Revision Guide for Chapter 1

Contents

Student's Checklist

Revision Notes

Summary Diagrams (OHTs)

Student's Checklist

Back to list of Contents

Assumed previous knowledge:

know the meaning of frequency, wavelength and amplitude of a wave and be able to use the relationship $v = f\lambda$ Revision Notes: Frequency, wavelength and wave speed	
know about the electromagnetic spectrum and some uses of radio waves, microwaves, infrared and visible light in communications Revision Notes: Electromagnetic spectrum	

I can show my understanding of effects, ideas and relationships by describing and explaining:

how a thin converging (positive) lens produces a real image by changing the curvature of a wave front Revision Notes: Converging lens; Focal length, power and magnification of a lens. Summary Diagrams: Rays and waves spreading; Rays and waves focused; Formation of an image; Action of a lens on a wave front; Where object and image are to be found	
how images are stored in a computer as an array of numbers which may be manipulated to alter the image Revision Notes: Images; Pixels; Resolution; Image processing; Average	
how computerised (digitised) images may be improved by smoothing and reducing 'noise' Revision Notes: Image processing; Average	

I can show my understanding of the physics involved by using the following words and phrases accurately:

in the context of computerised images: pixel, bit, byte, amount of information, resolution Revision Notes: Images; Pixels; Bits and bytes; Amount of information; Resolution; Prefixes Summary Diagrams: Bits and bytes, Comparing logarithms base 2 and base 10	
for lenses: focus, focal length, power (dioptre), magnification Revision Notes: Converging lens; Focal length, power and magnification of a lens.	

I can show my understanding of the physics involved by sketching and interpreting:

how light passes through a lens using either ray diagrams or wave fronts Summary Diagrams: Rays and waves spreading; Rays and waves focused; Formation of an image; Action of a lens on a wave front.	
plots (graphs) using a logarithmic ('times') scale of distances and sizes Revision Notes: Logarithms; Logarithmic scales Summary Diagrams: 'Plus' and 'times' scales of information, Logarithmic ladder of distance, Logarithmic ladder of time	

I can calculate:

the amount of information (in bits) in an image by using the relationship amount of information = number of pixels x bits per pixel See Bits and bytes; Amount of information Summary Diagrams: Bits and bytes, Comparing logarithms base 2 and base 10	
the power or focal length of a lens using the relationship power = 1/(focal length) Revision Notes: Focal length, power and magnification of a lens. Summary Diagrams: Where object and image are to be found	
the third quantity given any two using the relationship $\frac{1}{v}=\frac{1}{u}+\frac{1}{f}$ Summary Diagrams: Rays and waves spreading; Rays and waves focused; Formation of an image; Action of a lens on a wave front; Where object and image are to be found	
the magnification of an image, e.g. as the ratio of image and object size, using the relationship $m = v/u$ Revision Notes: Focal length, power and magnification of a lens.	

I can show understanding of sensor devices and their applications by giving and explaining my own examples of:

the way an image is produced in physics or an application of physics; this should include the basic physical processes involved in making the image, and the advantages and disadvantages of the processes for their purpose (e.g. using film, video, ultrasound scans, charge-coupled devices, tunnelling microscopes, etc) Revision Notes: Images; Electromagnetic spectrum; Ultrasound scanning; Charge-coupled device; Scanning tunnelling microscope	

Revision Notes

Back to list of Contents

Frequency, wavelength and wave speed

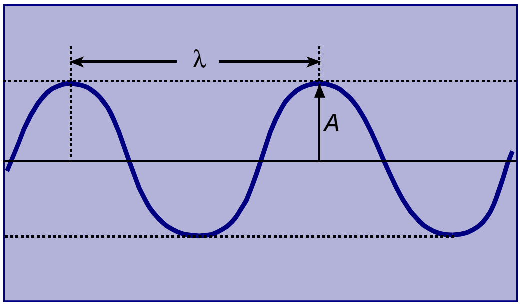
The period *T* of an oscillation is the time taken for one complete oscillation.
The frequency *f* of an oscillation is the number of complete cycles of oscillation each second.
The amplitude *A* of an oscillation is the magnitude of the maximum departure of the oscillating quantity from its mean value.

The SI unit of frequency is the hertz (Hz), equal to one complete cycle per second.

The wavelength λ of a wave is the distance along the direction of propagation between adjacent points where the motion at a given moment is identical, for example from one wave crest to the next.

The SI unit of wavelength is the metre.

Wavelength



Relationships

Frequency *f* and period *T*

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

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

Frequency *f*, wavelength λ and wave speed *v* $v = f\lambda$

Back to Student's Checklist

Electromagnetic spectrum

The electromagnetic spectrum covers the full wavelength range of electromagnetic waves from gamma radiation and x-radiation at the short-wavelength end of the spectrum to radio and TV waves at the long-wavelength end.

Summary of the main bands of the electromagnetic spectrum

Waveband	**Wavelength range**	**Typical source**	**Detector**	**Application**
Gamma radiation	< 1 nm	Radioactive decay of a nucleus	Geiger counter, film, ionisation chamber	Medical imaging, therapy, sterilisation of medical instruments
X-rays	< 1 nm	Inner shell atomic electron transitions	As above	X-ray imaging in medicine and dentistry
Ultraviolet	1-400 nm	Atomic electron transitions	Photocell, film	Sun bed, security marker
Visible	400-700 nm	Outer-shell atomic electron transitions	Eye, film, CCD, photocell	Camera, seeing
Infrared	700 nm -1 mm	Vibrations of atoms and molecules	Thermopile, solid state detectors	Thermography in medicine, fibre-optic communications
Microwave	1 mm - 0.1 m	Electrons in resonant cavities (e.g. magnetron)	Microwave diode	Cooking, line-of-sight communications, satellite communications
Radio and TV	> 0.1 m	Electrons accelerated and decelerated in an aerial	Aerial	Communications

Back to Student's Checklist

Converging lens

Lenses are used in optical instruments such as the camera, eye, microscope and telescope to form images. The effect of a lens is to change the curvature of the wave fronts passing through it.

