Surname	Centre Number	Candidate Number
Other Names		2

GCE A level

1325/01

PHYSICS

ASSESSMENT UNIT PH5: ELECTROMAGNETISM, NUCLEI & OPTIONS

A.M. MONDAY, 27 June 2011

$1\frac{3}{4}$ hours

1325 010001

ADDITIONAL MATERIALS

In addition to this paper, you will require a calculator a **Case Study Booklet** and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.

Write your name, centre number and candidate number in the spaces at the top of this page.

Write your answers in the spaces provided in this booklet.

INFORMATION FOR CANDIDATES

This paper is in 3 sections, **A**, **B**, and **C**.

Section A: 60 marks. Answer **all** questions. You are advised to spend about 1 hour on this section.

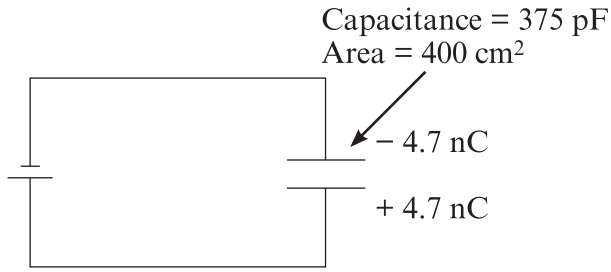
Section B: 20 marks. The Case Study. Answer **all** questions. You are advised to spend about 20 minutes on this section.

Section C: Options; 20 marks. Answer **one option only.** You are advised to spend about 20 minutes on this section.

Examiner only

SECTION A

1. A parallel plate capacitor with no dielectric between the plates is charged by a cell as shown in the diagram.



(a) (i) Calculate the emf of the cell. [2]

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(ii) Calculate the separation of the plates of the capacitor. [2]

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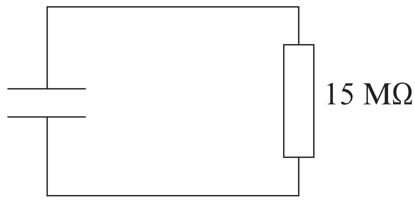
(b) The capacitor is now discharged through a 15 MΩ resistor.

Calculate the time for the charge on the capacitor to drop from 4.7 nC to 0.7 nC.



[4]

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(c) The capacitor is employed as a fog detector and uses the fact that water is a good dielectric. Explain briefly how the capacitor could detect the presence of fog. [2]

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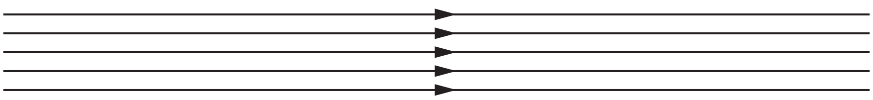
2. Each of five long, straight, parallel wires carries a current of 0.3A.



(a) The wires are very close together. Show that the magnetic field strength, B, at a distance of 12.5 cm away from them is 2.4 μT. [2]

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(b) An α particle travelling with speed 8.8×10^6 m s^{-1} passes through a point where the magnetic field strength is 2.4 μT. Explain briefly in which direction the α particle is travelling when it experiences

(i) no force, [2]

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(ii) a force of 3.38×10^{-18} N. [2]

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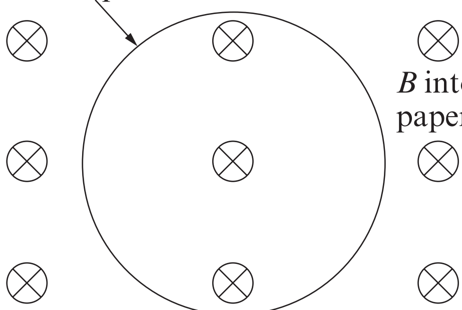
(c) The α particle travels in the Earth's magnetic field. This may be assumed to be uniform and of strength 2.4 μT as shown. The α particle travels in a circular path, as shown, at a constant speed of 8.8×10^6 m s^{-1}.
The mass of the α particle is 4 u.

path of α particle



$v = 8.8 \times 10^6$ m s^{-1}

(i) **Indicate with an arrow** the direction of motion of the α particle. [1]

(ii) Calculate the radius of the path of the α particle. [3]

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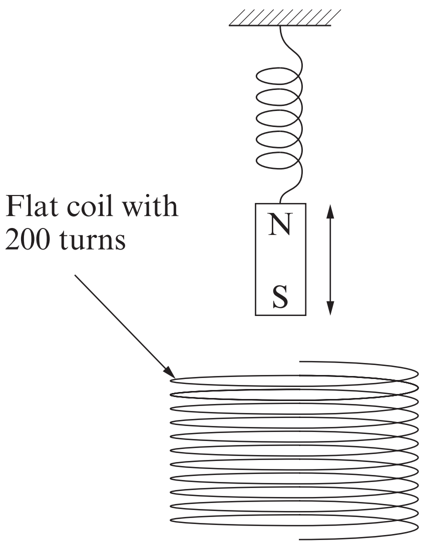
3. A strong magnet is held on a spring and performs simple harmonic motion near a flat coil as shown.



(a) Explain briefly why an alternating emf is induced in the coil. [3]

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(b) (i) The induced emf varies in magnitude sinusoidally with a peak value of ±0.707 V. Calculate the rms value of the induced emf. [1]

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(ii) State the value of the rate of change of flux through each turn of the coil when the peak value of 0.707 V is obtained and explain how you obtained your answer. [3]

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Examiner only

(c) One end of the coil is connected with the other so that there is an induced current. Explain why the magnet's motion is now damped. [3]

