# L1 WHAT IS LIGHT ?

## OBJECTIVES

**Aims**

This chapter is essentially an introduction to the wave theory of light. At this stage you should get a basic understanding of the wave model of light, which involves the idea of light as a complex superposition of many component waves, or elementary waves, each with its own wavelength, frequency, amplitude and phase. You should be able to explain these ideas to yourself and to others.

**Minimum learning goals**

1. Explain, interpret and use the terms:

   *wave, elementary wave, wavelength, frequency, period, wave speed, speed of light, refractive index, amplitude of a wave, irradiance, intensity, monochromatic light, spectrum, continuous spectrum, line spectrum.*
2. Describe the basic features of the wave model of light.
3. State and apply the relation among wavelength, frequency and speed of a wave.
4. State and use typical values for the wavelengths in vacuum of the components of visible light and for the speed of light in vacuum.
5. Explain the distinction between coherent and incoherent sources and waves.
6. Name the parts of the electromagnetic spectrum and arrange them in order of wavelength or frequency.
7. State and apply the inverse square law for light intensities.

## PRE-LECTURE

### 1-1 INTRODUCTION

There was an ancient belief, which is regularly reinvented by children, that you see something by sending out some kind of probe from your eyes. A more scientific view is that we see things because light comes from them to our eyes. But only a few things generate their own light. Before the middle of the nineteenth century, practically all light came from a few kinds of luminous object - the sun, the stars and fires. So those were the only objects that could be seen by their own light. To see other things we need a luminous object as a source of light. Light travels from the luminous source to the object and then to our eyes. In the process the character of the light may be changed. Some of the so called "white light" from the sun bounces off grass to become "green" light.

Somehow light must also carry information about the location and shape of the objects that we see. We normally assume that a thing is located in the direction where the light comes from. So it would seem that when it is not actually bouncing off something light must travel in more or less straight lines. This idea that light travels through space along straight lines, although not strictly correct, is the basis of the very useful **ray model** of light, which explains a great deal about how we see things. The elements of the ray theory, called **geometrical optics**, will be explored in chapters L2 and L3.

Until the work of Huygens in the late seventeenth century the accepted idea of the nature of light was that it consisted of a flow of invisible corpuscles, like a stream of minute bullets. All the familiar optical phenomena, such as straight line propagation, reflection and refraction could be explained by that corpuscular hypothesis. Although Huygens showed (around 1678) that these phenomena could also be explained by a wave theory, it was the crucial experiments in the nineteenth century by Young and Fresnel on the interference of light which provided convincing evidence that a wave model of light was necessary. Young measured the wavelength of light and its very small value explained why many of the wave properties were so difficult to investigate.

Even after the work of Young not everyone was convinced; it was still possible to explain most of the behaviour of light using the corpuscular idea. Then Foucault found that the speed of light in water was less than its speed in air. On the other hand, the corpuscular theory could explain the bending of a light beam only by supposing that its speed had to be greater in water. So that was the end of the classical corpuscular theory.

A quite different particle theory of light came with quantum theory in the early part of the twentieth century. The current view is that some questions can be answered using a wave model and others can be understood in terms of particles called photons, but the two pictures are never used simultaneously. In this book we need to use only the wave model, while the modern particle model will be used in the *Atoms and Nuclei* unit.

## 1-2 WAVES

Many kinds of wave carry energy. For mechanical waves which travel in a material medium, such as sound waves, water waves and earthquakes, the energy is mechanical energy - kinetic energy plus potential energy. The potential energy is associated with the forces between particles and their displacements from their equilibrium positions, while the kinetic energy is associated with their movement. The wave energy is propagated through the continual interchange between potential and kinetic energy as the medium oscillates. Electromagnetic waves, on the other hand, can travel through empty space so there is no material medium involved - the energy oscillates between the electric and magnetic fields. Whatever the kind of wave, there are always at least two physical variables associated with its propagation. In the case of sound waves these variables might be the velocity and displacement of particles and in the case of light they are the electric and magnetic fields.

In a material medium sound waves and other kinds of mechanical waves consist of disturbances in some property of the medium. These disturbances move through the medium but the medium itself does not move along with the wave. For example, in mechanical waves (waves on a string, water waves, sound waves) small sections of the medium (the string, the water, the air) vibrate to and fro, but there is no net flow of material from one end of the medium to the other. For example a wave on a string might look like figure 1.1; the string oscillates up and down and energy flows along with the wave but there is no movement of matter along the string.

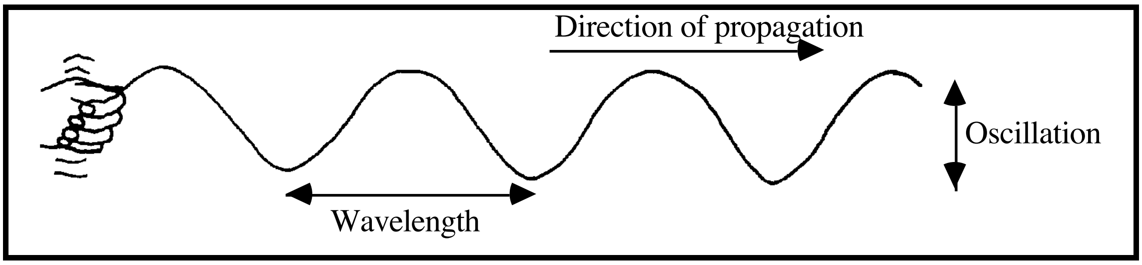

**Figure 1.1. A transverse wave on a string**

A complete description of an ordinary beam of light using the wave model would be immensely complex. Even water waves on the surface of the sea can be very intricate. But it is not necessary to go into detail about that complexity if all you want to do is understand the underlying principles of wave motion and behaviour. The mathematical theory of waves includes the very useful principle that any complex wave at all can be represented as the sum, or superposition, of simple harmonic waves; so all the fundamental properties of waves are expressed in terms of the behaviour of simple harmonic waves. Figure 1.2 shows an example of a relatively uncomplex wave which can be analysed as a combination of only four elementary waves.