A **converging lens** adds to the curvature of wave fronts of light falling on it, making light from a point object converge (or diverge less).

Images from a converging lens

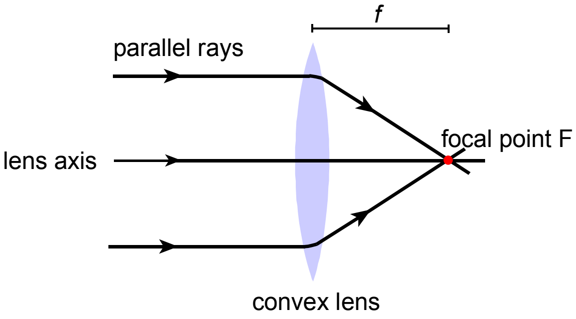
Object position	**Image position**	**Type of Image**	**Magnification**	**Which way up?**	**Application**
Beyond 2F	Between F and 2F	Real	Diminished	Inverted	Camera, eye
At 2F	At 2F	Real	Same size	Inverted	Inverter lens
Between F and 2F	Beyond 2F	Real	Magnified	Inverted	Projector lens
Between the lens and F	Beyond 2F	Virtual	Magnified	Upright	Magnifying glass

Back to Student's Checklist

Focal length, power and magnification of a lens

The focal point *F* of a converging lens is the point where light from a very distant point object on the axis of the lens is brought to a focus by the lens. This point is also called the **focus**. The focal length *f* of a thin lens is the distance from the centre of the lens to *F*.

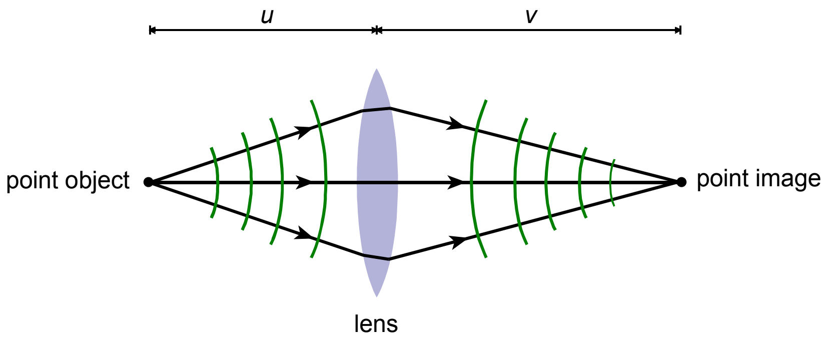
Definition of focal length of a convex lens



Converging lenses are assigned positive values of *f*. Diverging lenses are assigned negative values.

The **power of a lens** in dioptres = 1 / *f* where *f* is the focal length in metres. The shorter the focal length the more powerful the lens.

Lens sign convention



Cartesian convention $\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$ where distances from lens are assigned $\left.\vphantom{\frac{1}{1}}\right\}$ – values to left
+ values to right

In the Cartesian convention, distances measured to the left from the lens are assigned negative values and distances measured rightwards are assigned positive values, as in the rules for the *x*-axis of a graph. The source is usually assigned to be on the left of the lens.

The lens equation
The curvature of a spherical wave front of radius *r* is 1 / *r*. A converging lens adds curvature 1/*f* to the wave fronts passing through it. Thus for a point object at distance *u* from a lens, the radius of curvature of the wave fronts at the lens is changed from 1 / *u* to 1 / *u* + 1 / *f*. Therefore the image of a point object is formed at distance *v* from the lens, where 1 / *v* = 1 / *u* + 1 / *f*.

Linear magnification
The linear magnification is the ratio of the height or length of the image to the height or length of the object viewed directly.

$$\text{linear magnification } m = \frac{\text{height of image}}{\text{height of object}}$$

Because the heights of image and object are proportional to their distances *v* and *u* from the lens:

$$\text{linear magnification } m = \frac{v}{u}$$

Back to Student's Checklist

Images

Images are very efficient ways of representing and communicating information. Human beings are very good at seeing patterns in visual displays.
For scientific examples see Advancing Physics AS 2000 CD:
Chapter 1>Resource manager>Files>Images

Images include, besides photographs and drawings or paintings, patterned displays of data, mathematical forms, and graphs and charts.

Images can represent objects more or less as they are seen, as in a photograph or realistic painting or drawing. But images can also be used to represent unseen objects, for example organs inside the body, or astronomical objects 'seen' at wavelengths outside the visible region. An example is an image of the cosmic microwave background, detected at microwave wavelengths.

Images can be altered and manipulated, particularly if in digital form. See Image Processing.

Back to Student's Checklist

Pixels

A digital image consists of a rectangular array of picture elements, called pixels. Similarly, a television picture consists of an array of dots of different brightness and colour. A million or more pixels make up a typical image. You can see individual pixels by looking at a computer screen with a magnifying glass.

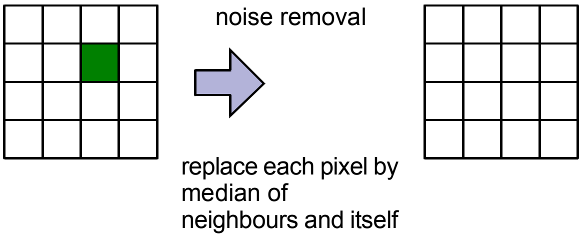
Each pixel is stored as a number. A typical grey-scale image may have 256 alternative levels of brightness for each pixel, using one 8-bit byte per pixel to store its value ($2^8 = 256$). More bits can be used for a scale with higher brightness resolution. Three bytes are often used for colour images, one byte for each of three primary colours.

