OCR
RECOGNISING ACHIEVEMENT

Wednesday 23 January 2013 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

Candidates answer on the Question Paper.

OCR supplied materials:
- Data, Formulae and Relationships Booklet (sent with general stationery)
- Insert (inserted)

Other materials required:
- Electronic calculator
- Ruler (cm/mm)

Duration: 2 hours

Candidate forename		Candidate surname	

Centre number						Candidate number				

INSTRUCTIONS TO CANDIDATES
- The Insert will be found in the centre of this document.
- Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.
- Use black ink. HB pencil may be used for graphs and diagrams only.
- Answer **all** the questions.
- Read each question carefully. Make sure you know what you have to do before starting your answer.
- Write your answer to each question in the space provided. If additional space is required, you should use the blank pages at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the bar codes.

INFORMATION FOR CANDIDATES
- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **100**.
- You may use an electronic calculator.
-  Where you see this icon you will be awarded marks for the quality of written communication in your answer.

  This means for example, you should:
  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear
  - organise information clearly and coherently, using specialist vocabulary when appropriate.
- You are advised to show all the steps in any calculations.
- This document consists of **24** pages. Any blank pages are indicated.
- The questions in Section C are based on the material in the Insert.

SECTION A

Answer **all** the questions.

1 Here is a list of quantities and units. Draw lines from one box to another to match the quantity to its unit.

induced emf	$N\,C^{-1}$
electric field strength	$Wb\,m^{-2}$
magnetic field strength	$J\,C^{-1}$
magnetic flux	Wb

[2]

2 A magnet is attached to a motor and rotates below a freely-suspended copper disc as shown in Fig. 2.1.

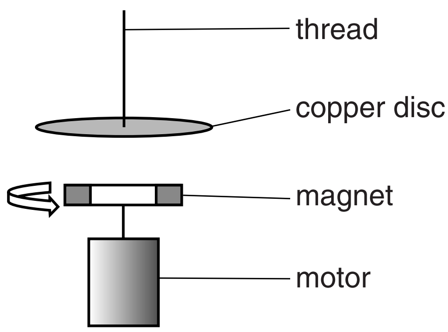

Fig. 2.1

Choose the correct statement from the sentences below.

A The disc will not rotate because copper is not magnetic.

B The disc will rotate because copper is magnetic.

C The disc will not rotate because it has a high resistance.

D The disc will rotate because currents are induced in the copper.

The correct statement is .... **[1]**

3 A thundercloud has a flat base 500 m above the ground as shown in Fig. 3.1.

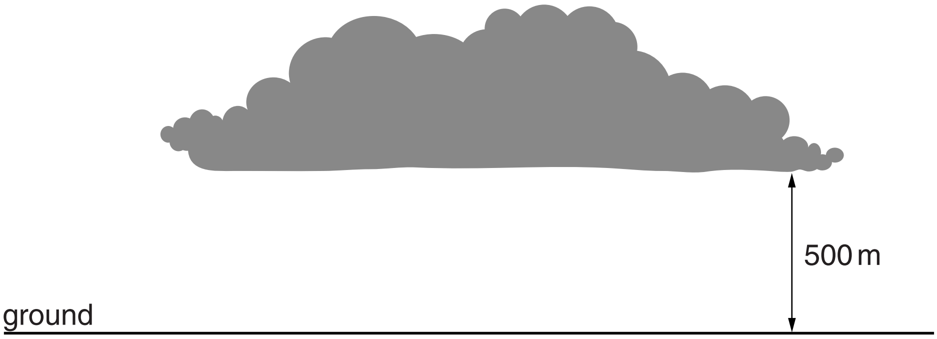

Fig. 3.1

The base of the cloud is at a potential of +70 MV compared to the ground. Assume that there is a uniform field between the base of the cloud and the ground.

(a) Draw and label the +35 MV equipotential line on the diagram. **[1]**

(b) Calculate the strength of the electric field between the base of the cloud and the ground.

field strength = ... $V\,m^{-1}$ **[1]**

4 A model of the hydrogen atom pictures the electron as a standing wave trapped in a box.

A hydrogen atom has a diameter of about 1×10^{-10} m. Calculate the momentum of an electron with a wavelength of 1×10^{-10} m.

