

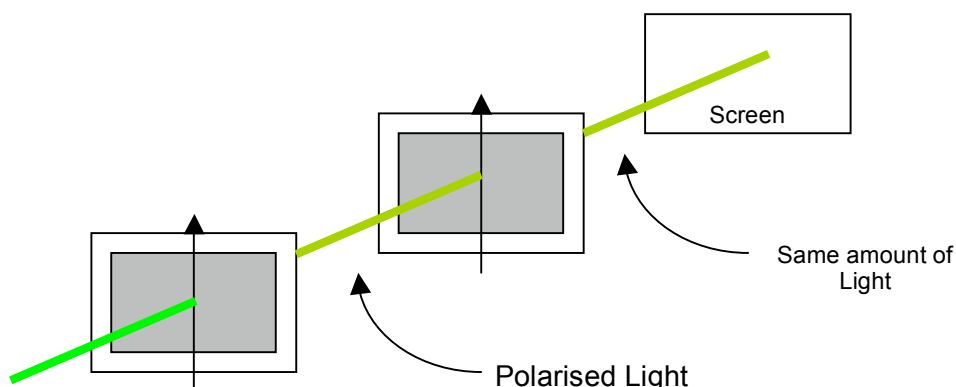
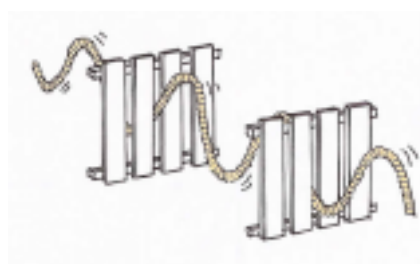
Polarising Light

Consider a string that is passing through a wire grid. Wave passes are sent along the string in two directions as shown below.

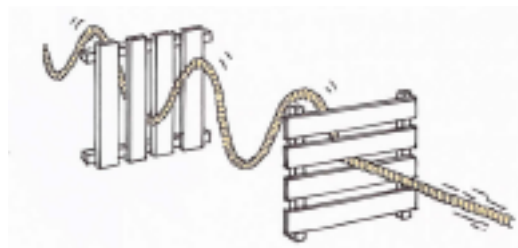
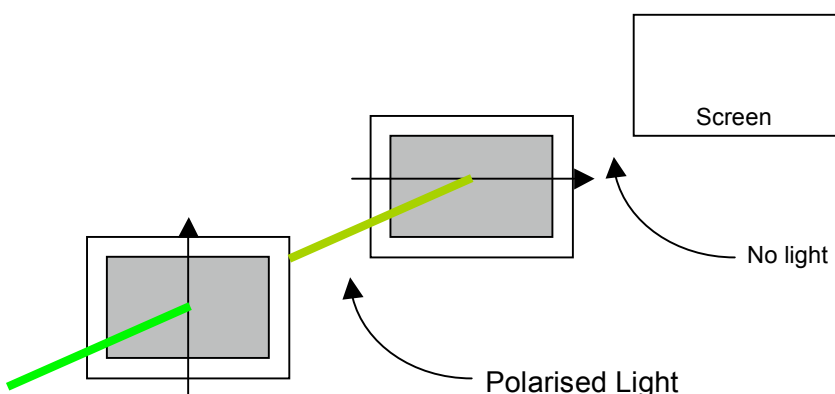


In a similar way, optical devices called polarisers only allow light with a specific polarisation to pass through them.

If a second polariser is placed behind the first polariser, the amount of light getting through can be adjusted by rotating the second polariser. The arrows below indicate the polarisation of light that gets through the polariser. If the directions of both polarisers are the same, then all of the light that gets through the first polariser will pass through the second polariser.



If the directions of both polarisers are at right angles to each other then no light will pass through.



For other angles, the amount of light getting through to the screen vary from almost all if the second polariser is nearly aligned, to next to nothing if the polarisers are almost crossed.

Sunglasses

When light reflects from a wet surface, it becomes partially horizontally polarised. Many sunglasses are designed to eliminate this glare. These sunglasses are polarised, so that they only allow light with a vertical polarisation to go through them. Light that is reflected from the water surface is not able to get through, and so the glare from the road is reduced.