Back to Student's Checklist

Image processing

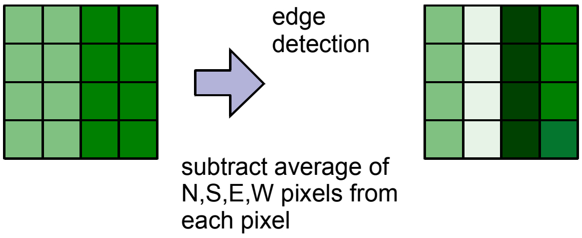
Noise reduction: noise in an image can be reduced by replacing the byte representing a pixel with the median of the values of that pixel and its neighbours.

Noise reduction



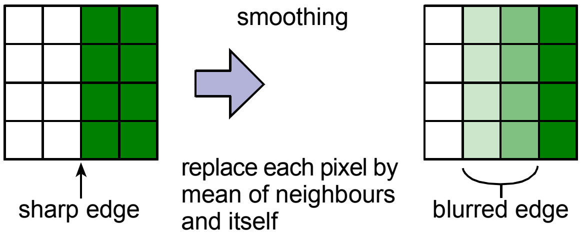
Edge detection: edges in an image can be located and enhanced. An edge is a place where the gradient of light intensity across the image changes sharply. Where the gradient is smooth the average of values either side of a pixel will be equal to the value of that pixel. Thus a difference between the value of a pixel and the average of its neighbours indicates a possible edge.

Edge detection



Smoothing: Smoothing of sharp edges can be achieved by replacing a pixel with the mean of its value and its neighbours.

Smoothing



False colour: the usefulness of some images can be enhanced using false colour. One way this can be done is to assign different colours to different ranges of brightness.

Back to Student's Checklist

Average

Here are two different kinds of average:

1. The arithmetic mean
2. The median.

For a set of N readings or values, x_1, x_2, x_3, x_4, …,x_N: The **mean** value:

$$x_m = \frac{x_1 + x_2 + x_3 + x_4 + \ldots + x_N}{N}.$$

is the sum of the values divided by their number. The mean is often called 'the average'. In smoothing images, it is often useful to replace pixels by the average of themselves and their neighbours.

The **median** value is the middle value of the set when the values are arranged in order of magnitude. Median values are important in the processing of digital images, for example removing noise by replacing the value of a pixel with the median of it and its neighbours.

You can find out much more about the uses and abuses of averaging in the A-Z section of the Advancing Physics AS or A2 CD-ROMs. Look for these entries:
Average; Accuracy, Error analysis, Random error

Back to Student's Checklist

Bits and bytes

Bits and bytes are amounts of information, expressed in digital form.

A **bit** is the smallest unit of digital information, represented as a 0 or a 1.

A finite sequence of bits is referred to as a word. An n-bit word can represent 2^n alternatives.

A **byte** is an eight bit word, able to represent one of 256 (= 2^8) alternatives. The ASCII system uses 8-bit words (bytes) to represent up to 256 keyboard symbols including the numerals 0 to 9 and the letters of the alphabet.

Data transferred between computers can be corrupted in the transmission process. Extra information is transmitted so that errors can be detected and corrected.

Back to Student's Checklist

Amount of information

Information is stored in a computer memory in bits, that is as zeroes or ones.

A sequence of n bits has 2^n different possibilities. An 8-bit byte can thus represent $2^8 = 256$ different binary numbers. In the same way, a message containing information I, can be one of 2^I alternative possibilities.

For a certain number of alternatives $N = 2^I$, then the amount of information $I = \log_2 N$.

A digital colour camera with 1 million pixels, each pixel generating three bytes, one for each primary colour, would need a storage capacity of about 3 megabytes. Digital cameras use image compression methods to reduce this to less than 1 Mbyte per image.

A CD-ROM can store about 650 MB. This is only a few seconds worth of viewing of a TV movie. DVD discs store each bit in a smaller space, and have larger capacity, but data compression is needed for them to store a whole movie.

Relationships

Information $I = \log_2 N$ where N is the number of alternatives.

Number of alternatives $N = 2^I$

Back to Student's Checklist

Resolution

The resolution of an image is the scale of the smallest detail that can be distinguished. The size of the pixels sets a limit to the resolution of a digital image. In an ultrasound system, the pixel dimensions may correspond to about one millimetre in the object imaged. A high-quality CCD may have an array about 10 mm × 10 mm consisting of more than 2000 × 2000 light-sensitive elements, each about 5 μm in width. In a big close-up picture of a face 200 mm across, the width of each pixel would correspond to 1 / 10 mm in the face photographed.

Back to Student's Checklist

Prefixes

The letter 'k' in 'km' (kilometre) is the symbol for the prefix kilo, meaning one thousand. The prefix 'm' in 'ms' (millisecond) is the symbol for the prefix milli, meaning one-thousandth.

Power of ten	**Prefix**	**Symbol**
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	µ
10^{-3}	milli	m
10^{+3}	kilo	k
10^{+6}	mega	M
10^{+9}	giga	G
10^{+12}	tera	T
10^{+15}	peta	P
10^{+18}	exa	E

Examples of the use of prefix symbols include mA for milliampere, kV for kilovolt and MΩ for megohm. Other prefixes not included in the above table include deci (d) = 10^{-1} and centi (c) = $10^{-2.}$

Back to Student's Checklist

Logarithms

Logarithms can be thought of as a way of turning multiplying into adding (and dividing into subtracting).