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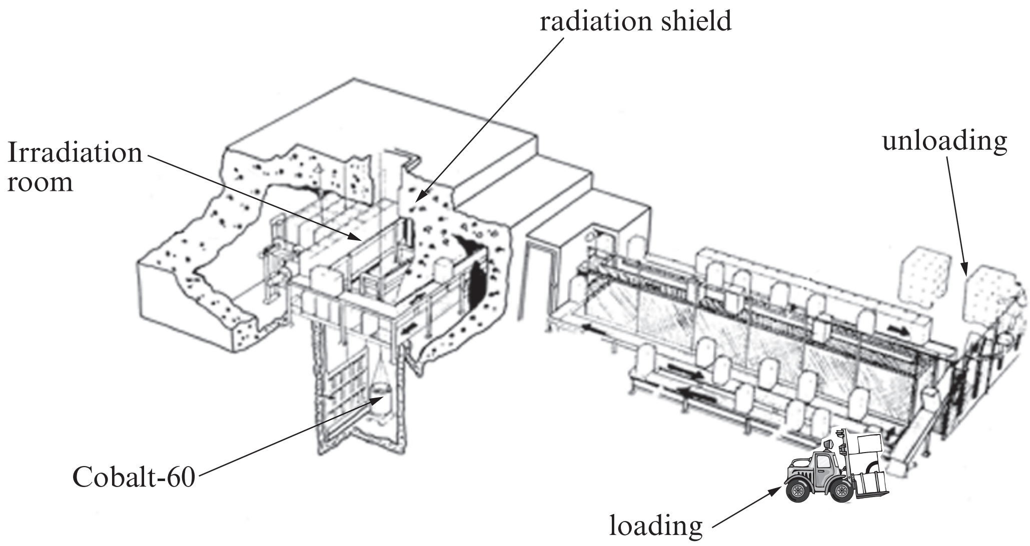
4. Radioactive cobalt-60 ($^{60}_{27}Co$) is used to irradiate and sterilise surgical equipment. Many instruments can be irradiated simultaneously as shown.



(a) Explain briefly which type of radiation (α, β, or γ) would be most appropriate to irradiate metallic surgical instruments in this way. [2]

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(b) The half life of cobalt-60 is 5.3 years.

(i) Calculate the decay constant of cobalt-60. [2]

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(ii) Calculate the activity of 1 mg of cobalt-60. [3]

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(iii) Calculate the time taken (in years) for the activity of a cobalt-60 source to drop from 4.16×10^{10} Bq to 1.04×10^{10} Bq. [3]

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Examiner only

5. Americium-241($^{241}_{95}$Am) is an artificially made radioactive isotope and is commonly used in smoke detectors. It decays through emission of an α particle to neptunium (Np).

(a) Complete the following reaction equation by entering the appropriate numbers on the dotted lines. [2]

$$^{241}_{95}\text{Am} \longrightarrow \, ^{\cdots\cdots}_{\cdots\cdots}\text{Np} \quad + \quad ^{\cdots\cdots}_{\cdots\cdots}\alpha$$

(b) Use the following data to calculate the energy released in the above reaction. [3]

mass of americium 241 nucleus = 241.00471 u mass of α particle = 4.00151 u,
mass of neptunium nucleus = 236.99712 u 1u = 931 MeV

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(c) (i) Calculate the binding energy per nucleon of americium-241. [4]

mass of proton = 1.00728 u, mass of americium nucleus = 241.00471 u,
mass of neutron = 1.00866 u, 1u = 931 MeV

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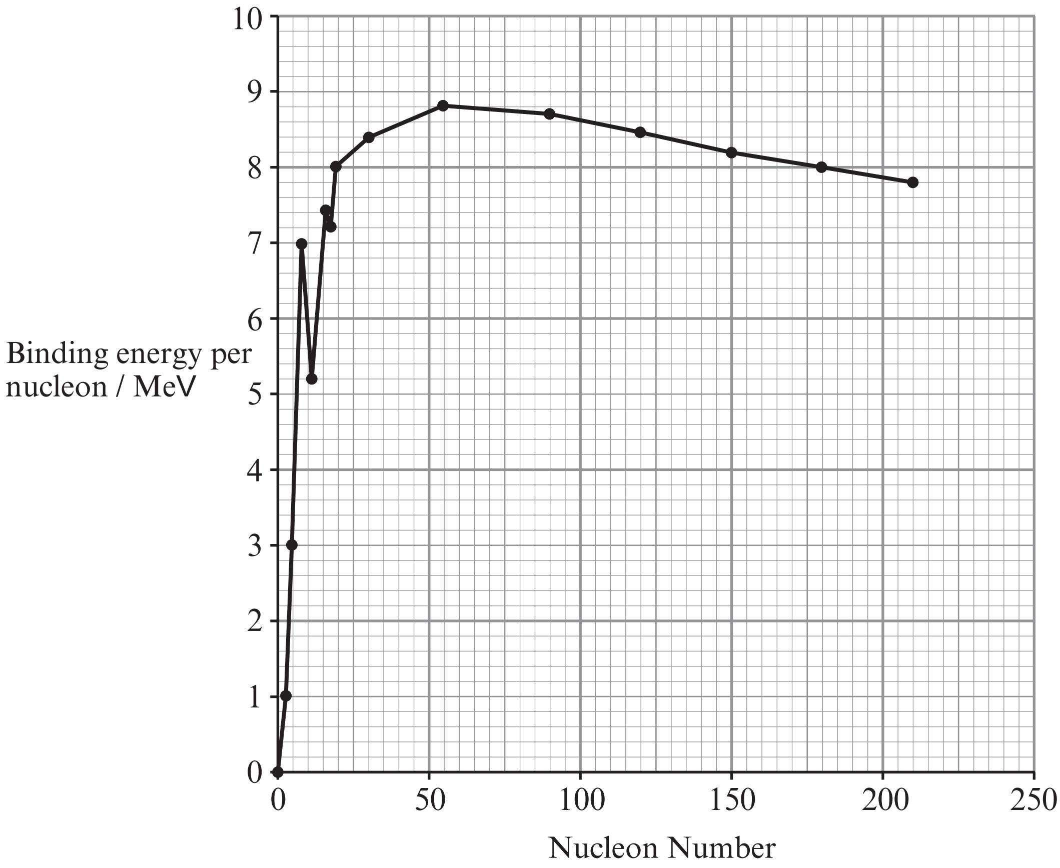
Examiner only

(ii) Plot your answer from *(c)*(i) on the graph below. [1]