$h = 6.6 \times 10^{-34}$ J s

momentum of electron = ... $kg\,m\,s^{-1}$ **[2]**

5 Here is a list of particles:

electron **photon** **neutrino** **neutron** **gluon**

Choose a particle from the list to complete the sentences below.

The .... is a hadron composed of two down quarks and one up quark.

The .... is the carrier particle of the force that holds quarks together.

The .... and the .... are both leptons. **[3]**

6 An ideal transformer is used to convert a 230 V 50 Hz supply into a 12 V output.

(a) Calculate the turns ratio:

$$\frac{\text{number of turns on primary coil}}{\text{number of turns on secondary coil}}$$

turns ratio = ... **[1]**

(b) State the frequency of the 12 V output.

frequency = ... Hz **[1]**

7 Fig. 7.1 shows a graph of electric potential due to a point charge against distance from the point charge.

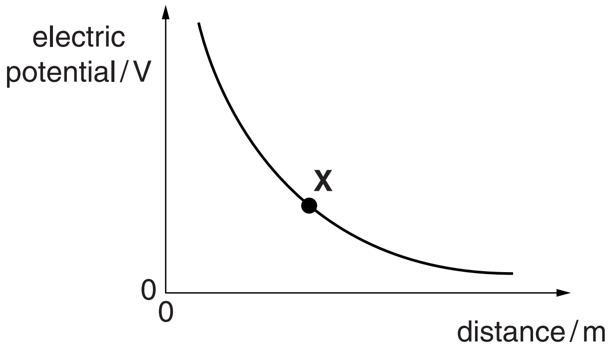

Fig. 7.1

(a) Explain the meaning of the term *electric potential*.

[2]

(b) State what the gradient at point **X** represents.

[1]

8 In one example of nuclear fission, uranium-235 breaks into two smaller, daughter nuclei and two neutrons. The binding energy per nucleon in a uranium-235 nucleus is –7.6 MeV.

(a) Calculate the total binding energy of a uranium-235 nucleus.

total binding energy = ... MeV **[1]**

(b) The average binding energy per nucleon for the smaller daughter nuclei is –8.5 MeV.

Calculate the energy released in this fission event.

energy released = ... MeV **[2]**

9 A worker in the nuclear industry has an average absorbed dose of 18 mSv per year over her 25 years of working. Calculate an estimate for the total energy absorbed by her body from the radiation over 25 years.

mass of worker = 65 kg

quality factor of radiation = 1

total energy absorbed = ... J **[2]**

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Question 10 begins on page 8

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SECTION B

10 This question is about accelerating protons in the Large Hadron Collider.

Fig. 10.1 shows how the energy of a proton changes as it approaches the velocity of light *c*.

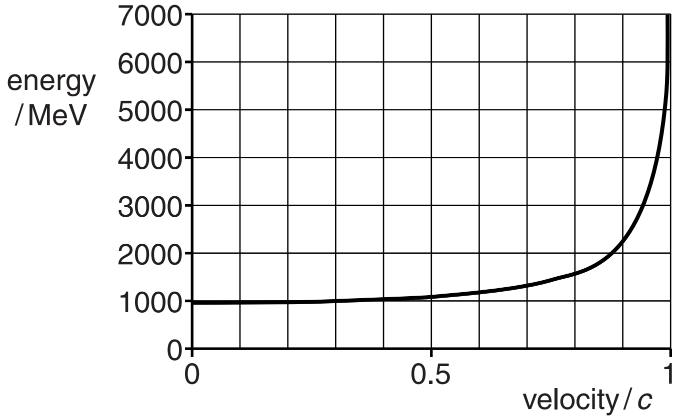


Fig. 10.1

(a) State the feature of Fig. 10.1 that suggests that protons can never reach the speed of light.

[1]

(b) (i) Protons of energy 4 TeV (4×10^{12} eV) circle in the Large Hadron Collider.

Calculate the relativistic factor γ at this energy.

rest energy of proton = 938 MeV

relativistic factor γ = ... **[2]**

(ii) Explain by calculation how your result shows that the protons are travelling at more than 99% of the speed of light.

[3]

(c) Although the protons are accelerated to extremely high energies, the kinetic energy of a 4 TeV proton is described as being 'about that of a mosquito'.