The number 100 can be written as 10^2. Similarly, the number 1000 000 = 10^6. The powers of ten here, 2 and 6, are called the logarithms (base 10) of 100 and 1000 000 respectively.

Notice that when numbers are multiplied, the logarithms simply add:

$$\text{As numbers: } 100 \times 1000\,000 = 100\ 000\ 000$$

$$\text{As powers: } 10^2 \times 10^6 = 10^{2+6} = 10^8$$

$$\text{As logarithms: } 2 + 6 = 8$$

When a number is written as a power of a base number, the power is called the logarithm of the number to that base. If $n = b^p$, then $p = \log_b n$. The logarithm does not have to be an integer (whole) number.

Three bases are used widely for logarithms in physics and engineering:

Base 10 logarithms, written lg or $\log_{10}$ (or sometimes just 'log'); the base 10 logarithm of a number n is therefore $p = \log_{10} n$ where $n = 10^p$. Thus $\log_{10} 100 = 2$, and $\log_{10} 10^6 = 6$.

Natural logarithms, also referred to as base e logarithms, written ln or $\log_e$. The natural logarithm of a number n is therefore $p = \ln n$ where $n = e^p$.

Base 2 logarithms, written $\log_2$. The base 2 logarithm of a number n is $p = \log_2 n$, where $n = 2^p$.

Product rule
The logarithm of a product (or a quotient) is equal to the sum (or the difference) of the individual logarithms.

If $z = x\,y$, then $\log z = \log x + \log y$.

Quotient rule
If $z = x / y$, then $\log z = \log x - \log y$.

Inverse rule
The inverse of the logarithm of a number is equal to that number.

For $p = \log_{10} n$, then $10^p = n$. Also $\log_{10} 10^p = p$.

For $p = \ln n$, then $e^p = n$. Also, $\ln e^p = p$.

Back to Student's Checklist

Logarithmic scales

Logarithms are related to 'times' scales, where a quantity is multiplied by a constant at each step.

For example, the Richter scale for earthquakes is a logarithmic scale on which every extra point on the scale corresponds to 10 times larger amplitude of vibration. Thus an earthquake at point 8 on the Richter scale is 100 times more powerful than an earthquake at point 6.

It is often convenient to use a logarithmic scale when the range of values of a quantity is very large. Examples where logarithmic scales are used include:

1. Brightness of stars
2. Loudness of sounds
3. Strengths of materials
4. Information stored in a computer (see Summary diagram 'Plus' and 'times' scales of information.

See Summary diagrams Logarithmic ladder of distance and Logarithmic ladder of time for further examples.

Back to Student's Checklist

Ultrasound scanning

Ultrasound scanning uses ultrasound to form images.

Ultrasound is sound of very high frequency, higher than the human ear can detect. At a boundary between two different substances, a certain proportion of the waves is reflected, depending on the difference in density and/or elasticity between the two substances.

An ultrasound scanner emits ultrasound pulses and detects their reflections at boundaries between different substances inside an object (e.g. the human body). The detected reflections are used to reconstruct an image of the interior of the object studied.

The ultrasonic pulses are emitted by a piezoelectric disc. It emits pulses of about a microsecond duration at a rate of about 1000 per second. The transducer also behaves as a receiver, detecting reflected pulses. A medical scanner uses ultrasound at a frequency of about 10 MHz, having a wavelength of about a millimetre in body tissues. Higher ultrasound frequencies would give less diffraction and hence better resolution but absorption by tissue becomes increasingly significant beyond about 10 MHz.

A gel is applied between an ultrasonic transducer of a scanner system and the skin, to reduce ultrasonic wave reflection at the skin.

Back to Student’s Checklist

CCD (charge-coupled device)

In a CCD camera, a lens is used to form a real image on a chip with an array of the order of a million very small light-sensitive detectors. Each detector corresponds to one pixel in the final image. Each detector stores a charge in proportion to the amount of light that has fallen on it, which can be read out as a sequence of voltage pulses used to recreate the image on a visual display. This signal is used to generate a bright spot at a pixel position corresponding to the position of the original element.

Back to Student’s Checklist

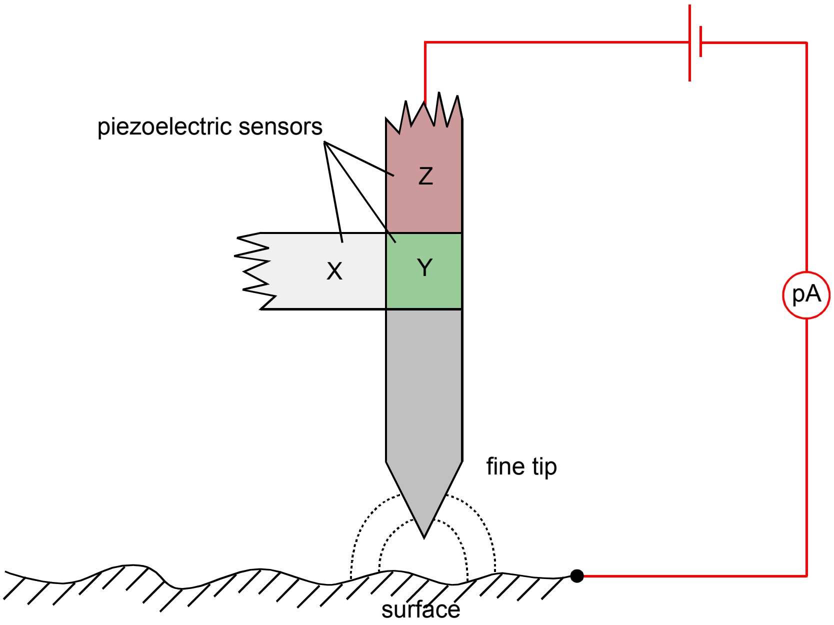
Scanning tunnelling microscope

The **scanning tunnelling microscope** (STM) was invented in 1981 by Gerd Binnig and Heinrich Rohrer.