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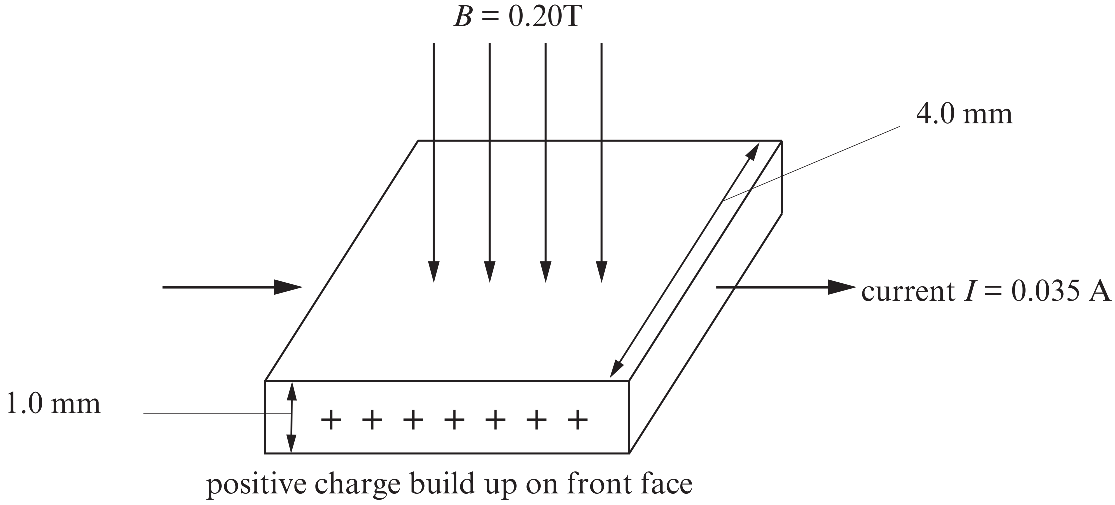
Examiner only

6. The number n of free electrons per unit volume in a silicon chip can be found by measuring the Hall voltage across it when placed in a uniform magnetic field as shown.



(a) Insert a voltmeter on the above diagram to show how you would measure the Hall voltage. [1]

(b) Explain why a positive charge builds up on the front face. [3]

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(c) There is a uniform electric field between the front and the back faces and the Hall voltage is 8.5 mV. Calculate the value of this electric field. [2]

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Examiner only

(d) Calculate n, by equating the magnetic and electrical force on an electron in the Hall probe and using the relationship $I = nAve$. [4]

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Examiner only

SECTION B

The questions refer to the Case Study.
Direct quotes from the original passage will not be awarded marks.

7. *(a)* The distance between the Earth and the Moon is 400 000 km. Calculate the time taken for laser light to travel from Texas to the Moon and back (paragraph 5). [2]

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(b) Explain why a pit depth of a quarter wavelength in a CD 'maximises the interference' (paragraph 11). [2]

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(c) Paragraph 12 states that the 7 beams, after passing through the diffraction grating, are evenly spaced. This suggests that the angles between the diffracted beams are equal. By calculating the angles of the beams to the normal, check whether or not this is true. The DVD laser has a wavelength of 640 nm and the diffraction grating has 815 lines per centimetre. [4]

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Examiner only

(d) A sodium atom has a mass of 23 u. Use equations relating to kinetic theory to check that a sodium atom's rms velocity is 570 m s^{-1} when the temperature is 300 K (paragraph 15). [3]

(e) Explain, in your own words, why tuning the laser light 0.97 GHz below the sodium line will result in sodium atoms travelling at 570 m s^{-1} being slowed down rather than accelerated (paragraph 16). [3]

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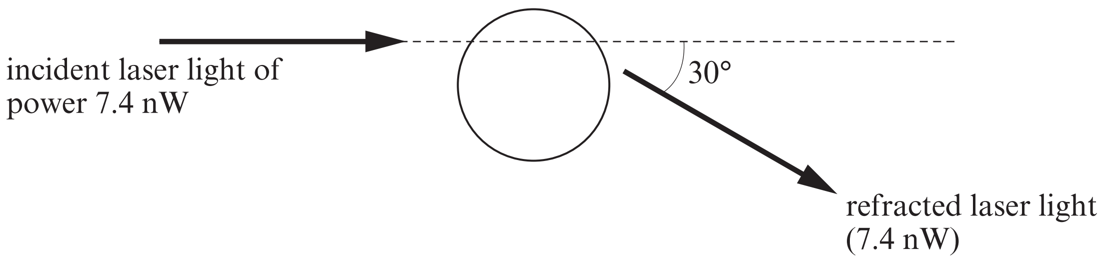
Examiner only

(f) Calculate the net vertical force acting on the spherical particle below due to the change in momentum of the incident light (paragraphs 21&22). [4]
The wavelength of the laser light is 520 nm.



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(g) Discuss some advantages and disadvantages of inertial confinement fusion (para 24).[2]

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Examiner only

SECTION C: OPTIONAL TOPICS

Option A: **Further Electromagnetism and Alternating Currents** ☐

Option B: **Revolutions in Physics - Electromagnetism and Space-Time** ☐

Option C: **Materials** ☐

Option D: **Biological Measurement and Medical Imaging** ☐

Option E: **Energy Matters** ☐

Answer the question on **one topic only.**

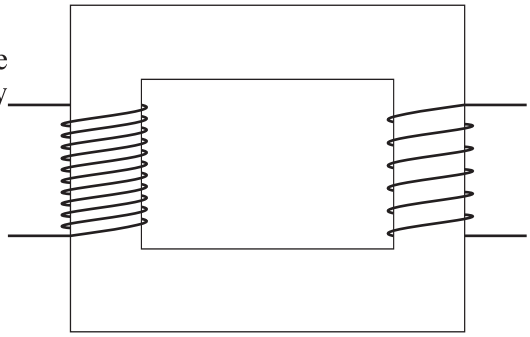
Place a tick (✓) in one of the boxes above, to show which topic you are answering.

You are advised to spend about 20 minutes on this section.

Examiner only

Option A: Further Electromagnetism and Alternating Currents

C8. *(a)* Explain two ways in which the design of the core of a transformer can reduce its energy dissipation. [4]



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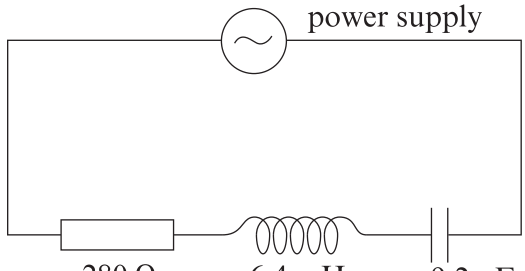
Examiner only

(b) A series LCR circuit is constructed as shown.