Use the data below to estimate the speed of a mosquito with similar kinetic energy to a 4 TeV proton.

mass of a mosquito = 2×10^{-6} kg
$e = 1.6 \times 10^{-19}$ C

speed of mosquito = ... $\mathrm{m\,s^{-1}}$ **[2]**

(d) The high speed protons of charge *q* pass into a magnetic field of strength *B*, where they travel in a circle of radius *r*.

(i) If all the quantities are expressed in S.I. units, use the relationship

$B\,q\,r$ = energy of particle / speed of light

to show that the unit of magnetic field strength, the tesla (T) is equivalent to $\mathrm{N\,A^{-1}\,m^{-1}}$.

[2]

(ii) Calculate the magnetic field strength *B* required to make 4 TeV protons follow a circular path of radius 4250 m.

$c = 3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$

B = ... T **[2]**

[Total: 12]

11 This question is about using plutonium-238 as a power source in nuclear batteries.

Plutonium-238 decays into uranium-234 as shown below:

$$^{238}_{94}\text{Pu} \rightarrow \, ^{234}_{92}\text{U} + \, ^{4}_{2}\text{He}$$

(a) Use the data below to show that the energy produced in one decay of plutonium–238 is about 9×10^{-13} J. Show each stage of your working clearly.

mass of $^{238}_{94}\text{Pu}$ = 237.9979 u

mass of $^{234}_{92}\text{U} + \, ^{4}_{2}\text{He}$ = 237.9919 u

$u = 1.7 \times 10^{-27}$ kg

$c = 3.0 \times 10^{8}\,\text{m}\,\text{s}^{-1}$

[3]

(b) One type of nuclear battery has been implanted into patients to power heart pacemakers.

The sealed plutonium source in this type of battery has an initial activity of 6.0×10^{10} Bq.

(i) Calculate the initial power released by the plutonium source.

power = ... W **[2]**

(ii) Show that the mass of plutonium in the battery is about 1×10^{-4} kg.

decay constant of plutonium-238 = $2.5 \times 10^{-10}\,s^{-1}$.

$N_A = 6.0 \times 10^{23}\,mol^{-1}$

mass of one mole of plutonium-238 = 0.238 kg

[2]

(c) The working life of the plutonium battery is about twenty years. Nuclear batteries were used in younger patients requiring pacemakers as they did not need to be frequently replaced. Plutonium-238 was considered an ideal source for use in such a battery as it is an alpha source with a half-life of about 88 years.

The effective dose from such batteries is about one millisievert per year. The uranium-234 produced in the decay does not contribute to the dose. The risk of developing cancer is given as about 5% per sievert per year.

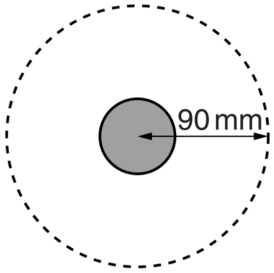
Discuss why plutonium-238 is well-suited to use in such a battery. You may use calculations in your answer.

1 year = 3.2×10^{7} s

[4]

[Total: 11]

12 This question is about the electric field near a charged conducting ball. Fig. 12.1 shows an equipotential near the ball.



not to scale

Fig. 12.1

(a) **(i)** The potential at 90 mm from the centre of the ball is 230 V. Calculate the charge on the ball.

$k = 9.0 \times 10^{9}\,\mathrm{N\,m^{2}\,C^{-2}}$

charge = ... C **[2]**

(ii) The ball is at a potential of 4000 V. Show that the radius of the ball is about 5 mm.

[1]

(b) The ball is clamped above a second, similar conducting ball placed on an electronic balance which is zeroed. Both balls are given a charge of $+5.2 \times 10^{-9}$ C. The centres of the balls are separated by 14 mm. See Fig. 12.2.