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Chapter 29 Light Waves
Polarization

The amplitude of a light wave has magnitude and direction, and can be represented by a vector. Polarized light that vibrates in a single direction is represented by a single vector. To the left the single vector represents vertically polarized light. The pair of perpendicular vectors to the right represents nonpolarized light. The vibrations of nonpolarized light are equal in all directions, with as many vertical components as horizontal components.

1. In the sketch below, nonpolarized light from a flashlight strikes a pair of Polaroid filters.

NON-POLARIZED LIGHT VIBRATES IN ALL DIRECTIONS
VERTICAL COMPONENT PASSES THROUGH FIRST POLARIZER ... AND THE SECOND
VERTICAL COMPONENT DOES NOT PASS THROUGH THIS SECOND POLARIZER

2. Consider the transmission of light through a pair of Polaroids with polarization axes at 45° to each other. Although in practice the Polaroids are one atop the other, we show them spread out side by side below. From left to right:

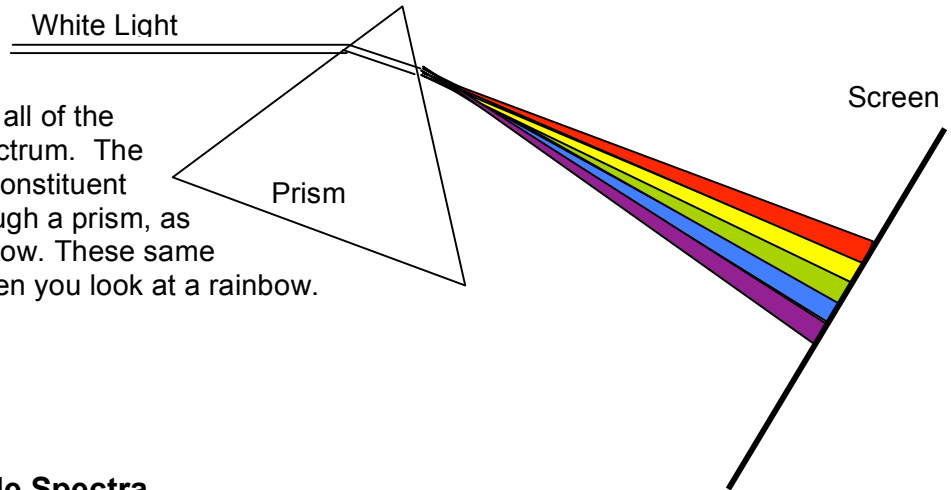
- Nonpolarized light is represented by its horizontal and vertical components.
- These components strike filter A.
- The vertical component is transmitted, and
- falls upon filter B. This vertical component is not aligned with the polarization axis of filter B, but it has a component that is aligned—component t , which is transmitted.

a. The amount of light that gets through Filter B, compared to the amount that gets through Filter A is [more] [less] [the same].

b. The component perpendicular to t that falls on Filter B is [also transmitted] [absorbed].

Colour

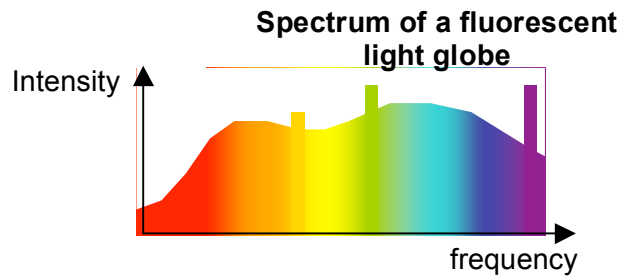
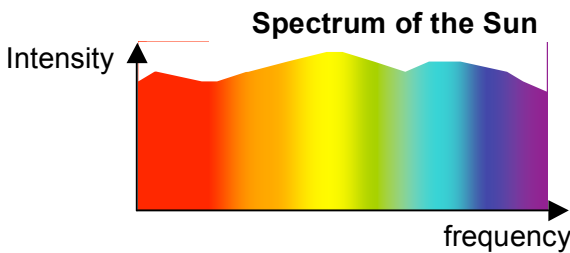
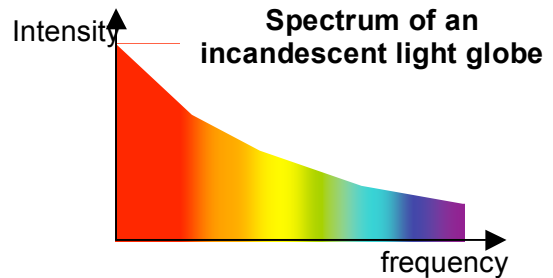
White light is made up of all of the colours of the visible spectrum. The light can be split into its constituent colours by shining it through a prism, as shown in the diagram below. These same colours are observed when you look at a rainbow.