(i) Use a phasor diagram to show that the impedance of an LCR circuit is given by

$$Z = \sqrt{\left(\omega L - \frac{1}{\omega C}\right)^2 + R^2}$$

[3]

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(ii) Show that the resonance frequency of the LCR circuit is 20.7 kHz. [2]

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Examiner only

(iii) Explain why the rms current at resonance is approximately 40 mA. [2]

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(iv) Calculate the Q factor of the circuit. [2]

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(v) Calculate the rms current when the frequency is half the resonance frequency (10.35 kHz). [4]

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(vi) The current has exactly the same value as in (v) when the frequency is **twice** the resonance frequency. Explain briefly why this is so. This can be done without a calculator. [3]

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Examiner only

Option B: Revolutions in Physics - Electromagnetism and Space-Time

C9. *(a)* By 1820 there was considerable evidence that light was a *transverse wave.*

(i) Write two or three sentences about the contributions of

(I) Malus, [2]

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(II) Fresnel. [2]

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(ii) At that time, light waves were believed to propagate as mechanical waves through a material medium. Why was the *transverse* nature of the waves problematic? [2]

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Examiner only

(b) Maxwell used his *vortex ether* to predict the existence of *electromagnetic waves.*

(i) How were magnetic fields and electric fields represented in the *vortex ether*? [2]

(ii) What two properties of the material of the vortex ether determined the speed at which the waves propagated? [1]

(iii) How did Maxwell infer from experimental measurements that 'light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena'? [2]

(iv) Describe an electromagnetic wave in terms of *fields.* [2]

(c) (i) Maxwell believed his *Equations* applied only in the frame of reference of the ether. Discuss whether this view is consistent with the *Principle of Relativity.* [2]

Examiner only

(ii) The *time dilation* equation of *Special Relativity* has been tested using particles called *muons* travelling downwards through the atmosphere at very high speeds.

In one experiment muons of speed 0.9952 c travelled to sea level through a measured distance of 1907 m.

(I) Calculate the time taken for this descent, as would be read by clocks in the Earth's frame of reference. [1]

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(II) Use the *time dilation equation* to predict the time for the descent that would be recorded by a clock travelling with the muons. [2]

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(III) A batch of muons can be regarded as its *own* clock. Muons are unstable, decaying with a half-life of 1.52 μs, so we can use their decay to obtain the proper time (from the muon point of view). The proper time, t, for the number of muons to decrease from N_0 to N is given by

$$t = \frac{1}{\ln 2}\left[\ln \frac{N_0}{N}\right] \times 1.52\ \mu\text{s}$$

In one experiment, for every 563 muons detected at a height of 1907 m, 408 were detected at sea level.

Calculate t for the descent from these experimental results and comment on whether this gives support for this time dilation formula. [2]

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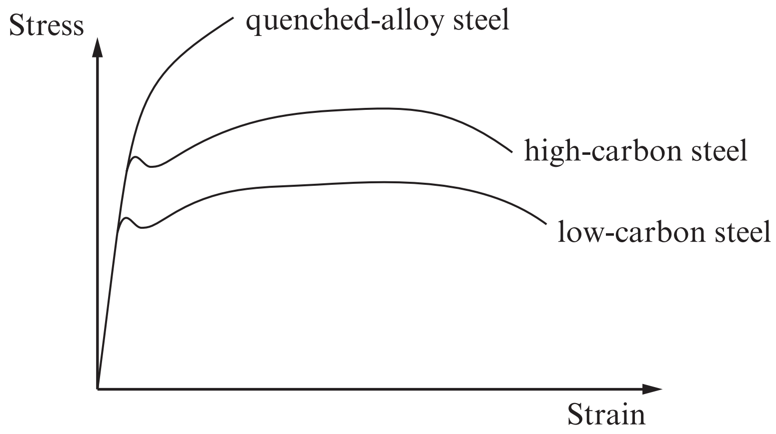
Examiner only

Option C: Materials.

C10. A. Stress - Strain curves for several kinds of steel are shown.



(a) State, giving reasons, which steel

(i) is the most ductile; [1]

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(ii) has the highest breaking stress. [1]

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(b) What can be said about their Young moduli? [1]

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Examiner only

(c) Compare the physical properties of high-carbon steel with low-carbon steel and explain these properties in terms of molecular structure. [4]

(d) (i) Long steel wires are used for towing oil platforms out at sea. If a wire were to break, about 25% of the stored elastic energy would be transformed to kinetic energy. Show that the speed, v, of the wire when it breaks can be estimated from

$$v = \frac{1}{2}\sqrt{\frac{\sigma\varepsilon}{\rho}}$$

where ρ is the density of the steel and σ and ε have their usual meanings. [4]

Examiner only

(ii) Estimate the speed of a quenched-alloy steel wire which breaks given that its breaking stress is 700 MPa and the corresponding strain is 0.2%. Assume $\rho = 8000\ \text{kg m}^{-3}$. [2]

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(iii) Using the graphs on page 22 as guides, explain how you would expect the speed of a breaking wire made of low-carbon steel of the same dimensions (i.e. length and diameter) to compare with your answer to *(d)*(ii). Assume the densities are equal. [2]