## Elementary waves

The simplest kind of wave to describe mathematically is a simple harmonic wave that travels in one direction. The wave property (electric field, pressure or whatever it is that does the waving) is represented here by $W$ and varies with position $x$ in space and with time $t$. The wave can be described by the equation:

$$W = A \sin(kx - \omega t + \phi) \qquad \text{... (1.1)}$$

in which $A$, $k$, $\omega$ and $\phi$ are constants. Their significance is discussed below.

This equation tells us several things about the wave. The expression in parentheses, $(kx - \omega t + \phi)$, which is called the **phase** of the wave, tells what stage the oscillation has reached at any point $x$ and time $t$. The quantity $\phi$ is called the initial phase. We can get a kind of snapshot of the wave by making graphs of $W$ plotted against $x$ for particular values of the time $t$ (figure 1.3). The graphs show the familiar sine-curve shape of the wave. The constant $A$ is called the **amplitude** of the wave and the value of the wave property varies between $-A$ and $+A$. As time progresses the wave moves forward, but its shape is the same.

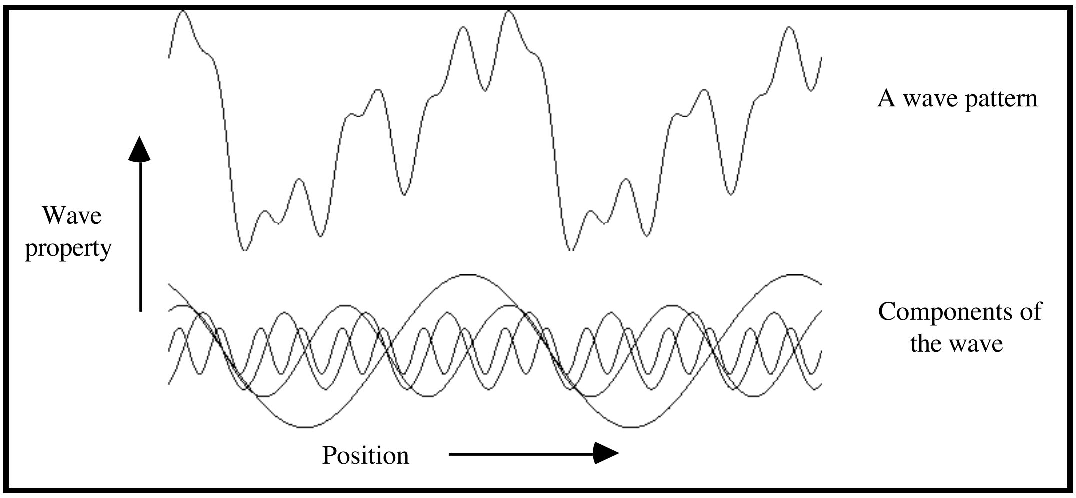

**Figure 1.2. Analysis of a wave in terms of elementary sine waves**
The complex wave is plotted in the top diagram and the mixture of its four components is shown below.

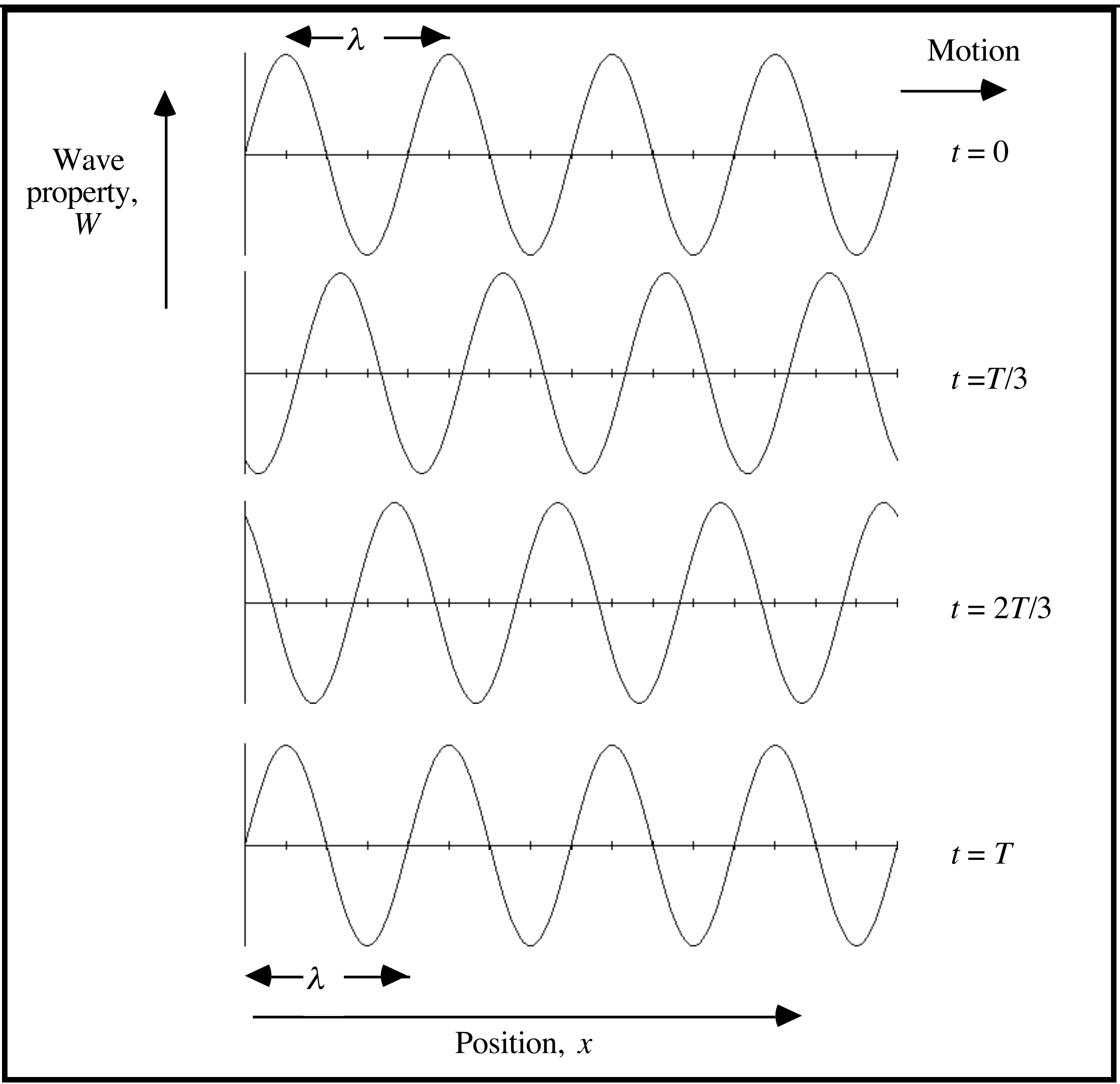

**Figure 1.3. Progress of a simple wave**
The whole wave pattern moves to the right. In one period ($T$) it moves one wavelength ($\lambda$).

