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ADVANCED Higher PHYSICS

BrightRED Study Guide

CfE ADVANCED Higher

PHYSICS

REVISED AND UP-TO-DATE WITH SQA CHANGES

NEW EDITION

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INTRODUCTION

INTRODUCING CfE ADVANCED HIGHER PHYSICS

AIMS AND STRUCTURE OF THE BOOK

This book covers the syllabus for the CfE Advanced Higher Physics course and should complement the coursework done in class. The book will help students succeed in the final exam by presenting the subject arrangements in an attractive and concise format.

Each sub-topic in the Specifications is presented in a double-page spread making the book ideal both for revision and self-study.

Each double-page spread covers the physics content in a logical and accessible way, and makes full use of graphics and colour illustrations to support your learning. Spreads contain the mandatory course physics information and **Worked examples** demonstrating how key physics relationships are used to solve numerical problems. There are also **Exercises** for you to try with answers available on the **Bright Red Digital Zone**. Examinable derivations are included in the text where appropriate.

On each spread you will find **Don't Forget** tips which highlight key points or common mistakes. **Internet Links** suggest sites for additional information, useful videos, interactive simulations or practical applications of the topic in question. Each double-page spread finishes with a **Things to do and think about** section designed to extend and expand your knowledge and interest in physics and its applications.

The treatment of uncertainties at Advanced Higher level is covered in three double-page spreads. This treatment can apply to all units in the course. There is also advice on the production of the **project report** and there are appendices with guidance on open-ended questions and on understanding accuracy and precision in physics.

COURSE STRUCTURE AND ASSESSMENT

The AH Physics course comprises these topics:

- Rotational Motion and Astrophysics
- Quanta and Waves
- Electromagnetism
- Investigating Physics (including the production of a project report)

The external assessment consists of two parts.

- A written examination paper of 3 hours duration with an allocation of 155 marks, which will be scaled to 120. In addition to the questions based around the mandatory coursework there will be two open-ended questions and at least one question using given knowledge which is not in the syllabus. You will be provided with a Data Sheet containing relevant data, and a Relationships Sheet containing formulae and a periodic table.
- A project report on the investigation will be marked externally by an SQA marker with a total allocation of 30 marks for the report. This mark is scaled to 40.

The total for the two external assessments is 160 marks. The course award is graded A, B, C or D depending on the overall mark out of 160.

RELATIONSHIPS REQUIRED FOR AH PHYSICS

$v = \frac{ds}{dt}$

$a = \frac{dv}{dt} = \frac{d^2s}{dt^2}$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$\omega = \frac{d\theta}{dt}$

$\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$

$\omega = \omega_0 + \alpha t$

$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega^2 = \omega_0^2 + 2\alpha\theta$

$s = r\theta$

$v = r\omega$

$a_t = r\alpha$

$\omega = \frac{2\pi}{T}$

$\omega = 2\pi f$

$a_r = \frac{v^2}{r} = r\omega^2$

$F = \frac{mv^2}{r} = mr\omega^2$

$I = \Sigma mr^2$

$\tau = Fr$

$\tau = I\alpha$

$L = mvr = mr^2\omega$

$L = I\omega$

$E_{K\,(rotational)} = \frac{1}{2}I\omega^2$

$E_p = E_{K\,(translational)} + E_{K\,(rotational)}$

$F = G\frac{Mm}{r^2}$

$F = G\frac{Mm}{r^2} = \frac{mv^2}{r} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$

$V = -\frac{GM}{r}$

$E_p = Vm = -\frac{GMm}{r}$

$v_{esc} = \sqrt{\frac{2GM}{r}}$

$b = \frac{L}{4\pi d^2}$

$\frac{P}{A} = \sigma T^4$

$L = 4\pi r^2\sigma T^4$

$r_{Schwarzschild} = \frac{2GM}{c^2}$

$E = hf$

$\lambda = \frac{h}{p}$

$mvr = \frac{nh}{2\pi}$

$\Delta x \Delta p_x \geqslant \frac{h}{4\pi}$

$\Delta E \Delta t \geqslant \frac{h}{4\pi}$

$F = qvB$

$F = -ky$

$a = \frac{d^2y}{dt^2} = -\omega^2 y$, $y = A\cos\omega t$ or $y = A\sin\omega t$

$v = \pm\omega\sqrt{(A^2 - y^2)}$

$E_K = \frac{1}{2}m\omega^2(A^2 - y^2)$

$E_P = \frac{1}{2}m\omega^2 y^2$

$E = kA^2$

$y = A\sin 2\pi\left(ft - \frac{x}{\lambda}\right)$

$\Phi = \frac{2\pi x}{\lambda}$

opd $= n \times gpd$

opd $= m\lambda$
or $\left(m + \frac{1}{2}\right)\lambda$ where $m = 0, 1, 2\ldots$

$\Delta x = \frac{\lambda l}{2d}$

$d = \frac{\lambda}{4n}$

$\Delta x = \frac{\lambda D}{d}$

$n = \tan i_P$

$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$

$E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$V = \frac{Q}{4\pi\varepsilon_0 r}$