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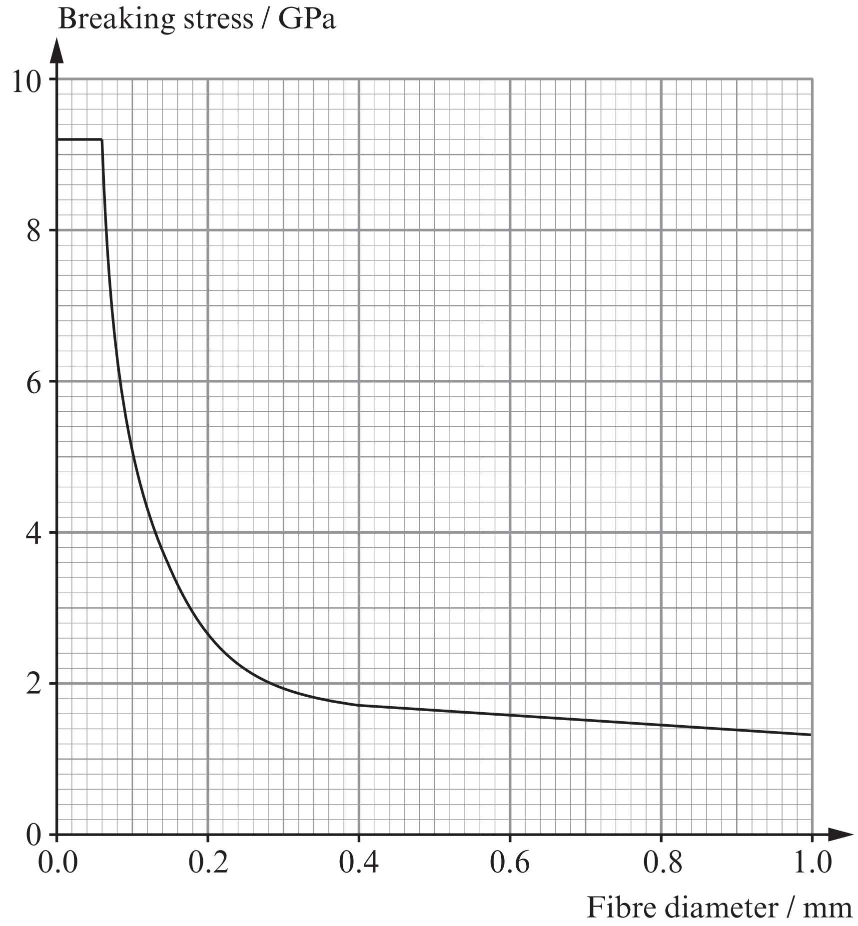
Examiner only

B. Glass is a brittle material. The graph shows how the tensile breaking stress of glass, in the form of thin fibres and rods, varies with the diameter of the fibre.



(a) Use the graph to estimate the greatest **mass** which can be hung from a glass fibre of diameter 0.20 mm. [2]

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(b) Explain why very thin fibres (or 'whiskers') have a greater breaking stress than thicker ones and suggest why there is a maximum value. [2]

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(c) 'Fibre-glass' is a widely used composite material. State what it consists of. [1]

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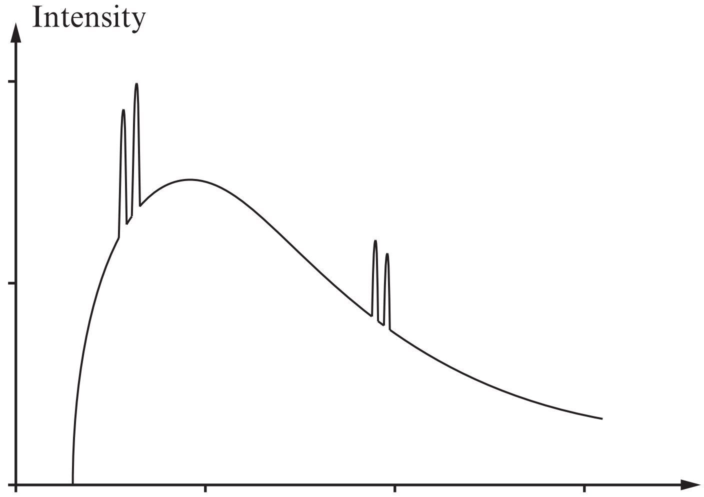
Examiner only

Option D: Biological Measurement and Medical Imaging

C11. *(a)* The diagram to the right is a typical X-ray emission spectrum for an X-ray tube with a tungsten target



(i) Draw on the graph another curve that would be typical for the tube when operated at a lower potential difference. [2]

(ii) What difference(s) would there be to the graph if the tungsten target were replaced by another metal? [1]

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(iii) The X-ray tube has a working potential difference of 75 000V. Calculate the minimum wavelength of an X-ray photon emitted from the tube. [2]

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(iv) If the anode current is 0.125 A and the X-ray tube has an efficiency of 0.5%, calculate the rate of production of heat at the anode. [2]

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Examiner only

(b) Describe how X-rays are used in CT (computerised axial tomography) scanning. State how a CT scan differs from a conventional X-ray. [3]

(c) MRI (magnetic resonance imaging) can also be used in diagnostic medicine. Both MRI and CT scans use electromagnetic radiation. State the region of the electromagnetic spectrum used in MRI and explain its effect on hydrogen nuclei. [3]

(d) An ultrasound probe is used to study the flow of blood from the heart.

(i) Explain how a piezoelectric transducer can be used to produce ultrasound. [1]

(ii) The wavelength of ultrasound used is 0.50 mm and it travels through blood at $1500\,\mathrm{m\,s^{-1}}$. If the wavelength shift is 0.60 μm, calculate the speed of the flow of blood. [2]

QUESTION CONTINUES ON PAGE 28

Examiner only

(e) (i) Describe the effect on living matter when it is exposed to ionising radiation. [2]

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(ii) Explain what is meant by absorbed dose, and dose equivalent. [2]