The equation (1.1) and the graphs (figure 1.3) both show that the pattern of the wave is repeated exactly once every time that the position coordinate $x$ increases by a certain amount $\lambda$, which is called the **wavelength**. The constant $k$ in equation (1.1) is called the **propagation constant** or the wave number. It is inversely related to the wavelength:

$$\lambda = \frac{2\pi}{k}.$$

By looking at what happens at a fixed point ($x$) as the wave goes past, we can see that the variation of the wave property with time is also described by a sine function: the variation of $W$ is a simple harmonic oscillation (figure 1.4).

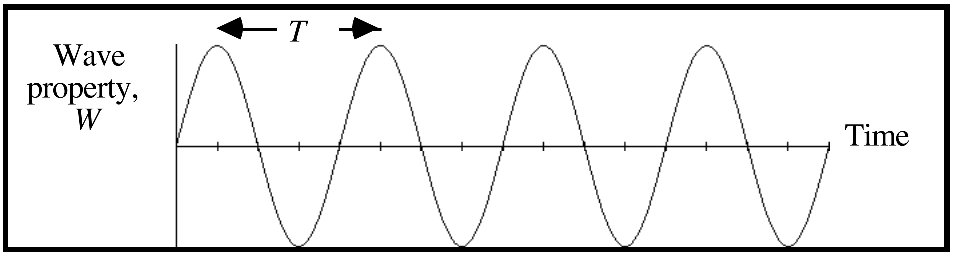

**Figure 1.4. The wave oscillation at a fixed location**
Although $W$ is now plotted against time, the shape of the graph is just like the shape of the wave shown in figure 1.3 .

The constant $\omega$ in the equation is the **angular frequency** of the oscillation and the wave. The wave's **period** $T$ and its **frequency** $f$ are given by the relations:

$$T = \frac{2\pi}{\omega} = \frac{1}{f} . \qquad \text{... (1.2)}$$

By studying the graphs in figure 1.3 you should be able to satisfy yourself that the wave moves forward by one wavelength in one period, so the **wave speed** must be equal to $\lambda/T$ or $f\lambda$:

$$v = f\lambda . \qquad \text{... (1.3)}$$

Note that the wave equation quoted above describes the progression of an idealised wave in a one-dimensional space. The main differences for real waves in three-dimensional space are that the amplitude $A$ generally decreases as the wave moves further away from its source and that we need some way of describing how the waves spread out as they go.

## LECTURE

### 1-3 LIGHT WAVES

In the wave model light is viewed as electromagnetic waves. Since these waves consist of oscillating electric and magnetic fields which can exist in empty space, light can travel through a vacuum.

Since light can be analysed as a complex mixture of a huge number of individual electromagnetic waves, the important properties of light and other electromagnetic waves can therefore be understood in terms of the properties of these simple **elementary waves**.

At any point on the path of a simple harmonic light wave the strengths of the electric and magnetic fields are continually changing. At each point the two fields always change in step, so that the maximum value of the electric field occurs at the same time as the maximum magnetic field. The electric and magnetic fields point in directions at right angles to each other and also at right angles to the direction in which the wave travels. Since a complete knowledge of the electric field determines the magnetic field, the wave can be described adequately by specifying the electric field only.

Figure 1.5 is an instantaneous representation of the fields in part of an elementary electromagnetic wave. Notice that the electric and magnetic fields are in phase, their maxima occur at the same place at the same time. Since both fields are perpendicular to the direction of travel of the wave, the wave is said to be **transverse**. (A wave in which the direction of the wave property is parallel to the direction of travel is called a longitudinal wave.)

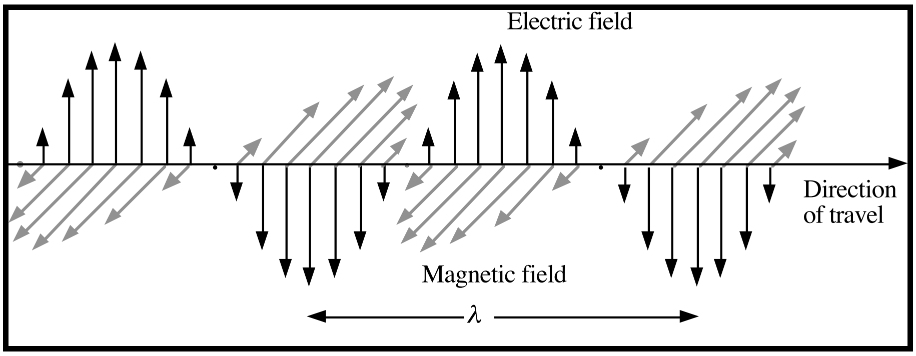

**Figure 1.5. Instantaneous plot of part of a simple electromagnetic wave**
The direction of each field is shown by the direction of the arrow and its magnitude is represented by the length of the arrow.

## Wavelength and frequency

An important property of electromagnetic waves is that in empty space they all travel at exactly the same speed of about 300 000 kilometres per second ($2.997\,924\,58 \times 10^8$ m.s$^{-1}$ to be more precise) quite independently of their wavelength and frequency.