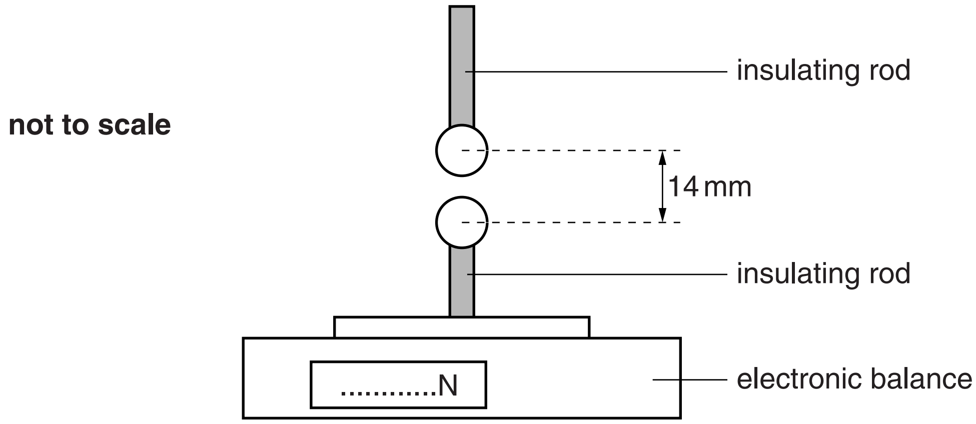


Fig. 12.2

The balance reads to the nearest 0.001 N.

Show that the balance will read 0.001 N. Assume that the balls behave as point charges.

[2]

(c) The separation is reduced to 11 mm. The reading of the balance does not change.

Explain, with calculations, why the reading may be expected to change. Give a reason why no change in reading is actually observed.
You may assume that the total charge on each ball does not change.

[4]

[Total: 9]

13 This question is about a torch that does not require cells. See Fig. 13.1.

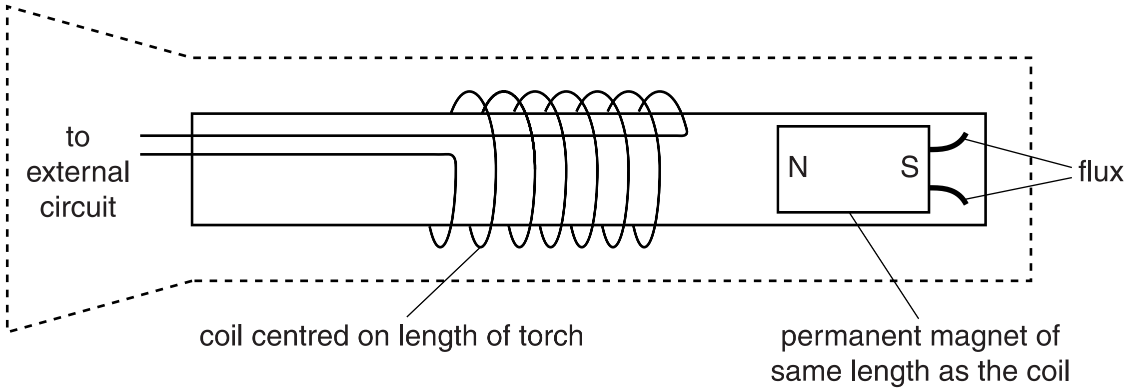


Fig. 13.1

When the torch is tilted the permanent magnet falls through the coil of copper wire. This induces an emf across the coil.

(a) Complete the two flux loops of the permanent magnet on Fig. 13.1. **[1]**

(b) At time $t = 0$ s the torch is tilted so that the magnet falls through the coil.

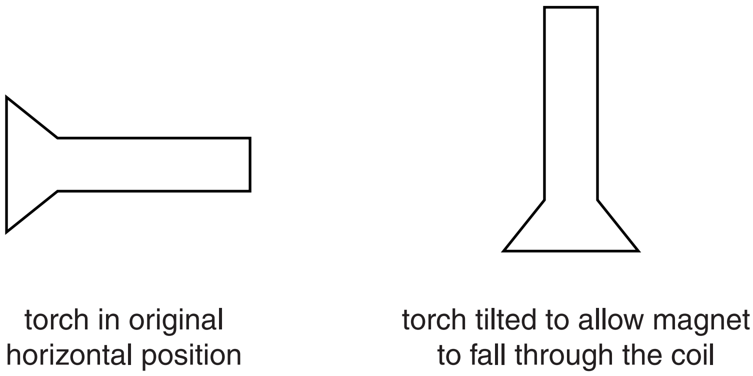


Fig. 13.2

Fig. 13.3 shows the emf induced as the magnet falls through the coil.