An STM makes an image of an electrically conducting surface, by allowing electrons to 'tunnel' across a gap between the surface and a fine conducting tip above the surface.

Due to its quantum behaviour, there is a small probability for an electron to cross the gap. With a small constant potential difference of the order of 1 V between the tip and the surface, the probability of transfer from surface to tip is much greater than for transfer from tip to surface, giving a net tunnelling current between them.

The scanning tunnelling microscope



The tip is positioned and the gap width adjusted by means of piezoelectric sensors. The narrower the gap, the greater the tunnelling current. Variations in the gap width are detected as variations in the tunnelling current. These are used to form an image of the surface. Surface structures as small as individual atoms can be seen in STM images.

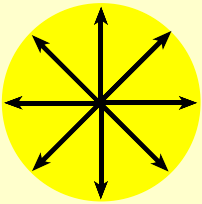
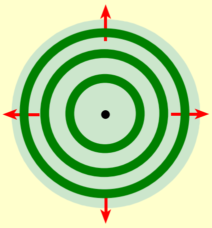
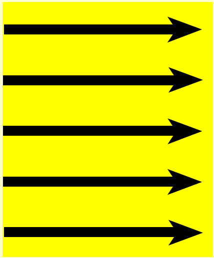
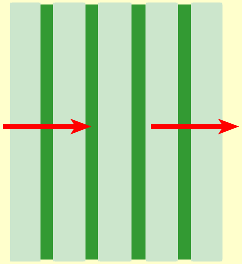
Back to Student’s Checklist

Summary Diagrams (OHTs)

Back to list of Contents

Rays and waves spreading

This compares and contrasts the complementary descriptions of light as waves and rays.

Ray point of view	Wave point of view
	
Ray point of view: Light travels out in straight lines from a small source	**Wave point of view:** Light spreads out in spherical wave fronts from a small source
	
Ray point of view: Light in a parallel beam or from a very distant source has rays (approximately) parallel to one another	**Wave point of view:** Wave fronts in a parallel beam or from a very distant source are straight (not curved) and parallel

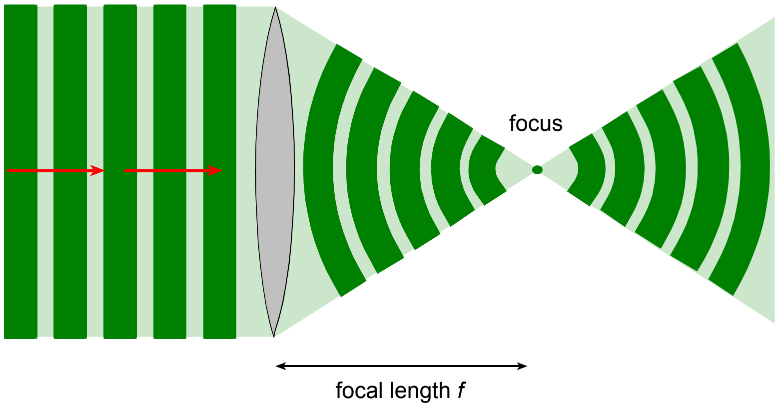
Back to Student’s Checklist

Rays and waves focused

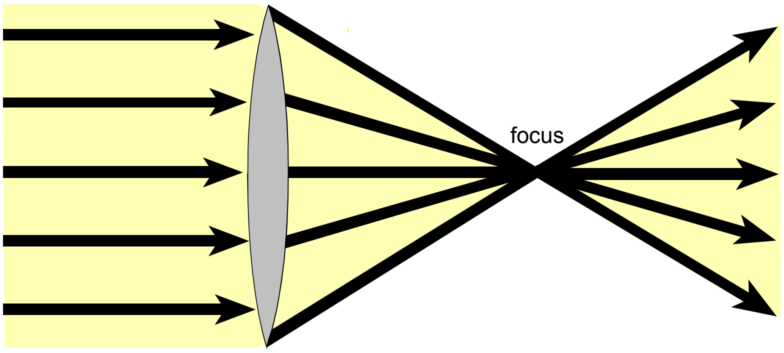
This compares and contrasts the complementary descriptions of light as waves and rays.

Wave and ray points of view:

