Episode 504: How lasers work

This episode considers uses of lasers, and the underlying theory of how they work.

Safety:

Ensure that you are familiar with safety regulations and advice before embarking on any demonstrations (see TAP 504-2).

Summary

Demonstration: Seeing a laser beam. (10 minutes)

Discussion: Uses of lasers. (15 minutes)

Discussion: Safety with lasers. (10 minutes)

Discussion: How lasers work. (20 minutes)

Worked examples: Power density. (10 minutes)

Student calculations: (10 minutes)

Demonstration:

Seeing a laser beam

A laser beam can be made visible by blowing smoke or making dust in its path. Its path through a tank of water can be shown by adding a little milk.

Show laser light passing through a smoke filled box or across the lab and compare this with a projector beam or a focussed beam of light from a tungsten filament light bulb.

Show the principle of optical fibre communication by directing a laser beam down a flexible plastic tube containing water to which a little milk has been added.

Show a comparison between the interference pattern produced by a tungsten filament lamp (with a 'monochromatic' filter) and that produced by a laser.

Discussion:

Uses of lasers

Talk about where lasers are used – ask for suggestions from the class. As far as possible this should be an illustrated discussion with a CD player, a laser pointer, a set of bar codes, a bar code reader and the school's laser with a hologram available for demonstration.

TAP 504-1: Uses of lasers

Show the list of uses. Invite students to consider the uses shown in the list. Can they say why lasers are good for these? The reasons might be:

- A laser beam can be intense.
- A laser beam is almost monochromatic.

- A laser beam diverges very little.
- Laser light is coherent.

Discussion:

Safety with lasers

Lasers must be used with care. Use the text as the basis of a discussion of the precautions which must be taken.

TAP 504-2: Lasers and safety

Discussion:

How lasers work

If students are familiar with energy level diagrams for atoms, and of the mechanisms of absorption and emission of photons, you can present the science behind laser action. Point out the difference between:

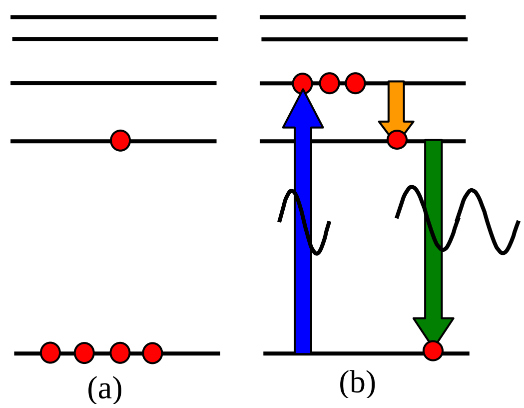
(a) excitation – an input of energy raises an electron to a higher energy level

(b) emission - the electron falls back to a lower energy level emitting radiation and

(c) stimulated emission – the electron is stimulated to fall back to a lower energy level by the interaction of a photon of the same energy

Define population inversion: Usually the lower energy levels contain more electrons than the higher ones (a).

In order for lasing action to take place there must be a population inversion. This means that more electrons exist in higher energy levels than is normal (b).



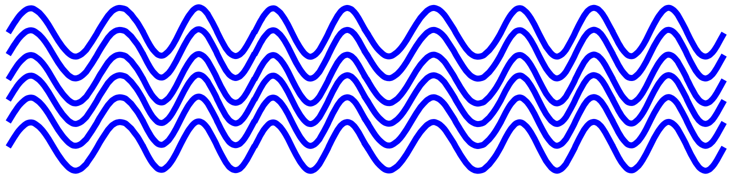
(Diagram: resourcefulphysics.org)

For the lasing action to work the electrons must stay in the excited (metastable) state for a reasonable length of time. If they 'fell' to lower levels too soon there would not be time for the stimulating photon to cause stimulated emission to take place.

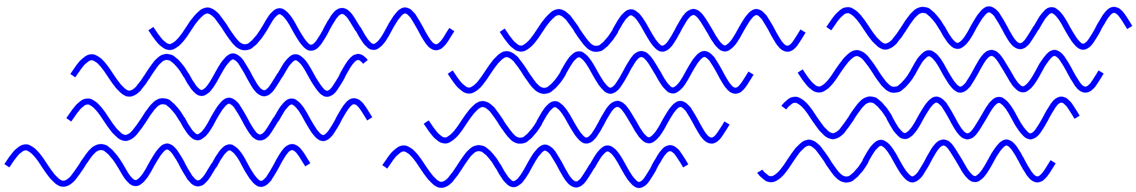
'Laser' stands for Light Amplification by Stimulated Emission of Radiation. The diagrams in

TAP 503 shows the ruby laser and the snowball effect of photons passing down a laser tube, and the diagram above shows the three level laser action. The electrons are first 'pumped' up to the higher energy level using photons. They then drop down and accumulate in a relatively stable energy level, where they are stimulated to all drop back together to the ground state by a photon whose energy is exactly the energy difference to the ground state.