Some Common Visible Spectra

Spectroscopes are also able to reveal the particular frequencies of light sources.

Here are some examples of three different “white” light sources. Notice that they all contain the full spectrum of colours, however each contains a different proportion of the spectrum.



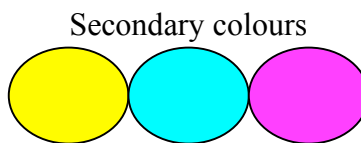
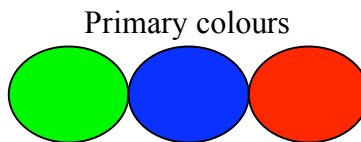
Question

Which white light source looks more blue – an incandescent light or fluorescent light globe? Why?

Colour Addition

Instead of adding every colour in the spectrum to produce white light, just red, green and blue can be added together.

Therefore, the primary colours of light are red green and blue. (Note, not red blue and yellow.)



Colour addition rules of light are different to those you learned about paint in primary school.

When pairs of the primary colours are combined they produce the secondary colours

- magenta (red and blue)
- cyan (blue and green) and
- yellow (red and green).

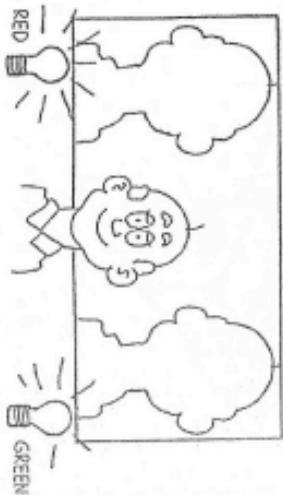
Combining the secondary colours will also produce white.

Chapter 27 Color
Color Addition

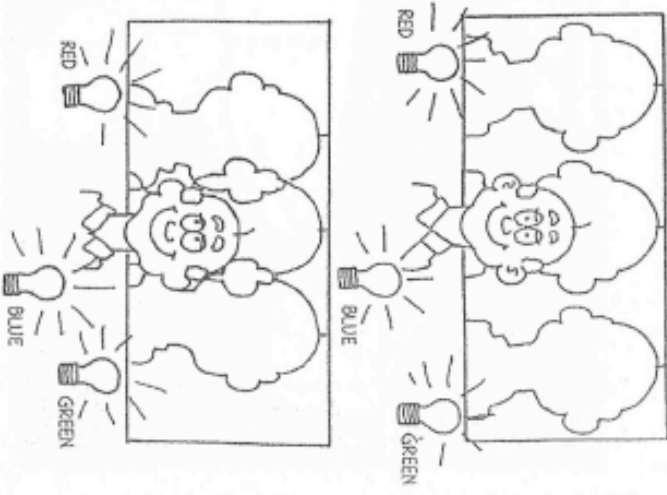
The sketch to the right shows the shadow of an instructor in front of a white screen in a dark room. The light source is red, so the screen looks red and the shadow looks black. Color the sketch, or label the colors with pen or pencil.



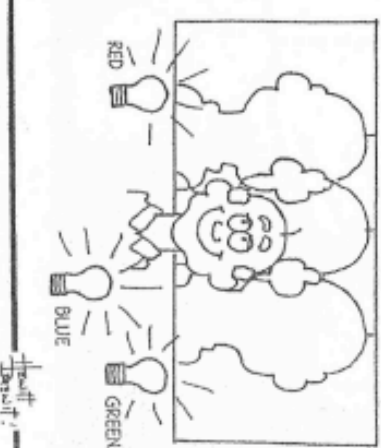
A green lamp is added and makes a second shadow. The shadow cast by the red lamp is no longer black, but is illuminated by green light. So it is green. Color or mark it green. The shadow cast by the green lamp is not black because it is illuminated by the red lamp. Indicate its color. Do the same for the background, which receives a mixture of red and green light.



A blue lamp is added and three shadows appear. Indicate the appropriate colors of the shadows and the background.