The quantities which characterise each elementary wave are its amplitude, its frequency and its wavelength. Amplitude and frequency are difficult or impossible to measure directly but there are several kinds of experiment which can be used to measure wavelength. Experiments have yielded values for the wavelengths of visible light which lie roughly in the range, 400 nm to 700 nm. The usual unit for light wavelengths, which is consistent with SI, is the nanometre; 1 nm = $1 \times 10^{-9}$ m. (In older literature you may find reference to two obsolete units. The angstrom, symbol Å, is 10 nm and the micron is equivalent to the micrometre, $\mu$m.)

Since the speed of light in vacuum is fixed, each wavelength corresponds to a different frequency. The range of frequencies for visible light is from about $7 \times 10^{14}$ Hz (at 400 nm wavelength) to about $4 \times 10^{14}$ Hz (at 700 nm). When the wave theory of light is extended to take account of light's interaction with matter, it turns out that when an elementary light wave goes from one material into another its frequency is unchanged but the speed and the wavelength are altered. So the property which really distinguishes each elementary wave is its frequency, rather than its wavelength. The common practice of describing light in terms of wavelengths is related to the fact that wavelengths can be measured reasonably directly but frequencies are to hard to measure. Since wavelength changes what does it mean to quote values for wavelength? The answer is that unqualified references to wavelength are understood to mean wavelength in vacuum, or possibly air. (Fortunately wavelengths of the same wave in air and vacuum are almost equal.)

Light which contains a relatively narrow range of wavelengths looks coloured. The colours correspond to those in the rainbow, ranging from violet (upwards of 400 nm) through blue, green (around 550 nm) and yellow, to red (up to about 700 nm). Normal sunlight, which contains the whole range, is usually described as white light.

## Speed of light and refractive index

The speed of light in a transparent material is always less than the speed, $c$, in vacuum. The ratio of the speed in a vacuum to the speed in the medium is called the **refractive index** ($n$) of the medium.

$$n = \frac{c}{v} \quad . \qquad \text{... (1.4)}$$

| **Medium** | **Speed** $\dfrac{v}{10^8 \text{ m.s}^{-1}}$ for $\lambda$ = 589.3 nm | **Refractive index** $n = \dfrac{c}{v}$ for $\lambda$ = 589.3 nm |
|---|---|---|
| Vacuum | 2.998 | 1.0000 |
| Air | 2.997 | 1.0003 |
| Water | 2.249 | 1.333 |
| Glass | 1.972 | 1.520 |
| Diamond | 1.239 | 2.419 |

When any elementary electromagnetic wave, including light, passes from one medium into another, its frequency remains the same. This can be explained in terms of the interaction between the radiation and the electrons in the material. The electromagnetic waves actually interact with the atoms or unbound electrons which then re-radiate the energy, forming a new wave at the same frequency.

## Polarisation

Have another look at figure 1.5 and notice that the directions of the electric fields are all parallel or anti-parallel; they all lie in the same plane. Hence the wave is said to be **plane polarised** or

**linearly polarised**. (Similarly, note that the magnetic field vectors all lie in a common plane, which is perpendicular to the plane of the electric field.)

In ordinary light, which is a complex mixture of elementary waves, the only restriction on the plane of vibration of the electric field is that it should be at right angles to the direction of travel of the light wave. Otherwise it can have any orientation. Consider radiation from an ordinary light globe. The total electric field at a particular place (due to the radiation from all parts of the filament) changes direction quite randomly but always stays perpendicular to the direction of travel of the light wave. Light waves which behave like this are said to be **randomly polarised** or **unpolarised** (figure 1.6).

However, if by some means the electric field is restricted to one plane only, i.e. if the individual elementary waves all have the same polarisation, then the light beam as a whole is said to be plane polarised or linearly polarised**.**

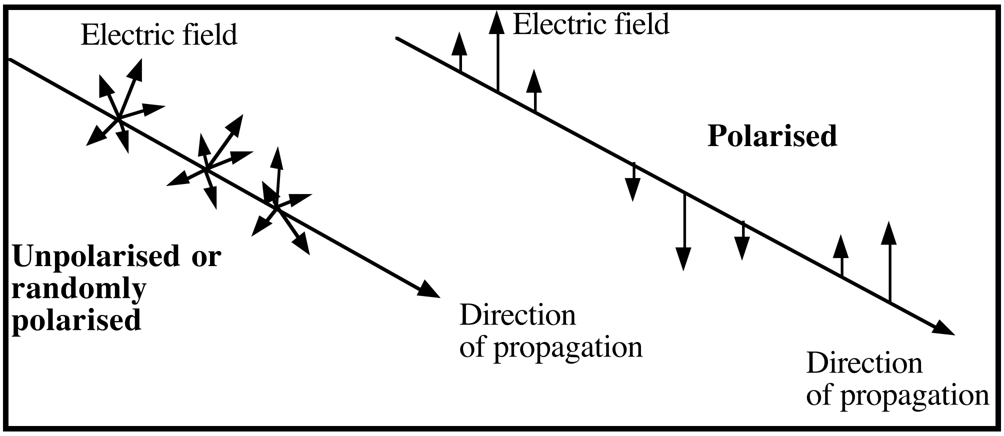

**Figure 1.6. Polarised and unpolarised light**

## 1-4 DETECTING LIGHT

Light detectors respond in many different ways. For example light entering a light meter produces an electric current which deflects the pointer of the meter. And light interacting with a photographic plate causes a chemical change in the emulsion which gives a permanent record of the incident light pattern.

Most kinds of continuously operating light detectors respond to the rate at which the light's energy is absorbed by the detector; they indicate the power. How is this response related to the electric field of the light waves? No detector can respond to the instantaneous value of the field because the field changes far too rapidly, so the response must be to some kind of average of the field over time. A detector which responded simply to the time-averaged value of the electric field itself would be useless, because that average value is zero. On the other hand most detectors respond to the time average of the *square* of the field's value, i.e. to $E^2$. This can be related to the rate at which waves deliver energy by recalling that the energy in a simple harmonic motion is proportional to the square of its amplitude (chapter FE7). In the case of an elementary light wave with amplitude $E_0$ the rate of energy transfer is proportional $E_0^2$, the square of the amplitude, which is also equal to the average value of $E^2$.

