OCR B Physics A Level

Module 3.1: Imaging, Signalling & Sensing

Notes

3.1.1. Imaging and Signalling

Curvature

Light can be modelled either as rays or as wave fronts. In the ray model, light travels in a beam parallel to the direction of motion. In the wave model, light travels as wave fronts which lie perpendicular to the direction of motion.

Wave fronts have curvature, unless they come from a very distant light source, in which they are described as **plane wave fronts**. These are parallel to each other and do not appear to curve. This is because:

$$curvature = \frac{1}{radius}$$

As r approaches infinity, (for example from an infinitely distant light source) curvature approaches zero.

Converging Lenses

Converging lenses focus light onto a point behind it, called the principle focus (or just focus) of the lens, f.

The more powerful the lens, the smaller the focal length.

A converging lens works by adding a curvature of $\frac{1}{f}$ to any wave fronts which pass through it. $\frac{1}{f}$ is also equal to the power of the lens. Power is measured in **Dioptres**, D.

Converging lenses can focus light onto a screen in order to produce an image.

The **Lensmaker's Equation** is used to express this:

Curvature of waves leaving lens = curvature of waves entering + curvature added by lens

$$1/v = 1/u + 1/f$$

Where v = image distance
u = object distance
f = focal distance

Image distance and focal length are positive numbers.

Object distance is a negative value, as it is measured in the opposite direction.

Magnification

Linear magnification is when the size of an image is larger (or smaller) than the real size of the object.

$$\text{Linear magnification, } m = \frac{\text{image height}}{\text{object height}}$$

$$m = \frac{\text{image distance, } v}{\text{object distance, } u}$$

Storage of Images

Modern cameras store images using CCDs - **charge coupled devices**. These consist of a screen covered in **pixels**, which store charge when light falls on them. The charge they store is proportional to the light incident upon it, producing an image.

Information is stored in **bits**, and recorded using a **binary system**. Binary means a system with only two values: high and low (or on and off). 1 bit has 2 possible values, 2 bits have 4 possible values, 3 bits have 8 possible values, etc.

The number of alternatives produced by a number of bits can be determined by:

$$N = 2^b$$

Or the number of bits needed for a certain number of values can be determined from:

$$b = \log_2 N$$

The **resolution** of an image is the smallest distance between which two points can be distinguished. This is a result of the pixels used for the image.

$$\text{resolution} = \frac{\text{width of image}}{\text{number of pixels}}$$

The amount of information in an image can be calculated by the number of pixels multiplied by the number of bits in each pixel.

Image Processing

Images can be enhanced or altered by **processing**. There are 4 main ways of doing this:

1. Removal of Noise	**Method**: replacing the value of each pixel with the mean/median of the 8 pixels immediately around it. **Effect**: removes random speckling/disturbances, produces a smoother image.
2. Edge Detection	**Method**: subtracting the average value of the 8 pixels around it from the value of a pixel. **Effect**: removes areas of uniform colour, effectively producing the outlines of an image.
3. Increasing Contrast	**Method**: spreading the image across the whole range of available values by multiplying the value of each pixel by a fixed number. **Effect**: The image will be more vivid and easier to see.
4. Changing Brightness	**Method**: adding a fixed number to the value of each pixel. **Effect**: Produces a lighter image.

Digital and Analogue Signals

Analogue signals continuously vary between values. **Digital** signals only take discrete values.

Analogue signals can be converted into digital signals by the process of **sampling**. This involves taking regular measurements of analogue signals and rounding them to the nearest value, or **quantisation level**. The problem with sampling is that it produces **quantisation errors**, which is where there is a difference between the actual value and the quantisation level it has been rounded to.

	Analogue Signals	Digital Signals
Advantages	+ more detailed	+ noise resistant + easy to send/store/receive + faster transmission + can be compressed easily
Disadvantages	- cannot easily be amplified (you can't amplify them without amplifying any noise)	- loss of detail - easily scrambled

When sampling, each sample is coded in bits (or **bytes** - 1 byte is equal to 8 bits).