Wave point of view:
The lens adds curvature to the wave entering it



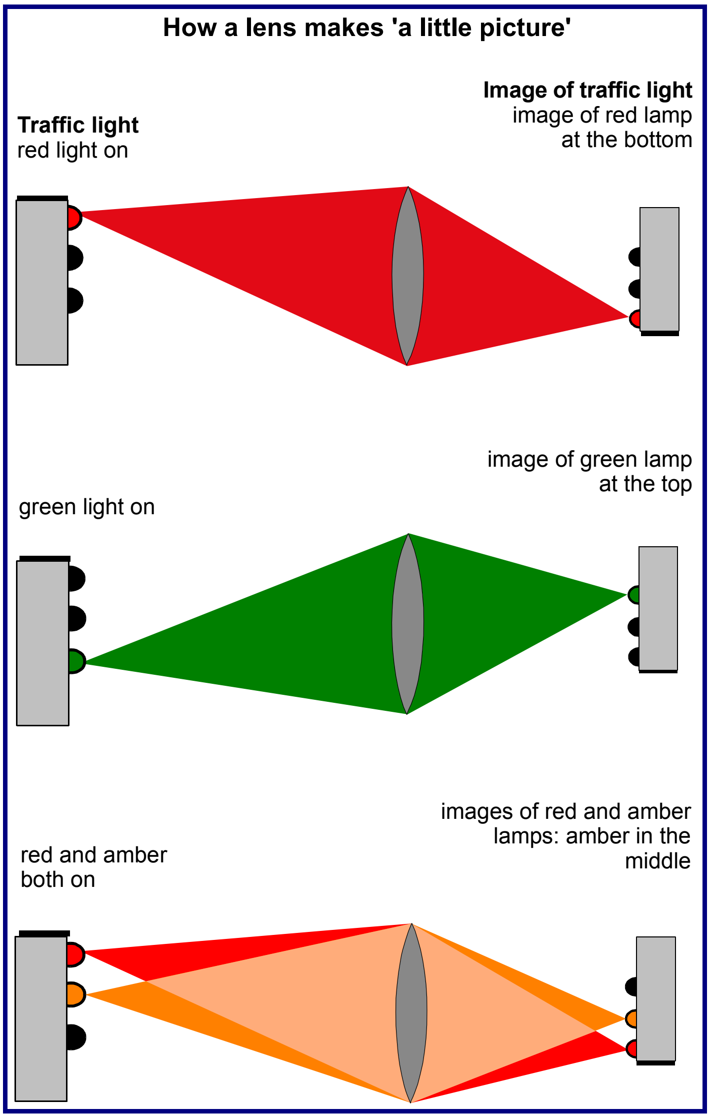
Ray point of view:
The lens bends the rays, bringing them to a focus



Back to Student’s Checklist

Formation of an image

This set of diagrams illustrates why the image is inverted.

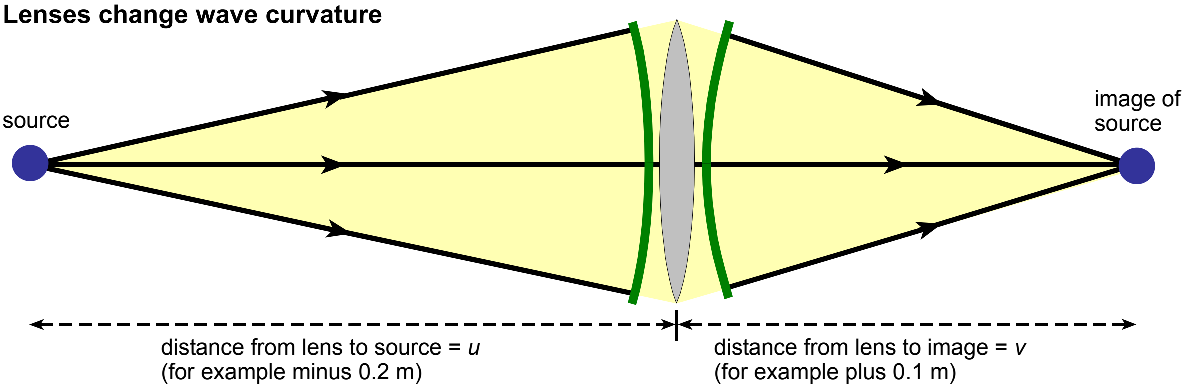


Back to Student's Checklist

Action of a lens on a wave front

This diagram shows the importance of the curvature of the wave front in describing the action of a lens.

Lenses change wave curvature



curvature of wave front after leaving the lens $= \frac{1}{v} = \frac{1}{0.1} = 10$

curvature of wave front on reaching the lens $= \frac{1}{u} = \frac{1}{-0.2} = -5$