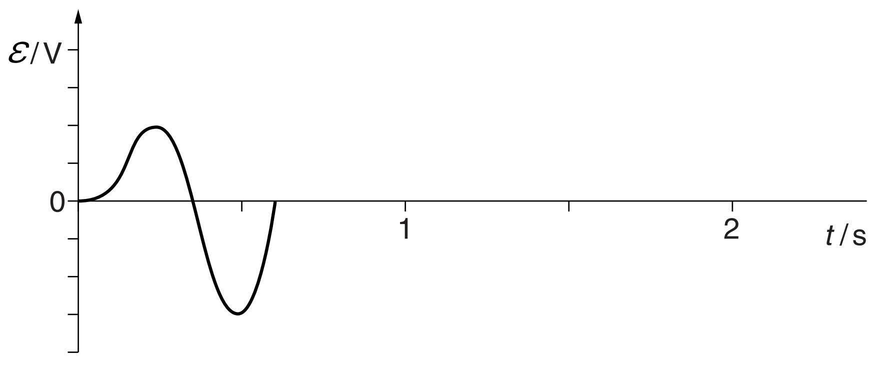


Fig. 13.3

Use a letter **X** to mark on Fig. 13.3 the time at which the magnet passed through the centre of the coil. **[1]**

(c) (i) The maximum emf induced is 1.4 V. The coil has 1500 turns. Calculate the maximum rate of change of flux.

maximum rate of change of flux = ... $Wb\,s^{-1}$ **[2]**

(ii) Explain how the magnet falling through the coil leads to the shape of the pulse shown in Fig. 13.3.

Make each stage in your explanation clear and refer to equations where appropriate.

[4]

(d) At time $t = 1\,s$ the torch is tilted in the opposite direction so that the magnet falls through the coil once again but in the opposite direction. The magnet takes the same time to pass through the coil as it did in the first pass. On Fig. 13.3 draw the emf pulse that will be generated by the second pass of the magnet through the coil.

[2]

[Total: 10]

SECTION C

The questions in this section are based on the Advance Notice.

14 In a He-Ne laser, the difference in electron energy levels for the stimulated emission of photons is 1.96 eV.

(a) **(i)** Show that 1.96 eV is about 3×10^{-19} J.

$e = 1.6 \times 10^{-19}$ C

[1]

(ii) Show that the wavelength of the radiation produced from this emission is about 630 nm.

$h = 6.6 \times 10^{-34}$ J s
$c = 3.0 \times 10^{8}$ m s^{-1}

[2]

(iii) If the output power of the laser is 3.0 mW, calculate the number of photons emitted per second by the laser operating in continuous wave mode.

number = ... s^{-1} **[2]**

(iv) Calculate the percentage efficiency of the laser when it is mains operated (230 V) and draws a current of 2.0 A.

efficiency = ... % **[2]**

(b) **(i)** In thermal equilibrium the ratio of the number of electrons in the higher energy level (N_2) to the number in the lower energy level (N_1) is given by the Boltzmann factor, $e^{-(\Delta E/kT)}$ where

ΔE = energy difference between the levels

k = the Boltzmann constant, $1.38 \times 10^{-23}\,JK^{-1}$

T = absolute temperature.

Use the result from **(a)(i)** to calculate the Boltzmann factor when $T = 300\,K$.

Boltzmann factor = ... **[2]**

(ii) Explain the meaning of the term *population inversion*. Use your answer to **(b)(i)** to explain why population inversion is required in order for a laser to work. (lines 3–12 in the article)

Make each stage in your explanation clear and use correct technical language.

[4]

[Total: 13]

15 A pulsed CO_2 laser of output power 3.0×10^{11} W produces pulses that each last for 1×10^{-9} s.

(a) Calculate the energy of each pulse.

energy = ... J **[1]**

(b) The energy of the pulse is absorbed by 1.5 g of water.
Calculate the temperature rise of the water.

specific thermal capacity of water = 4200 J kg^{-1} K^{-1}

temperature rise = ... K **[2]**

[Total: 3]

16 In a laser, the gain medium is put between parallel mirrors. When operating, standing waves are set up in the medium.

(a) Draw the longest wavelength standing wave possible in the space between the mirrors shown in Fig. 16.1.