Other factors which affect the response of a detector are its receiving area (the bigger it is the more light it collects) and the spectral composition of the light - i.e. the distribution of the light's power over the various wavelengths or frequencies of the light.

### The eye

The human eye is sensitive to light with wavelengths between about 400 nm and 700 nm. It is this sensitivity that makes this part of the electromagnetic spectrum so special to us. The eye is more sensitive to some frequencies than to others (figure 1.7). For example the eye is about seven times more sensitive to green light at 550 nm than it is to blue light at 480 nm. So a beam of blue light would need to be seven times as powerful as a similar green beam for the two beams to appear equally bright.

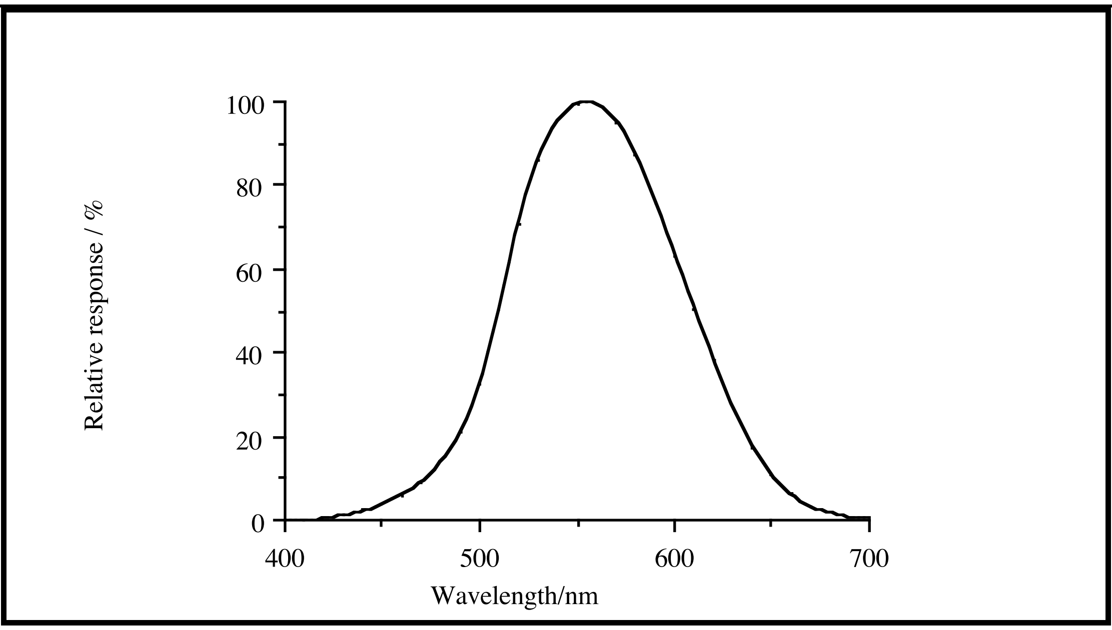

**Figure 1.7. Sensitivity of the eye**

### Irradiance

Since light carries energy we need a way of describing that. Imagine a small flat area of space which is perpendicular to the direction of travel of the light. For a given light beam the power (rate of energy transfer) passing through this small region is proportional to its area; the larger the area the more energy it receives. The relevant property of the light is then the power divided by the perpendicular area; or more precisely the limiting value of that quotient as the area is made smaller. Strictly this quantity should be called **irradiance** but it is commonly known as the **intensity** of the light.

For a harmonic electromagnetic wave the irradiance is proportional to the time-averaged value of $E^2$.

## 1-5 IRRADIANCE OF LIGHT FROM A NUMBER OF SOURCES

We now consider how to model the resultant irradiance when light from different sources arrives at the same place. The result depends on the relationship, or lack of relationship, between the phases of the elementary waves in each complex wave. In principle there is only one correct way of doing the calculation: at each instant of time find the total electric field by adding all the individual fields in both beams, taking proper account of their many different directions. Then the square of the total field will be proportional to the instantaneous intensity. In reality however, we are more interested in values averaged over reasonable time intervals (a few milliseconds for example) rather than instantaneous values and in such cases a simpler procedure will give accurate answers.

In most cases the irradiance of light produced at some place by several different independent sources can be found by adding the irradiances from the individual sources. As an example consider two light globes. For each globe the total light output is made up of many small contributions from the large number of atoms in the hot lamp filament. Each atom emits radiation in short bursts which occur at random times; excited atoms emit light quite independently of one another. The light from each globe therefore consists of a complex mixture of many elementary waves with different frequencies, phases and polarisations. Although both light beams contain much the same mixture of frequencies, the phases and polarisations of the elementary waves in the two beams do not match up. Even if we consider a specific frequency, the phases of the elementary waves from one globe are quite random, so they are not related in any way to the phases of the elementary waves from the other globe. The two light sources and the waves which come from them are said to be **incoherent**.

For two incoherent sources A and B, the total irradiance at some place, due to both sources together, can be found from the sum of the irradiances due to each source alone:

$$I_T = I_A + I_B .$$

On the other hand, if there is a definite fixed relationship between the phases and polarisations of the waves from the two sources this procedure gives the wrong answers. For a somewhat artificial example think of two pure, very long, harmonic waves with exactly the same frequency. Suppose that we look at a place in space where these two waves meet with their polarisations parallel. If the two waves are exactly in phase (in step) the amplitude of the total field will be the sum of the two individual amplitudes and if they are half a cycle out of step the resultant amplitude will be the equal to the difference in the individual amplitudes. If they are in step the irradiance will be given by

$$I_T \propto E_{0T}{}^2 = (E_{0A} + E_{0B})^2 ,$$

but if they are exactly out of step the irradiance will be

$$I_T \propto E_{0T}{}^2 = (E_{0A} - E_{0B})^2$$

This is certainly not the same result as we would get by adding the separate irradiances that would have been produced by each each wave in the absence of the other; i.e. $I_T \neq I_A + I_B$.