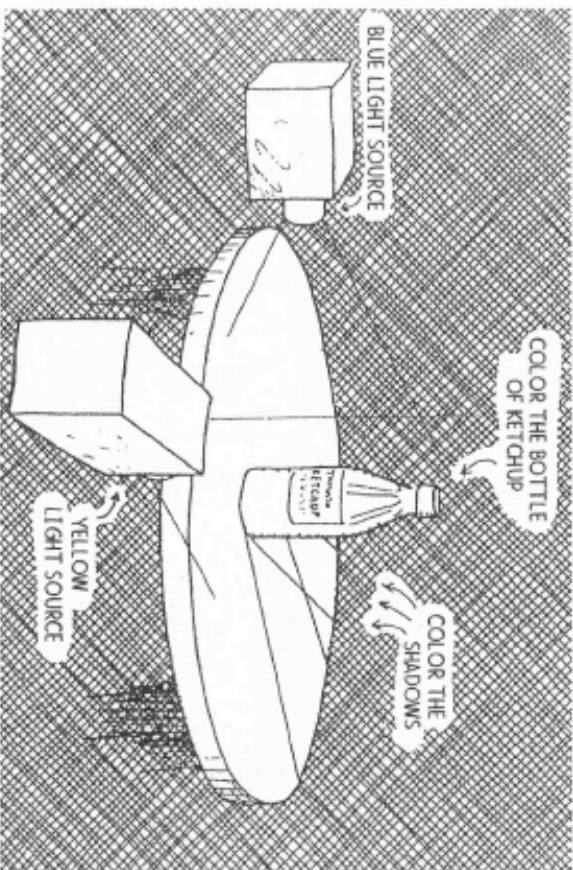
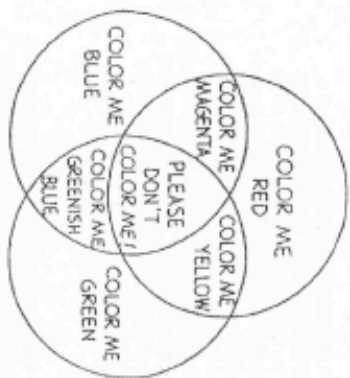
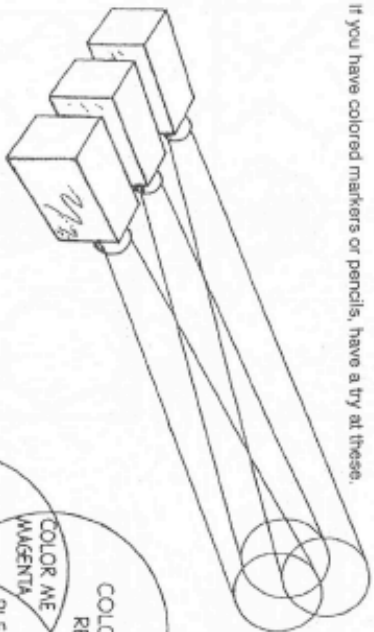


The lamps are placed closer together so the shadows overlap. Indicate the colors of all screen areas.



Chapter 27 Color
Color Addition—continued

If you have colored markers or pencils, have a try at these.



Questions

Complete the following

Red + Green =

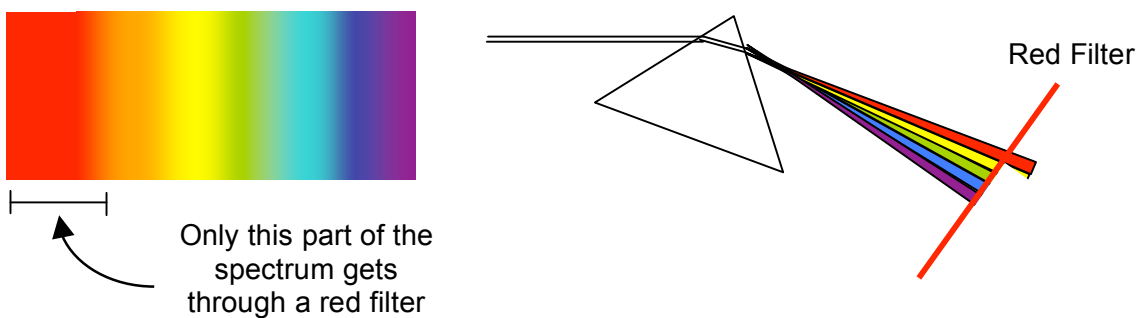
Blue + Yellow =

Green + Blue =

Red + Magenta =

Colour by Filtering (Colour Subtraction)

When you look through a piece of coloured cellophane, everything you see is tinged with the colour of the cellophane. The cellophane is acting as a *filter*. A filter is an object that only lets through a small part of the light source through. For instance a red filter would only let through the red part of the visible spectrum. The filter would absorb all of the other colours.