You can work out how many bits/bytes are needed by working out the number of useful quantisation levels:

Maximum useful quantisation levels = $\frac{total\ noisy\ signal\ variation}{noise\ variation} = \frac{V_{total}}{V_{noise}}$

To translate this into bits/bytes, use the equation:

$$2^b = \frac{V_{total}}{V_{noise}} \text{ or } b = log_2\left(\frac{V_{total}}{V_{noise}}\right)$$

The **resolution** of a sample depends on the number of quantisation levels used.

Resolution = $\frac{p.d.\ range\ of\ signal}{number\ of\ quantisation\ levels}$

Sampling Rates

When sampling, the minimum sampling rate must be at least 2x the highest frequency in the signal. Sampling too slowly may produce **aliasing**, or the production of a spurious (false) low frequency signal from a high frequency signal when it is sampled too infrequently.

Bit rate is the rate of information transmission, and can be calculated from:

Bit rate = samples per second x bits per sample

You can also use this to work out how long it will take to transmit a signal. The transmission time will be the total number of bits in the signal divided by the bit rate.

Be careful when using bits and bytes; values given in bytes must always be multiplied by 8 to obtain the value in bits before applying equations, etc.

The Electromagnetic Spectrum

The electromagnetic spectrum is a group of **transverse** waves with oscillating electric and magnetic fields.

Short wavelength High frequency High energy	Long wavelength Low frequency Low energy

gamma	x-rays	ultraviolet	visible	infrared	microwaves	radio

EM waves all travel at the same speed: $3 \times 10^8\ m/s$ in a vacuum.

The wave equation can be applied to EM waves:

wave speed = frequency x wavelength

$$v = f\lambda$$

Polarisation

Transverse waves, eg. EM waves, can be **polarised**. Normally, EM waves oscillate in two planes consisting of perpendicular magnetic and electric fields. Polarisation occurs when waves vibrate in one plane only.

This can be done with polarising filters. A demonstration of polarisation involves holding up two polarising filters aligned and in front of each other. You should be able to see light clearly through them. When you rotate the second filter 90 degrees, the light intensity should decrease to zero. If you rotate it a further 90 degrees, the light intensity should increase back to a maximum.

The same thing can be done using radio waves and a metal grille.

3.1.2 Sensing

Current

Current is the rate of flow of charge.

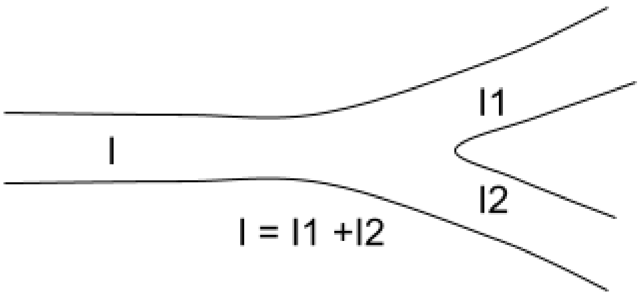
$$current = \frac{charge}{time}$$

$$I = \frac{Q}{t}$$

It is measured in **amperes**, **A**, and is measured using an **ammeter** wired in series with the component being measured.

In a single closed loop (a series circuit), the value of current is the same at any point. However, in a branched (parallel) circuit, the current is split between the branches.

This is due to **Kirchoff's first law**: the conservation of charge. When current reaches a junction, charge is conserved so the total current must remain the same. Hence, the current is split between the two branches.



Potential Difference

Batteries contain two terminals, with a different charge built up on each plate. This is stored as electrical potential energy, and means there is a potential difference between the plates. If the plates are connected to form a complete circuit, the potential difference (p.d.) will cause a current to flow.

Current flows from the negative plate to the positive plate because negative electrons are repelled from the negative pole.

When charges move down a potential difference, work is done. This can be calculated by:

$$work\ done = charge \times voltage$$

$W = Q \times V$ or $W = VIt$

Power Dissipation

When a p.d. causes a current to flow, particles in the metal wire provide resistance against the flow of charge. This causes some energy to be wasted as heat.