Now think of two sources of light which emit a complex mixture of elementary waves, but this time suppose that the mixture of light emitted by one of them is an exact copy of the collection of elementary waves emitted by the other. We can pair off the elementary waves and apply the argument about adding the fields. Once again the irradiances that the beams would have produced individually do not add; we must add the fields and then take the appropriate time-averages if we want to know the irradiance. In this case the two sources and the waves from them are said to be **coherent**. There is a definite relationship between the phases of the elementary waves in the two complex waves.

**Example**

Light from four identical incoherent sources arrives at the same place, having travelled the same distance from each. The total irradiance is the sum of the four individual irradiances:

$$I_T = I + I + I + I = 4\,I$$

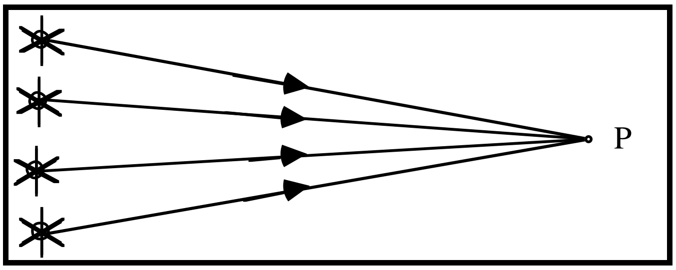

**Figure 1.8. Irradiance due to four identical sources**
The point P at which the irradiance is measured is equidistant from the sources.

If on the other hand the four identical sources are coherent and if the polarisations match up we could get all matching components from the two sources to arrive exactly in phase, so the amplitudes would add up and the resulting irradiance would be

$$I_T = (E_0 + E_0 + E_0 + E_0)^2 = 16\,I .$$

You may think that this result violates the law of conservation of energy. That is not so, because there are other places where the contribution to the total irradiance from the same elementary waves is quite small. The total energy is the same in both examples, it is just distributed differently.

The combination of coherent waves is called **interference**, a topic which will be discussed further in chapter L4.

## 1-6 SPECTRA FROM SOURCES OF VISIBLE LIGHT

Because of the short wavelengths (about $10^{-7}$ m) and high frequencies (about $10^{14}$ Hz) of light waves we can infer that light radiation must be emitted by something small such as the atoms and electrons of the material that forms the source of the light wave. Quantum theory describes how isolated atoms can radiate only at those frequencies which correspond to a particular change from one well-defined atomic energy level to another. The frequency of the emitted wave is given by the formula

$$f = \frac{\Delta E}{h} \qquad \text{... (1.5)}$$

where $\Delta E$ is the energy change and $h$ is Planck's constant. For more about this topic see the *Atoms and Nuclei* unit.

However, in a solid the atoms are packed so closely together than there is considerable interaction among them. This leads to a blurring out of the energy levels into a continuous band of energies. A **continuous spectrum** of light frequencies results. More atoms are excited as the temperature of the material increases. Thus a hotter object emits a greater total intensity of electromagnetic waves. Also, as the temperature of a body is increased, it emits a greater proportion of its radiation at higher frequencies (shorter wavelengths). So, as the temperature is increased, the peak irradiance in the spectrum moves to shorter wavelengths.

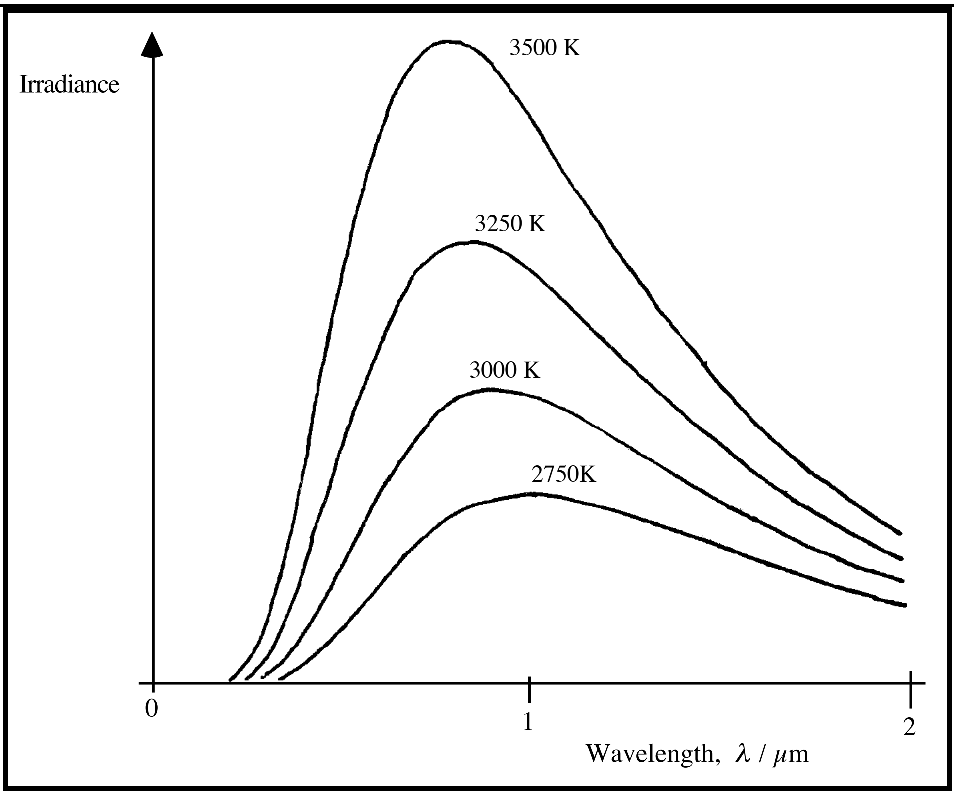

**Figure 1.9. Spectra of light from a hot solid**

The peak of the continuous spectrum shifts to shorter wavelengths as the temperature is increased. The intensity of radiation also increases with increasing temperature.

In general, gases and vapours, in which the atoms or molecules are well separated, emit line spectra. Every atom or molecule has a characteristic **line spectrum** corresponding to its energy level structure so the spectrum observed depends on the types and numbers of different atoms and molecules present.