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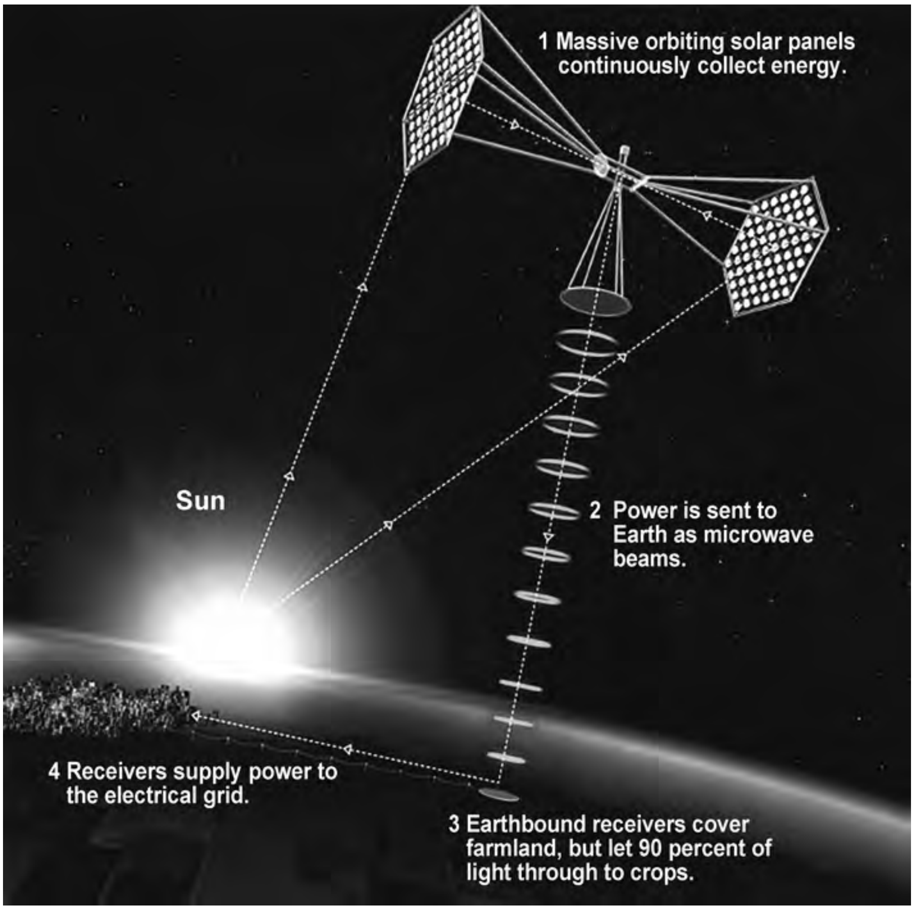
Examiner only

Option E: Energy Matters

C12. In 1968 an alternative energy source using Space Based Solar Panels (SBSP) was proposed by Peter Glaser. The SBSP system then beams solar energy to the Earth in the form of microwave radiation which is picked up by antennae and converted to electrical energy.



(a) (i) The solar constant is 1.37 kWm^{-2}. Calculate the total solar power incident on 7.8 km^2 of solar panels in orbit around the Earth. [2]

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Examiner only

(ii) Use the following data to confirm that the solar constant is 1.37 kWm^{-2}.
Sun's radius = 6.96×10^8 m, Sun's surface temperature = 5778 K,
Earth's orbital radius = 1.496×10^{11} m. [4]

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(b) Each kWh of electricity is sold for £0.20 and the overall efficiency of the SBSP system is 40%. Calculate the money that the solar panels can make in one year. [3]

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(c) The 7.8 km^2 of solar panels is made of a material 0.26 mm thick and of density 2 440 kg m^{-3}. Calculate the total mass of the solar panels. [3]

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Examiner only

(d) The payload of the space shuttle is approximately 25 000 kg and each round trip for the space shuttle costs around £350 000 000. Calculate the total cost of using the space shuttle to place the solar panels in orbit. [2]

(e) The SBSP system uses **no** heat engine to produce electricity unlike nearly all other methods of high power electricity production. Explain why this is a great advantage.

[The efficiency of an ideal heat engine is $1-\frac{T_1}{T_2}$]. [2]

(f) Discuss briefly whether or not the SBSP system seems feasible and discuss its possible advantages over ground based solar panels. [4]

END OF QUESTION PAPER

Examiner only

GCE A level

1325/01-A

PHYSICS

ASSESSMENT UNIT PH5

A.M. MONDAY, 27 June 2011

CASE STUDY FOR USE WITH SECTION B

Examination copy
To be given out at the start of the examination.
The pre-release copy must not be used.

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Paragraph

Lasers and their Applications

With over a billion lasers manufactured per year these elegant devices have proved their worth
since the first ruby laser started ‘lasing’ in 1960. At least seven Nobel prizes are attributable to the
theory or uses of lasers but, still, their applications seem to increase daily. Some uses of lasers are
slightly inelegant in that they just use their high power to vaporise, fuse, melt, blind or destroy 1
but many applications are more subtle - relying on their highly directional nature, their ability
to produce ultra short pulses or their monochromatic or coherent nature. Here are some wide-
ranging examples encompassing these invaluable properties of lasers.

Medical Uses of Lasers

The highly collimated beam of a laser can be further focused to a microscopic dot of extremely
high energy density. This makes it useful as a cutting and cauterizing instrument. A focused laser
can act as an extremely sharp scalpel for delicate surgery, cauterizing as it cuts. (“Cauterizing”
refers to long-standing medical practices of using a hot instrument or a high frequency electrical 2
probe to singe the tissue around an incision, sealing off tiny blood vessels to stop bleeding.) The
cauterizing action is particularly important for surgical procedures in blood-rich tissue such as the
liver.

Lasers have been used to make incisions half a micrometre wide, compared with about 80 μm for 3
the diameter of a human hair.

Surveying and Ranging

Helium-neon and semiconductor lasers have become standard parts of the field surveyor’s
equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and the time 4
of reflection is measured to get the distance.

Some such surveying is long distance! The Apollo 11 and Apollo 14 astronauts put corner
reflectors on the surface of the Moon for determination of the Earth-Moon distance. A powerful
laser pulse from the MacDonald Observatory in Texas had spread to about a 3 km radius by the 5
time it got to the Moon, but the reflection was strong enough to be detected. We now know the
range from the Moon to Texas within about 15 cm, a nine significant digit measurement. A pulsed
ruby laser was used for this measurement.

Laser Sights and Firearms

The laser has in most firearms applications been used as a tool to enhance the targeting of
other weapon systems. For example, a *laser sight* is a small, usually visible-light laser placed
on a handgun or a rifle and aligned to emit a beam parallel to the barrel. Since a laser beam by 6
definition has low divergence, the laser light appears as a small spot even at long distances; the
user places the spot on the desired target and the barrel of the gun is aligned (but does not allow
for bullet drop, wind or the target moving while the bullet travels).

Another limitation of a laser sight is that light leaving a laser is slightly diverging due to 7
diffraction of the beam as it exits the aperture. The beam divergence is given by equation 1.