This is called **joule heating**, or **power dissipation**.

Power is the rate of energy transfer.

$P = E / t$ or $P = IV$

Resistance and Conductance

Resistance is the ratio of p.d. to current. $R = V / I$

Resistance is provided by metal ions in a wire/component. Current is the flow of electrons, but when electrons flow they collide with ions, which causes them to slow down. This is the resistance.

Conductance is the opposite of resistance. It is a measure of how well electrons flow through a conductor.

Conductance, G, is given by the reciprocal of resistance, so $G = 1 / R = I / V$.

	Series	**Parallel**
Resistance	Resistances add in series. $R = R_1 + R_2 + ...$	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$ The total resistance is less than the lowest individual resistance.
Conductance	$G = \frac{1}{G_1} + \frac{1}{G_2} + ...$ The total conductance is less than the lowest individual conductance.	Conductances add in parallel. $G = G_1 + G_2 + ...$

Resistance increases with temperature; this is because the metal ions have more kinetic energy, so vibrate more, causing more frequent collisions with the electrons.

Conductivity and Resistivity

Resistance and conductance depend on the dimensions of a sample, length (L) & area (A).

$R \propto L/A$ and $G \propto A/L$

Resistivity, **ρ**, and **conductivity**, **σ**, are the same for every sample of a material. They depend only on the material and not on the dimensions of the sample.

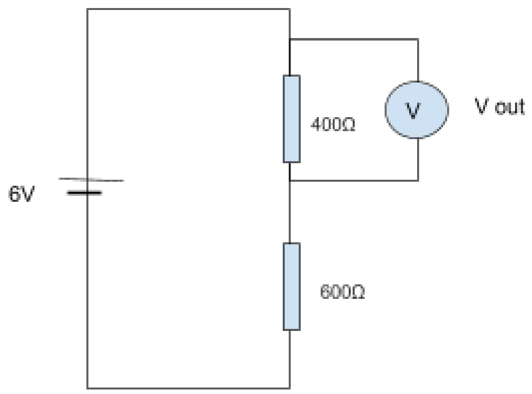
$R = \frac{\rho L}{A}$ and $G = \frac{\sigma A}{L}$

Conductors and Insulators

Conductors	Materials (such as metals) which have a high proportion of mobile charge carriers (free electrons), and can conduct electricity well.
Semiconductors	Materials with a low proportion of mobile charge carriers, but where often the number of mobile charge carriers increases with a factor like light or temperature, enabling them to conduct electricity. Under normal conditions, however, they do not conduct very well.
Insulators	Materials with no (or very few) mobile charge carriers, which do not conduct electricity.
Thermistors and LDRs	Examples of semiconductors. In thermistors, heat liberates electrons, enabling them to conduct, and in LDRs it is light which liberates them. This means they can be used for temperature or light sensors.

Potential Dividers

Potential difference in a series circuit is split between components in the ratio of their resistances.



The potential divider equation can be used to calculate the output voltage.

$$V_{out} = V_{in} \times \frac{resistance\ of\ component}{total\ resistance}$$

For example:

$$V_{out} = 6 \times \frac{400}{400+600} = 2.4\ V$$

EMF and Internal Resistance

EMF (**Electromotive Force**) is the energy provided by the source per unit charge.

Kirchoff's second law states that the sum of all the voltages across the circuit must be equal to the EMF of the circuit.

Most batteries/power supplies have **internal resistance**, which causes the voltage provided by the source to be slightly lower than expected.

Internal resistance can be worked out from the following equation:

$$\varepsilon = V + Ir$$

Where ε = EMF

V = circuit voltage

I = current

r = internal resistance

It can also be calculated graphically. Rearranging the equation gives $V = -rI + \varepsilon$, so a graph can be plotted of V against I. The y intercept will give the EMF, in volts, and the gradient will give -r.