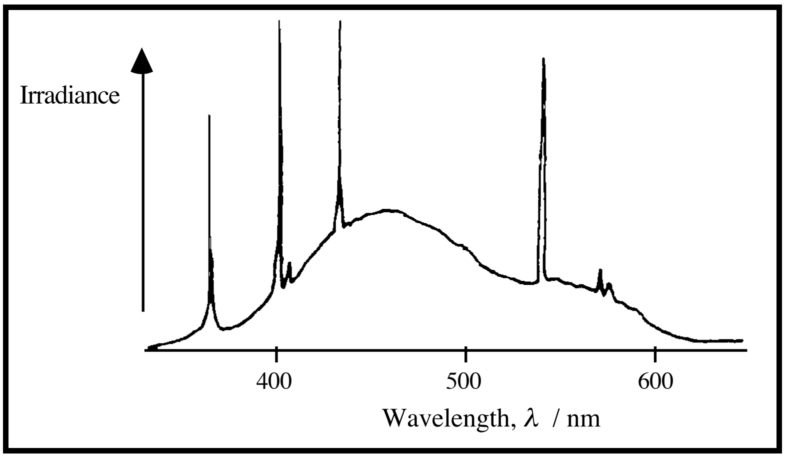

**Figure 1.10. Spectrum of light from a fluorescent tube**

Note the bright spectral lines from the gas superimposed on the continuous spectrum from the fluorescent solid coating on the inside of the tube.

A laser emits radiation in a very narrow range of wavelengths. Such light is called **monochromatic**.

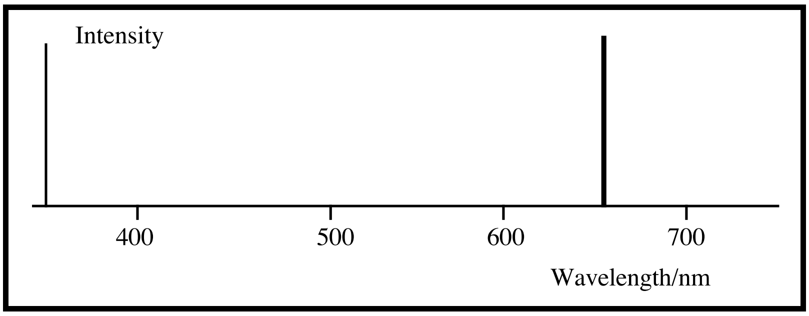

**Figure 1.11. The spectrum of radiation from a laser**

## POST-LECTURE

### 1-7 THE ELECTROMAGNETIC SPECTRUM

The spectrum of electromagnetic waves is divided up into a number of arbitrarily named sections. The dividing lines between these sections are determined by the detailed properties of a particular range of wavelengths. But there is considerable overlap and the divisions are to some extent arbitrary.

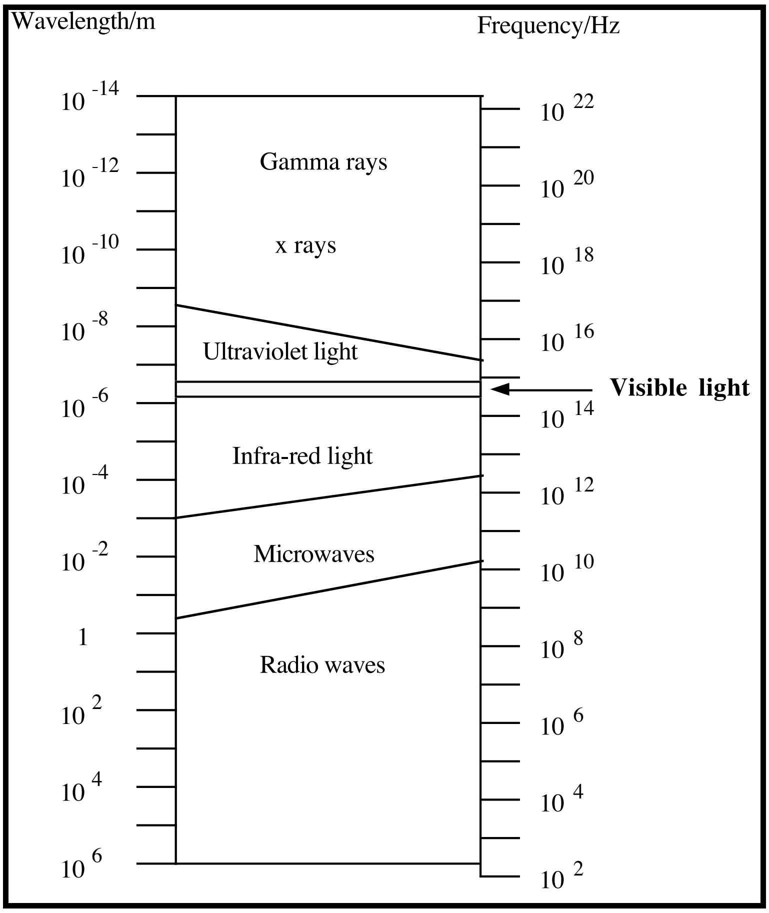

**Figure 1.12. The spectrum of electromagnetic waves**
Note the logarithmic scales.

### Radio waves

Radio waves have wavelengths from about 1 m upwards. They are produced by connecting an electronic oscillator to an antenna. The oscillating electrons in the antenna then lose energy in the form of electromagnetic waves. Radio waves are used for radio and television broadcasting and long-distance communications.

### Microwaves

Microwaves are short radio waves with wavelengths down to about 1 mm. They can be produced electronically by methods analogous to the production of sound waves when you blow across the top of a resonating cavity such as a bottle. Because microwaves are not absorbed very strongly by the atmosphere, but are reflected well off solid objects such as buildings and aircraft, they can be used for radar location of distant objects. Microwaves are also used extensively for communications but they require direct line-of-sight paths from transmitter to receiver so that microwave stations are located on top of hills and tall structures.

### Infrared radiation

The infrared part of the spectrum comprises wavelengths from 0.1 mm (far-infrared) down to about 700 nm. Infrared radiation is emitted by excited molecules and hot solids. Much of the energy released by the element of an electric oven is in the form of infrared radiation. The radiation is very easily absorbed by most materials so the energy becomes internal energy of the absorbing body. When you warm your hands by a fire you are absorbing infrared radiation.