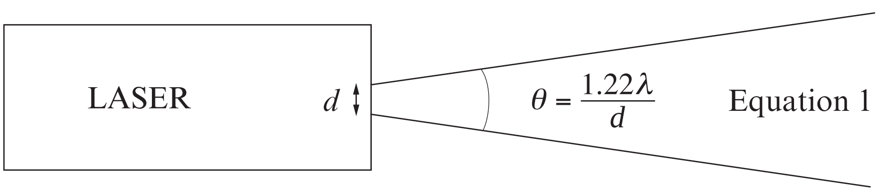


Diagram 1

Typical divergence of a laser beam is around 1 milliradian but this is far less accurate than that obtainable by a good marksman with a large telescopic lens.

Lasers in Communication
Fibre optic cables are a major mode of communication partly because multiple signals can be sent
with high quality and low loss by light propagating along the fibres. The light sources are lasers
or LEDs but lasers have significant advantages because they are more nearly monochromatic and 8
this allows the pulse shape to be maintained better over long distances. If a better pulse shape can
be maintained, then the communication can be sent at higher rates without overlap of the pulses.

Telephone fibre drivers may be solid state lasers the size of a grain of sand and consume a power
of only half a milliwatt. Yet they can send 50 million pulses per second into an attached telephone 9
fibre and encode over 600 simultaneous telephone conversations.

CD-ROMs and DVD-ROMs
Today, most CD-ROM and DVD-ROM disc drives use a single highly concentrated laser beam
to read the digital signal that is encoded onto tracks of an optical disc (CD or DVD). The single
laser beam is directed at a single track of information, which forms a continuous spiral on the disc 10
that begins at the disc centre and spirals outward towards the outer edge. Variations (in data pit
length) on the disc surface cause variations in the reflected laser beam, which are detected by an
optical sensor.

The disc drive rotates the disc and the tracks run under the laser beam. The drive system has an
optical motor control that allows the laser to exactly focus and follow the spiral path of the pits
and lands, to stay focused on the "track". The laser is reflected at different intensities for different
amounts of time (the length of a pit or land) as it passes over the spiral track. A zero actually
corresponds to high reflected intensity off a flat pit or a flat land section. A one corresponds to 11
low reflected intensity at the edge of a pit and land where destructive interference occurs between
the two reflections. In order to maximise the interference between light reflected from 'land' and
light reflected from a 'pit', the pit depth is chosen as a quarter of a wavelength. The reflected laser
light is then directed to a light sensitive detector that turns the light variations into a stream of
serial data, representing the pattern of pits and lands on the disc. This data stream is amplified
and sent to a microprocessor for interpretation. The laser, lenses to focus the beam, a mirror to
point the reflected beam and the light sensitive detector, combined are known as an "optical pick-up".

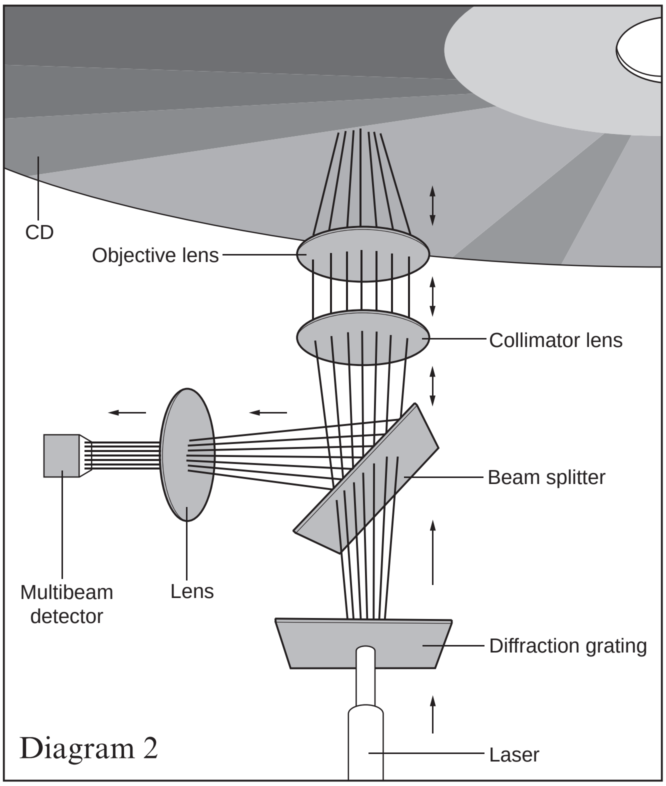


Diagram 2

The Multiple Beam approach to
illuminating and detecting multiple tracks
(see diagram at left) uses a diffracted laser
beam in conjuction with a multiple beam
detector array. The laser light from a
conventional laser diode is sent through a
diffraction grating, which splits the beam
into seven discrete beams, spaced evenly to 12
illuminate seven tracks. The seven beams
pass through a beam splitting (two-way)
mirror to the objective lens and onto the
surface of the disc. Focus and tracking are
accomplished with conventional detection
elements on the central beam. The three
beams on either side of the centre beam are
readable by a multibeam detector array as
long as the centre beam is on track and in
focus.

Turn over.

The reflected beams return from the disc via the same path and are directed to the multiple beam detector array by the reflective surface of the beam splitter. The detector contains seven discrete
detectors spaced to align with seven reflected tracks. Note that a standard single beam pick-up is 13
very similar. In a single beam pick-up, the diffraction grating would be removed and the detector would have a single data detection point.

Laser Cooling

Starting in about 1985, the use of lasers to achieve extremely low temperatures has advanced
to the point that temperatures of 10^{-9} K have been reached. If an atom is travelling toward a 14
laser beam and absorbs a photon from the laser, it will be slowed by the fact that the photon has momentum

$$p = \frac{E}{c} = \frac{h}{\lambda} \qquad \text{Equation 2}$$

If we take a sodium atom as an example, and assume that a number of sodium atoms are freely moving in a vacuum chamber at 300 K, the rms velocity of a sodium atom from kinetic theory would be about 570 ms^{-1}. Then if a laser is tuned just below a sodium emission line (about 2.1 eV), a sodium atom travelling toward the laser and absorbing a laser photon would have its
momentum reduced by the amount of the momentum of the photon. It would take a large number 15
of such absorptions to cool the sodium atoms to near 0 K since one absorption would slow a sodium atom by only about 3 cm/s out of a speed of 570 ms^{-1}. A straight projection requires almost 20,000 photons to reduce the sodium atom momentum to zero. The change in speed from the absorption of one photon can be calculated from

$$\Delta v = \frac{p_{\text{photon}}}{m_{\text{sodium}}} \qquad \text{Equation 3}$$

That seems like a lot of photons, but a laser can induce in the order of 10^7 absorptions per second so that an atom could be stopped in a matter of milliseconds.