Fig. 16.1

[1]

(b) In a particular GaAs semiconductor laser the gain medium has a length of 1.1×10^{-7} m. Show that the lowest frequency radiation which can produce a standing wave is about 4×10^{14} Hz.

speed of electromagnetic waves in GaAs = 0.83×10^{8} m s^{-1}

[2]

[Total: 3]

17 Fig. 3 in the article shows how different wavelengths of laser light are absorbed by water.

(a) Both scales of the graph are logarithmic. Explain why it is more useful to display the information shown as a logarithmic graph rather than a graph with linear axes.

[2]

(b) By taking a measurement from Fig. 3 in the article, show that a beam of laser radiation of wavelength 1000 nm would be reduced to about 5% of its original intensity after penetrating a depth of 3 m of water.

[4]

[Total: 6]

18 In lines 54–57 of the article the process known as "optical breakdown" using powerful laser pulses is described.

(a) It has been shown that shorter laser pulses cause less unwanted damage to nearby tissue.

(i) Explain why such lasers must be of higher power in order to produce the same effect as the longer pulses from lower power lasers.

[2]

(ii) Suggest why shorter laser pulses cause less damage to nearby tissue.

[1]

(b) By calculating the number of molecules of water in 1 cm^3, show that an electron density of 10^{21} electrons per cm^3 suggests that on average 3% of the molecules will lose an electron.

One mole of water has a mass of 18 g.

density of water = 1 $g\,cm^{-3}$
Avogadro constant $N_A = 6.0 \times 10^{23}\,mol^{-1}$

[4]

[Total: 7]

19 For some medical procedures laser light is directed along optical fibres made of high-purity glass.

(a) Suggest why it is important that high-purity glass is used in this application.

[1]

(b) If the fibre is perfectly straight, it is possible for the light to travel along the axis of the fibre. Because the fibre will rarely be straight, the light can travel at an angle to the axis of the fibre, resulting in zig-zag paths along the length of the fibre.

(i) Calculate the minimum time taken for a pulse of laser light to travel the length of a 0.75 m optical fibre.

refractive index of the glass = 1.20
$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$

time taken = ... s **[2]**

(ii) Explain why the calculation in **(i)** represents the **minimum** time.

[1]

(iii) The refractive index of the glass varies with the wavelength of the light. For one type of glass, the value is 1.19 for blue light and 1.21 for red light. Calculate the percentage difference in the time taken for red light to travel the length of the fibre compared to blue light.

percentage difference = ... % **[2]**

[Total: 6]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional answer space is required, you should use the blank page(s) below. The question number(s) must be clearly shown in the margins.

ADDITIONAL ANSWER SPACE

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Wednesday 23 January 2013 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

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Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This Insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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The laser – a surgeon's best friend

Since its invention and development over fifty years ago, the laser has found numerous applications in a wide range of contexts, including medicine. Although many different materials are used to make them, all lasers operate in essentially the same way. Electrons in the atoms of the selected material – called the gain medium – are excited to a higher energy level in such a way that the number of atoms with this energy E_2 is more than the number with a lower energy E_1. This is called a population inversion: normally the number of atoms in the excited state is much smaller than the number in the lower energy state. If a photon of energy $hf = E_2 - E_1$ passes through the gain medium an electron in the higher energy level can be stimulated to fall down to the lower level. Another photon is emitted when this happens – see Fig. 1. The emitted photon will have exactly the same direction, frequency and phase as the photon which stimulated its production in the first place: the two photons will be coherent. This process of stimulated emission was predicted by Einstein in 1917.