If a pure blue light was shone onto a pure red filter, no light pass go through (as only red light is allowed)

If two filters a placed in a row, light will only pass through both of them if there is a region of overlap between the two filters. For example a red filter followed by a yellow filter may let through a little orange light, as orange light may pass through both filters.

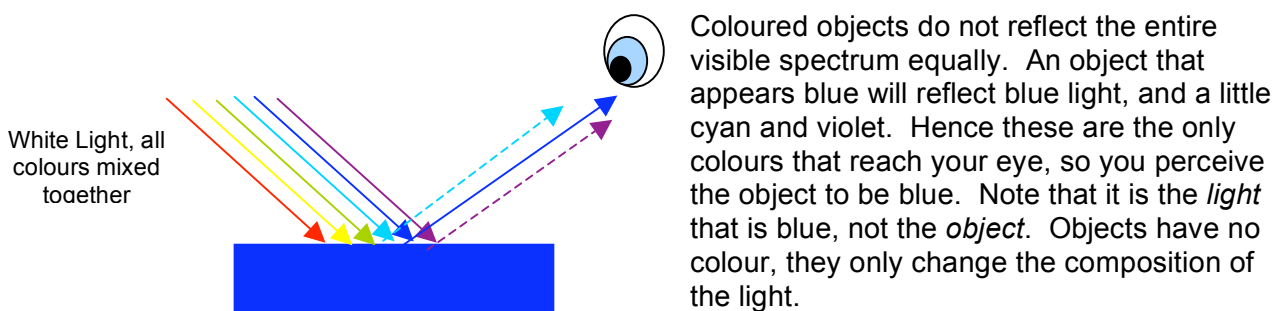
Non-pure light sources and non-pure filters

Often both light sources and filters are not “pure”. For example

- A red light may be mostly red but also contain a little blue, green, orange and yellow
- A red filter may mostly allow red light through but also a little blue, green and yellow

Hence, if a non-pure blue light source is shone onto a red filter, perhaps some red and blue may pass through (producing magenta.)

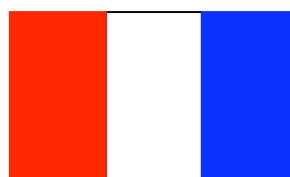
Colour by Reflection (Colour Subtraction)



Coloured objects do not reflect the entire visible spectrum equally. An object that appears blue will reflect blue light, and a little cyan and violet. Hence these are the only colours that reach your eye, so you perceive the object to be blue. Note that it is the *light* that is blue, not the *object*. Objects have no colour, they only change the composition of the light.

Illumination with Different Colours

Consider the French flag, illustrated in the diagram. If the flag was illuminated with light of different colours, then it would change. The diagrams below show the appearance of the flag in a dark room illuminated by red and blue light



opposite. If the flag was illuminated with light of the opposite colour, its appearance would be the opposite. If the flag was illuminated with light of the opposite colour, its appearance would be the opposite.

French Flag under a red light



The red section reflects the red light. The white section reflects the red light. The blue region does not reflect red light, so this appears black.

French Flag under a blue light



The blue section reflects the blue light. The white section reflects the blue light. The red region does not reflect blue light, so this appears black.

Questions

Why does a red shirt appear to be red?

A green filter allows green light along with a little yellow and blue light to pass through it.

A red filter allows red light along with a little yellow and orange light to pass through it.

A blue filter allows blue light along with a little green and indigo light to pass through it.

What colour emerges when white light is directed onto a red and green filter combination?

What colour emerges when white light is directed onto a red and blue filter combination? Justify your answer.

What colour would a red pen appear to be if it were illuminated by a primary blue light source?

A. Red B. magenta C. yellow D. black

Justify your answer.