curvature added by lens = power of lens = curvature after – curvature before

$$= \frac{1}{v} - \frac{1}{u}$$

$$= 10-(-5) = 15 \text{ dioptre}$$

power of lens $\frac{1}{f} = 15$ dioptre

focal length of lens $f = \frac{1}{\text{power}}$

$$= \frac{1}{15}$$

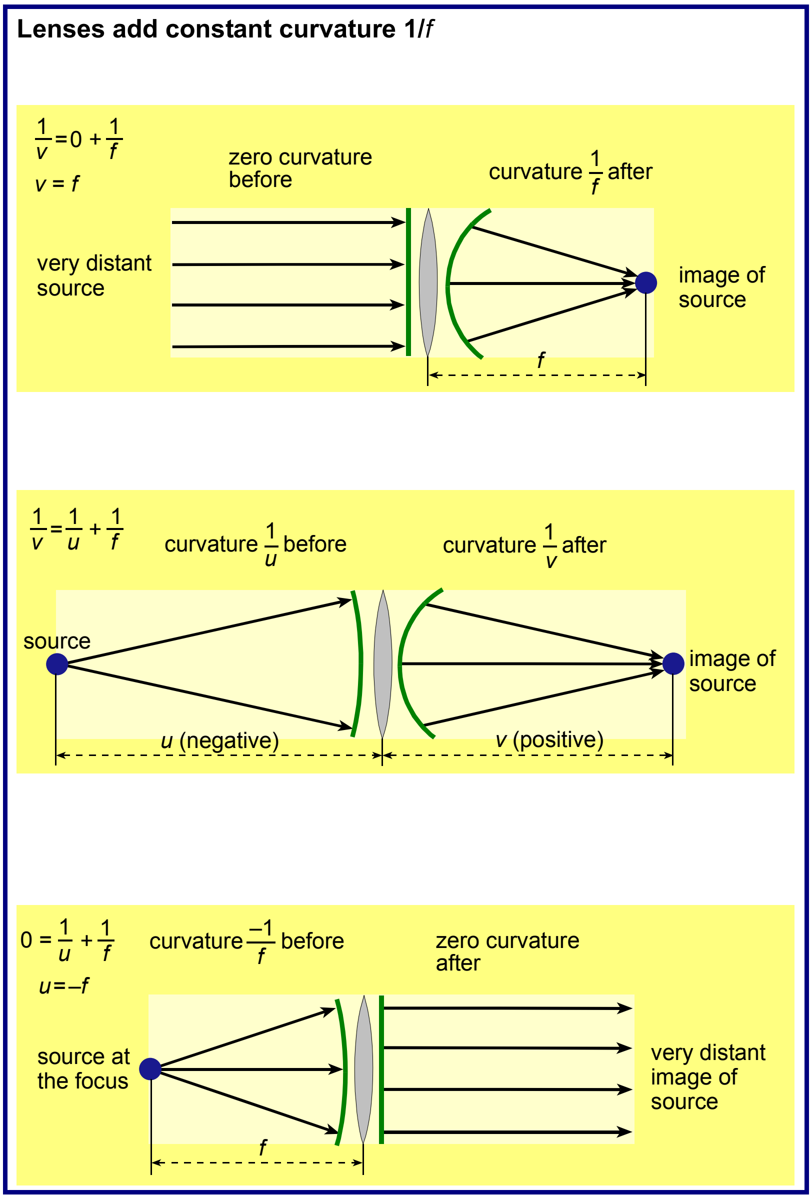
$$= 0.067 \text{ m}$$

$$= 67 \text{ mm}$$

Back to Student’s Checklist

Where object and image are to be found

This diagram shows some important special cases of object and image distances.