### Visible light

Light is that part of the electromagnetic spectrum which we can see. Visible light is emitted by excited atoms and molecules and by very hot solids.

### Ultraviolet radiation

Ultraviolet 'light' has wavelengths less than 400 nm. It is emitted by excited atoms. The 'black light' used to produce fluorescence in light shows is ultraviolet. Much of the ultraviolet radiation from the sun is absorbed by the atmosphere but that which gets through can cause sunburn and skin cancers. Ultraviolet light can also be harmful to the eyes. The irradiance of ultraviolet light increases at high altitudes where the atmosphere is thinner. Part of the concern about the depletion of the atmosphere's ozone layer is based on the fact that the ozone layer absorbs ultraviolet radiation from the sun.

### X rays and gamma rays

The wavelengths of x rays and gamma rays overlap, but the different names indicate different ways of producing the radiation. X rays are produced in processes involving atoms and electrons. For example they can be produced by bombarding a metal target with high energy electrons. They are also emitted in some high-energy atomic energy level transitions. X rays usually have wavelengths less than 10 nm. On the other hand the term gamma rays is reserved for electromagnetic radiation emitted in sub-atomic processes such as the decay of excited nuclei or collisions between sub-nuclear particles. Gamma radiation generally has wavelengths less than 0.1 nm. It is emitted by excited nuclei of atoms.

## 1-8 THE INVERSE SQUARE LAW FOR LIGHT

Take a point source of light which is radiating uniformly in all directions and consider a sphere of radius *r* centred on the source. The total light power, *P*, radiated by the source must pass through this sphere. Irradiance of radiation is defined as the power per area, which strikes (or passes through) a surface which is perpendicular to the direction of propagation.

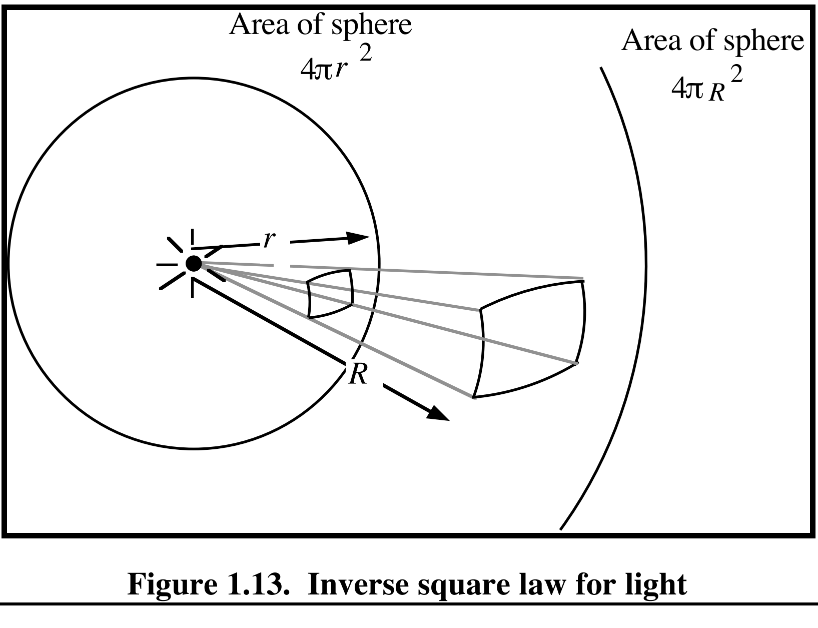

**Figure 1.13. Inverse square law for light**

In this case, since the energy is distributed uniformly over the surface of a sphere, so

$$I = \frac{\text{total power}}{\text{total area}} .$$

At distance $r$

$$I = \frac{P}{4\pi r^2} . \qquad \text{... (1.6)}$$

At a larger distance $R$,

$$I = \frac{P}{4\pi R^2} , \text{ which is smaller.}$$

The irradiance is inversely proportional to the square of the distance from the point source.

# QUESTIONS

## Exercises

**Q1.1** Calculate the distance travelled by light in 1.0 μs.

**Q1.2** A typical wavelength for visible light is 500 nm.

a) Calculate the frequency of this light.

b) Calculate the wavelength, frequency and speed of this light in a glass with refractive index 1.50.

**Q1.3** Calculate the irradiance of the light coming from three identical sources all at the same distance

a) when the three sources are incoherent;
b) when the three sources are coherent and the fields have the same polarisation and phase.

**Q1.4** On the large diagram of the electromagnetic spectrum mark the wavelengths of the following sources. You may have to do some searching for the answers.

a) Radio station 2GB.
b) TV Channel 2
c) A green spectral line.
d) X rays used by a radiographer.
e) The range of wavelengths of an electric radiator as it warms up to red heat.
f) A gamma ray.

**Q1.5** Suppose that a point source is radiating light waves at a rate of 10 W. Calculate the irradiance at a distance of 20 m from the source.

**Q1.6** Refer to the sensitivity curve for the eye, figure 1.7. At what wavelength does a normal human eye have maximum sensitivity? At what wavelengths does it have half its maximum sensitivity? At what wavelengths does it have only 1% of its maximum sensitivity?

## Discussion questions

**Q1.7** Give some scientific arguments against the view that we see things by sending some kind of probe out from our eyes.

**Q1.8** How could you measure the sensitivity curve for the human eye ?

**Q1.9** The eye detects the visible part of the electromagnetic spectrum. The human body is also affected by radiation in other parts of the electromagnetic spectrum. How?

**Q 1.10** People used to do experiments to measure the speed of light. But the metre is now defined in terms of the speed of light. Does this mean that those experiments are no longer useful? Discuss.

**Q1.11** Which of the following affect the speed of light in vacuum: (a) speed of the source, (b) speed of the observer, (c) intensity of the light (d) wavelength, (e) frequency ?

**Q1.12** Why does a microwave oven cook the chicken but not the plate?

**Q1.13** A photographic plate and a radio set both operate as detectors of electromagnetic waves. Yet they are not interchangeable. Comment.