Discuss coherent and non-coherent light. Coherent light is light in which the photons are all in 'step' – in other words the change of phase within the beam occurs for all the photons at the same time. There are no abrupt phase changes within the beam. Light produced by lasers is both coherent and monochromatic (of one 'colour').



Incoherent sources emit light with frequent and random changes of phase between the photons. (Tungsten filament lamps and 'ordinary' fluorescent tubes emit incoherent light)



Worked examples:

Power density

The laser beam also shows very little divergence and so the power density (power per unit area) diminishes only slowly with distance. It can be very high.

For example consider a light bulb capable of emitting a 100 W of actual light energy.

At a distance of 2 m the power density is $100 / 4\pi r^2 = 2$ W m^{-2}. The beam from a helium-neon gas laser diverges very little. The beam is about 2 mm in diameter 'close' to the laser spreading out to a diameter of about 1.6 km when shone from the Earth onto the Moon!

At a distance of 2 m from a 1 mW laser the power density in the beam would be

$0.001 / (\pi \times 0.001^2) = 320$ W m^{-2}! This is why you must never look directly at a laser beam or its specular reflection.

Student calculations

Ask the class to calculate the power densities for a 100 W lamp and a 1 mW laser at the Moon.

(Distance to Moon = 400 000 km; diameter of laser beam at Moon = 1.6 km)

TAP 504-1: Uses of lasers

- repairing damaged retinas
- bar code reader
- communication via modulated laser light in optical fibres
- neurosurgery - cutting and sealing nerves sterilization – key hole surgery (microsurgery)
- laser video and audio discs (CD and DVD)
- cutting metal and cloth
- laser pointer
- laser printer
- holography - three-dimensional images
- surveying - checking ground levels
- production of very high temperatures in fusion reactors
- laser light shows
- making holes in the teats of babies' bottles
- cutting microelectronic circuits
- physiotherapy - using laser energy to raise the temperature of localised areas of tissue e.g. removing tonsure tumours
- laser lances for unblocking heart valves; removal of tattoos or birth marks
- laser guidance systems for weapons
- laser defence systems ('Star Wars')
- a modification of the Michelson-Morley experiment to check the existence of the ether
- distance measurement
- laser altimeters

TAP 504-2: Lasers and safety

The following is an extract from the CLEAPSS Science Publications Handbook Section 12.12:

12.12 Lasers

A low-power, continuous-wave, helium-neon laser is useful for teaching wave optics because it produces a beam of light that is:

- highly monochromatic (very narrow spread of wavelengths) and coherent (the same phase) both across the beam and with time;
- of high intensity;
- of small divergence (typically 1 mm in diameter when it leaves the laser, 5 mm in diameter 4 m away).

Because of its intensity, care must be taken to prevent a beam from a laser falling on the eye directly or by reflection, as it could damage the retina. In fact, it is now known that eyes could be damaged by the beam from the low power Class II lasers used in schools only if a deliberate attempt were made to stare at the laser along the beam or to concentrate the beam from a IIIa laser with an instrument; the normal avoidance mechanism of the body would prevent damage in other cases. Nevertheless, it is good practice to take precautions to avoid a beam falling on the eye.

Lasers should be positioned so that beams cannot fall on the eyes of those present, i.e., are directed away from spectators. Ancillary optical equipment must be arranged so that reflected beams cannot reach eyes.

Ten years ago, the lasers affordable by schools would work for only a few years and then only if run periodically. Those currently available have longer lives and do not require this.

DES Administrative memorandum 7/70

This advises on the use of lasers in schools and FE colleges. It confines use at school level to teacher demonstration. Safety rules include the avoidance of direct viewing; screening pupils who should be at least 1 m away; keeping background illumination as high as possible (so that eye pupils are as small as possible); displaying warning notices; keeping lasers secure from unauthorised use or theft; use of goggles by the demonstrator. Because of the more recent realisation that the lasers used in schools and colleges will not harm an eye by a beam accidentally falling on it, these rules are not strictly necessary but following them is good training. However, goggles are expensive, impractical and do not reduce hazard as they make it harder for the demonstrator to see the beam, stray reflections etc.