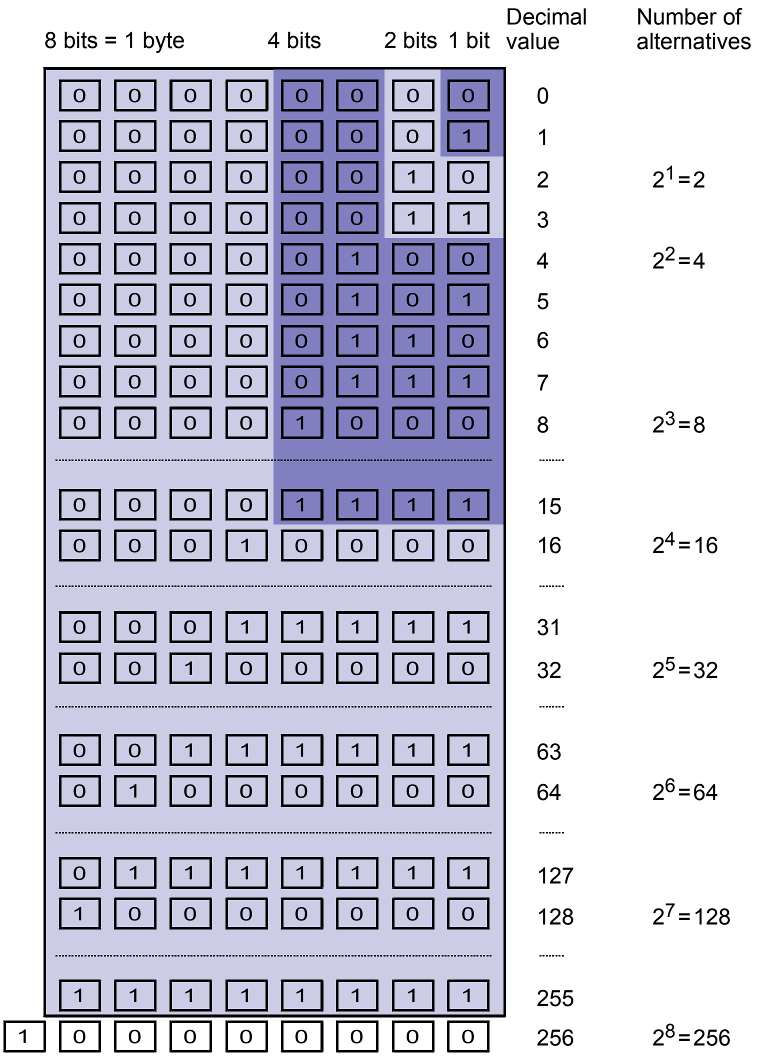
Lenses add constant curvature 1/*f*

Back to Student's Checklist

Bits and bytes

Bits and bytes

One byte stores 256 alternatives



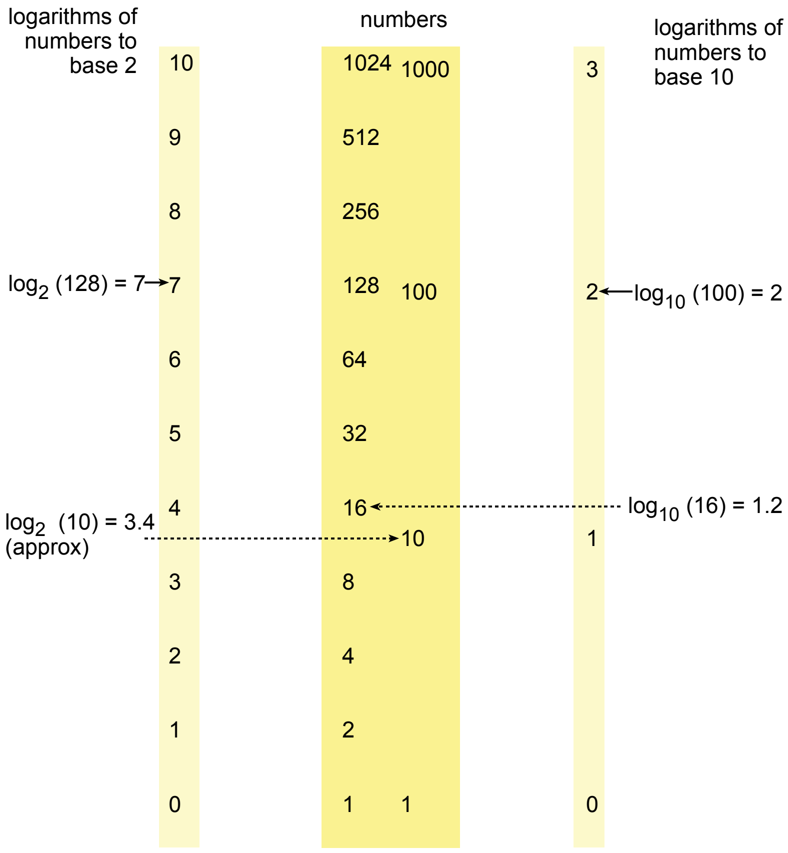
	8 bits = 1 byte				4 bits		2 bits	1 bit	Decimal value	Number of alternatives
	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	1	1	
	0	0	0	0	0	0	1	0	2	$2^1=2$
	0	0	0	0	0	0	1	1	3	
	0	0	0	0	0	1	0	0	4	$2^2=4$
	0	0	0	0	0	1	0	1	5	
	0	0	0	0	0	1	1	0	6	
	0	0	0	0	0	1	1	1	7	
	0	0	0	0	1	0	0	0	8	$2^3=8$
									……	
	0	0	0	0	1	1	1	1	15	
	0	0	0	1	0	0	0	0	16	$2^4=16$
									……	
	0	0	0	1	1	1	1	1	31	
	0	0	1	0	0	0	0	0	32	$2^5=32$
									……	
	0	0	1	1	1	1	1	1	63	
	0	1	0	0	0	0	0	0	64	$2^6=64$
									……	
	0	1	1	1	1	1	1	1	127	
	1	0	0	0	0	0	0	0	128	$2^7=128$
									……	
	1	1	1	1	1	1	1	1	255	
1	0	0	0	0	0	0	0	0	256	$2^8=256$

Back to Student's Checklist

Comparing logarithms base 2 and base 10

Comparing logarithms base 2 and base 10

Logarithms and bases



$2^{10} = 1024$

$10 = \log_2(1024)$

If *base* ^{index} = *number*

Then *index* = logarithm $_{base}$ *(number)*

$10^3 = 1000$

$3 = \log_{10}(1000)$

Back to Student’s Checklist

'Plus' and 'times' scales of information

‘Plus’ and ‘times’ scales of information

Number of alternatives* = 2 *number of bits

If 8 bits of information are used:

number of alternatives = 2^8 = 256

In general, if the amount of information is I bits:

number of alternatives = 2^I

If the number of bits *increases by one*, the number of alternatives *doubles*. Informaton is measured on a ‘plus’ scale; number of alternatives on a ‘times’ scale:

‘PLUS’ SCALE
(LINEAR)

Amount of information

increase by equal additions

amount = I

amount = $\log_2 N$

‘TIMES’ SCALE
(LOGARITHMIC)

Number of alternatives

increase by equal multiples

number of alternatives = 2^I

number of alternatives= N

The Summary Diagram ‘Bits and Bytes’ shows that the number of alternative values which can be represented grows rapidly as the amount of memory used increases.

Back to Student’s Checklist

Logarithmic ladder of distance

Logarithmic ladder of distance

A ladder of distances in multiples of metres

Examples		
10^{21}	galaxy	
10^{18}	nearest stars	1 Em (exa)
10^{15}		1 Pm (peta)
10^{12}	distance to the Sun	1 Tm (tera)
10^{9}	the Earth	1 Gm (giga)
10^{6}		1 Mm (mega)
10^{3}	small town	1 km (kilo)
10^{0}	human body	1 m
10^{-3}	width of a hair	1 mm (milli)
10^{-6}	microchip element	1 µm (micro)
10^{-9}	molecule	1 nm (nano)
10^{-12}	atomic nucleus	1 pm (pico)
10^{-15}	quark	1 fm (femto)
10^{-18}		1 am (atto)

Equal multiple scales

A logarithmic scale is one on which equal spaces correspond to equal multiples.

In this distance scale each upward step multiplies the distance by 1000.

Each downward step divides the distance by 1000.

Each upward step adds 3 to the logarithm (base 10) of the distance.

Each downward step subtracts 3 from the logarithm of the distance.

↑ × 1000

↓ $\times \frac{1}{1000}$

Back to Student's Checklist

Logarithmic ladder of time

Logarithmic ladder of time

A ladder of times in multiples of seconds

Examples		
10^{21}		
10^{18}	age of Universe	1 Es (exa)
10^{15}		1 Ps (peta)
10^{12}		1 Ts (tera)
10^{9}	one year	1 Gs (giga)
10^{6}		1 Ms (mega)
10^{3}		1 ks (kilo)
10^{0}		1 s
10^{-3}	flap of a fly's wing	1 ms (milli)
10^{-6}		1 μs (micro)
10^{-9}	light crosses a room	1 ns (nano)
10^{-12}		1 ps (pico)
10^{-15}		1 fs (femto)
10^{-18}		1 as (atto)

Equal multiple scales

A logarithmic scale is one on which equal spaces correspond to equal multiples.

In this time scale each upward step multiplies the time by 1000.

Each downward step divides the time by 1000.

Each upward step adds 3 to the logarithm (base 10) of the time.

Each downward step subtracts 3 from the logarithm of the time.

↑ × 1000

↓ $\times \frac{1}{1000}$

Back to Student's Checklist