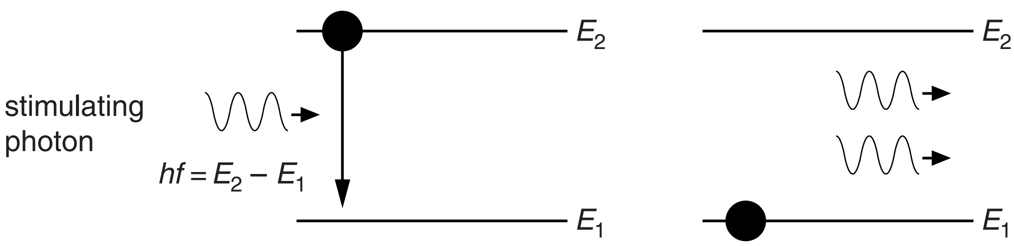

Fig. 1: stimulated emission

To make a laser, the gain medium is placed inside a 'cavity' made with two mirrors facing each other, Fig. 2. Photons travelling in a direction parallel to the cavity axis bounce back and forth within the cavity causing stimulated emission, increasing the number of photons all the time. A standing wave forms within the cavity which has a fixed length, d. One of the mirrors is a partial reflector so that light from the standing wave can leak through it and form the laser output. What emerges is a monochromatic, coherent and powerful beam of radiation.

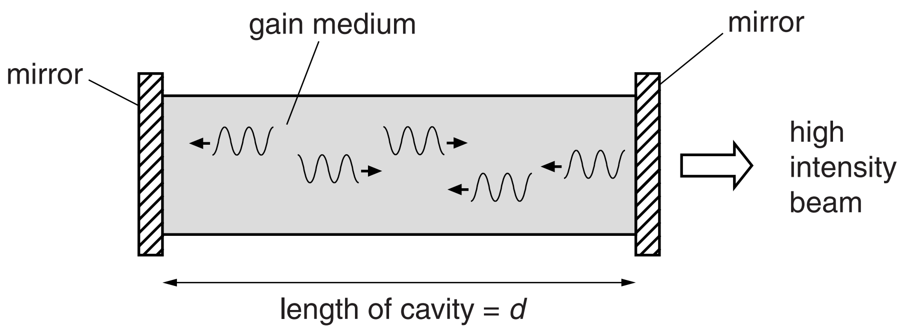

Fig. 2: the radiation reflects back and forth in the gain medium cavity, building up a standing wave

Laser energy

In some lasers, the population inversion is maintained by providing the energy needed to raise electrons to the higher levels in a series of optical or electrical pulses. Thus the photons also emerge in regular bursts and this is called a pulsed laser. In others, the population inversion is maintained continuously and the laser radiation emerges as a steady beam – these are continuous wave (cw) lasers. The amount of energy deposited into the target from a laser depends upon the energy of the photons, the rate at which the photons arrive and the amount of time over which they are arriving.

Lasers in Surgery

The use to which a laser is put depends mostly on the wavelength of the radiation it emits. Human tissue responds in different ways to different wavelengths of the electromagnetic spectrum. Soft tissue is made of many different substances and each absorbs light in its own way. Three substances in human skin and the soft tissue immediately beneath it are melanin (responsible for skin colouring), blood and water. The absorption by water of different wavelengths is shown in Fig. 3, in which the absorption coefficient, μ, is defined as the reciprocal of the depth within which the intensity falls by a factor of 1/e (about 0.37). For example, an absorption coefficient of $0.1\,\text{cm}^{-1}$ indicates that the intensity I of the radiation will have been reduced to about $0.37I$ within 10 cm. The absorption can be represented by the equation $I = I_0\,e^{-\mu x}$, where I_0 is the incident laser intensity and x is the depth in cm.