A conceptual problem is that an absorption can also speed up an atom if it catches it from behind, so it is necessary to have more absorptions from head-on photons if your goal is to slow down the atoms. This is accomplished in practice by tuning the laser slightly below the resonance absorption of a stationary sodium atom. From the atom's perspective, the head on photon is seen as Doppler shifted upward toward its resonant frequency and it is therefore more strongly absorbed than a photon travelling in the opposite direction which is Doppler shifted away from
the resonance. In the case of our room temperature sodium atom above, the incoming photon 16
would be Doppler shifted up 0.97 GHz, so to get the head on photon to match the resonance frequency would require that the laser be tuned below the resonant peak by that amount. This method of cooling sodium atoms was proposed by Theodore Hansch and Arthur Schawlow at Stanford University in 1975 and achieved by Chu at AT&T Bell Labs in 1985. Sodium atoms were cooled from a thermal beam at 500 K to about 240 μK. The experimental technique involved directing laser beams from opposite directions upon the sample, polarised at 90° with respect to each other. Six lasers could then provide a pair of beams along each coordinate axis.

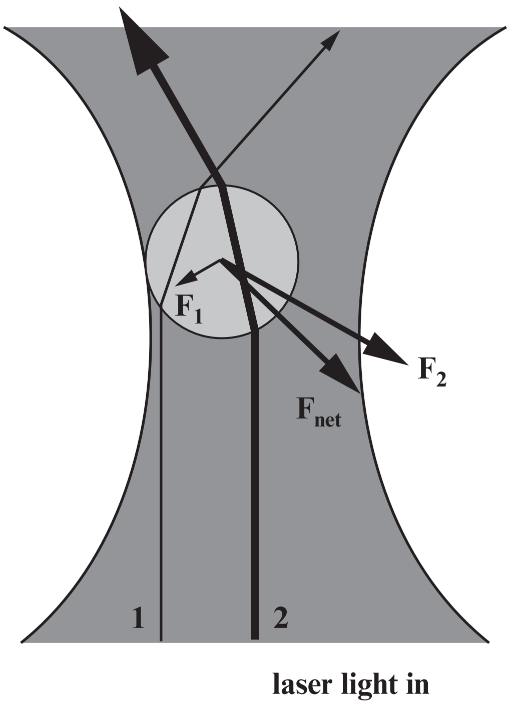
Continuing to cool the sodium atoms by this method requires the tuning of the laser upward in frequency toward the atomic resonance frequency because the Doppler shift will be smaller. This
places a practical limit on how much cooling can be achieved, because the differential cooling rate 17
is reduced and at a certain point the cooling mechanism is foiled by heating due to the random absorption and re-emission of photons.

Optical Tweezers
Optical tweezers are capable of manipulating nanometre and micrometre-sized high refractive
index particles by exerting extremely small forces via a focused laser beam. The beam is typically
focused by sending it through a microscope. The narrowest point of the focused beam, known
as the beam waist, contains a very high light intensity gradient. It turns out that particles are
attracted along the gradient to the region of strongest light intensity, which is the centre of the
beam. This is called an optical trap because it holds the particle in the centre of the beam. This 18
beam can then be moved so that the trap moves the particle and acts like an optical tweezers. The
force applied to the particle is actually linear with respect to its displacement from the centre of
the trap as long as the displacement is small. In this way, an optical trap can be compared with a
simple spring which follows Hooke's Law.

Optical traps are very sensitive instruments and are capable of the manipulation and detection of
sub-nanometre displacements for sub-micrometre particles. For this reason, they are often used to 19
manipulate DNA. The proteins and enzymes that interact with DNA are also studied in this way.

Here's an explanation of how the optical tweezers work based on refractive index (this theory 20
only applies to larger particles where we can use ray theory).

In cases where the diameter of a trapped particle is significantly greater than the wavelength of
light, the trapping phenomenon can be explained using ray optics. As shown in diagram 3, an
individual ray of light emitted from the laser will be refracted as it enters and exits the particle.
As a result, the ray will exit in a direction different from which it originated. Since light has a 21
momentum associated with it, this change in direction indicates that its momentum has changed.
Due to Newton's third law, there should be an equal and opposite momentum change on the
particle.



Ray optics explanation. When the particle is displaced from the beam centre, the larger momentum change of the more intense rays cause a net force to be applied back toward the centre of the trap

Diagram 3

The particle is displaced from the centre of the beam, as in diagram 3, and we consider light rays
on both sides of our spherical particle (see rays 1 and 2). Ray 1 veers to the right which means that
it exerts a force (F_1) to the left on the particle (due to Newton's third law). Ray 2 veers to the left 22
which means that it exerts a force (F_2) to the right on the particle (again, due to Newton's third
law). However, force F_2 is greater than F_1 because of the higher intensity of the beam towards the
centre of the beam waist; hence the net force is towards the centre of the beam.

Now all we have to do to move our tiny particle is to move the laser beam and the particle follows 23
in the 'optical trap'. Thus our focused laser beam is acting like optical tweezers.

Nuclear fusion

Some of the world's most powerful and complex arrangements of multiple lasers and optical amplifiers are used to produce extremely high intensity pulses of light of extremely short duration. These pulses are arranged such that they impact pellets of deuterium-tritium simultaneously from all directions, hoping that the squeezing effect of the impacts will induce atomic fusion in the pellets. This technique, known as "inertial confinement fusion", so far has not been able to
achieve "breakeven", that is, so far the fusion reaction generates less power than is used to power 24
the lasers. However, research continues and the recent introduction of a technique called 'fast ignition' along with improvements in laser efficiency means that inertial confinement fusion might soon be profitable. When you consider that 10 mg of deuterium-tritium mixture contains the same amount of energy as a barrel of oil (6 GJ) and that the sea contains around 10^{16} kilograms of both deuterium and lithium (from which tritium is made), laser nuclear fusion might well be the energy source of the future.