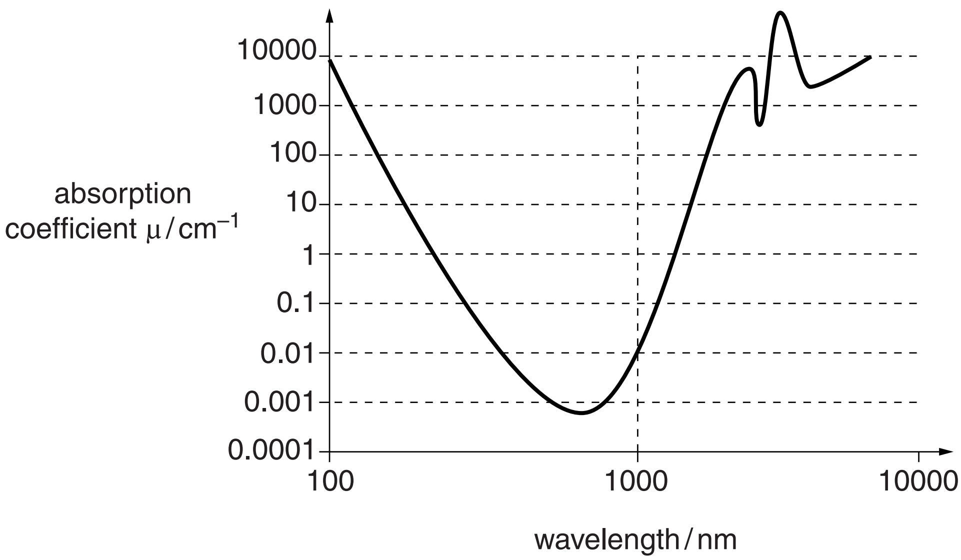

Fig. 3: different wavelengths of laser radiation are absorbed by different amounts by water, one of the main components (70%) of soft tissue

The interaction of laser radiation with such biological tissue occurs under the broad headings of thermal, mechanical, and chemical and the precise type of laser used in a surgical procedure will depend upon the particular type of surgery required.

Thermal effects

For surgical procedures, tissue cells need to be broken up in a controlled fashion but without excessive heating taking place as this could cause damage to surrounding tissue. Heating tissue to about 60 °C causes what is known as coagulation, a process which causes it to shrink. This can be very useful, for example, for sealing blood vessels and preventing bleeding. A very narrow beam of powerful laser light can thus be used as a "bloodless scalpel". At higher temperatures (greater than 100 °C), the water in tissue cells boils causing destruction of cells as the vapourised water expands, a process known as ablation. Carbon dioxide (CO_2) lasers, which can be used in pulsed or continuous wave mode, have a wide range of applications, including straightforward surgical techniques involving coagulation. The CO_2 laser radiation is invisible, so the visible red light from a helium-neon (He-Ne) laser is used to provide a guide beam.

Mechanical effects

When particularly powerful laser beams are used, energy can be given to the tissue in a very short space of time. A pulse of high energy photons delivered in a nanosecond or so can break apart molecules without much heating taking place. This is called optical breakdown and leads to the production of short-lived “micro-plasmas”, tiny regions of ionisation with a density of liberated electrons as high as 10^{21} per cubic centimetre. The rapid expansion of the plasma leads to mechanical damage to the surrounding medium, although this remains a tiny region. Because it is a non-thermal effect and cell destruction is highly localised this can be used to remove tissue on a very delicate scale, for example in the eye. One type of laser used for this work is the pulsed neodymium:YAG (Nd:YAG) laser in which the gain medium is an yttrium-aluminium-garnet crystal doped with the element neodymium. Its radiation is very penetrating and, when administered in short pulses, is used for eye surgery (Fig. 4).

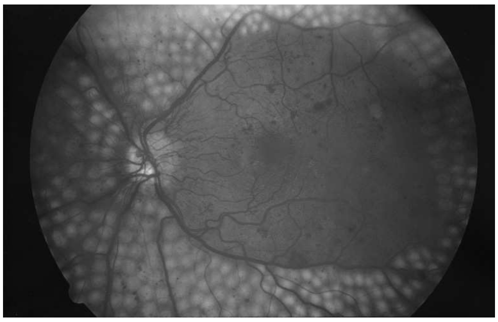

Fig. 4: neodymium:YAG lasers can be used to make repairs to tiny localised areas in the retina of the eye

Photochemical reactions

The behaviour of some chemicals can be affected very profoundly by light and other parts of the electromagnetic spectrum. Certain drugs, for example, become very active when illuminated with short-wavelength visible light. If the chemical is reacting in something not far below the skin, then the laser can be shone directly onto the skin surface. However, to illuminate deeper regions, the light has to be directed using optical fibres. For this work, metal-vapour lasers are used, in which the gain medium consists of a mixture of neon and a vapourised metal, often gold.

The future

By applying the same principles to different materials for more than fifty years, lasers have found uses in a very wide range of applications with many, such as DVD players, bar code readers and telecommunications, encountered every day. Current developments of solid state lasers have started a new era in laser technology, though the basic principle remains the same. As higher-powered semiconductor lasers become a reality, no doubt the world of medicine and surgery will continue to benefit from this truly cutting-edge technology.

END OF ARTICLE