$F = QE$

$V = Ed$

$W = QV$

$F = IlB\sin\theta$

$B = \frac{\mu_0 I}{2\pi r}$

$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$

$\tau = RC$

$X_C = \frac{V}{I}$

$X_C = \frac{1}{2\pi fC}$

$\varepsilon = -L\frac{dI}{dt}$

$E = \frac{1}{2}LI^2$

$X_L = \frac{V}{I}$

$X_L = 2\pi fL$

$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$

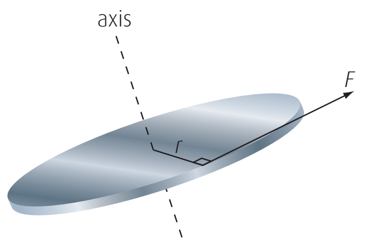
$\Delta W = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$

$\left(\frac{\Delta W^n}{W^n}\right) = n\left(\frac{\Delta W}{W}\right)$

ROTATIONAL MOTION AND ASTROPHYSICS

ROTATIONAL DYNAMICS: TORQUE

TORQUE: AN OVERVIEW

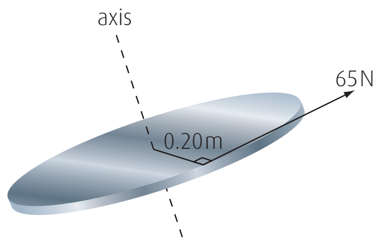


Torque T is the **turning effect** of a **force** on a **rotating object**. The disc can be made to turn about its **axis** by applying a **force** F at a **perpendicular distance** r from the axis of rotation. The turning effect on the disc will be less if distance r is reduced.

torque = applied force × perpendicular distance between direction of force and axis of rotation

$T = F \times r$ The **unit of torque** is **Nm**

Torque is sometimes called the **moment of a force**.



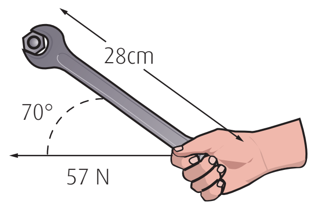
Example

A force of 65 N is applied tangentially to a disc of radius 0·20 m. The disc can rotate about an axis through its centre. Calculate the applied torque.

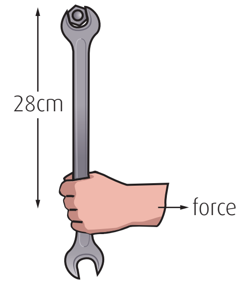
Solution:

$T = F \times r = 65 \times 0{\cdot}2 = 13$ Nm.

EXERCISE



1. A torque of 26 Nm is applied to a nut using a spanner as shown. Calculate the force exerted by the operator.
2. A 57 N force is applied to a spanner at an angle of 70° as shown. The spanner is held 28 cm from the nut. Calculate the torque applied to the nut.



TORQUE AND ANGULAR ACCELERATION

An **unbalanced torque** on an object will produce an **angular acceleration** about an axis of rotation. The **angular acceleration** produced by the **unbalanced torque** depends on the **moment of inertia** of the object.

The relationship linking **torque** T and **angular acceleration** α is

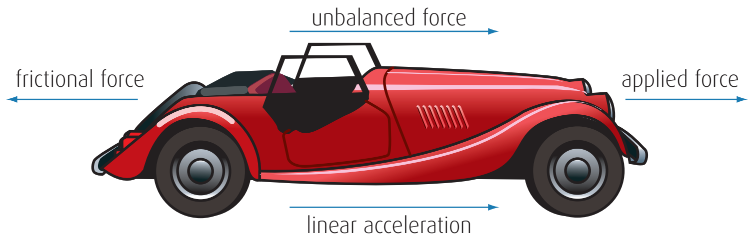
$T = I\alpha$ where I is the moment of inertia of the object about the axis.

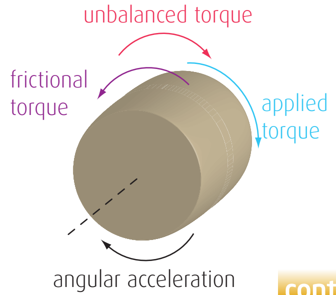
This is the **rotational analogue** to Newton's second law $F = ma$

If a rotating object is subjected to friction, then a **frictional torque** will **oppose** the **angular acceleration**.

unbalanced torque = applied torque − frictional torque

You are already familiar with finding the unbalanced force on an object. Unbalanced torque is found in a similar way.





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DON'T FORGET

$T = I\alpha$ is the rotational motion equivalent of $F = ma$

DON'T FORGET

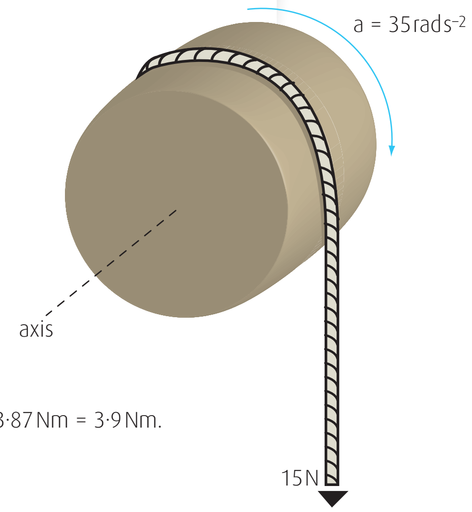
The symbol T in $T = I\alpha$ is the **unbalanced torque**.

Example

A force of 15 N is applied to a string wrapped round the circumference of a disc of radius 0·30 m. The disc has a mass of 0·40 kg and accelerates at 35 rad s^{-2} about the axis.

Calculate

a the torque applied to the disc (by the string)
b the unbalanced torque on the disc
c the frictional torque acting on the disc.

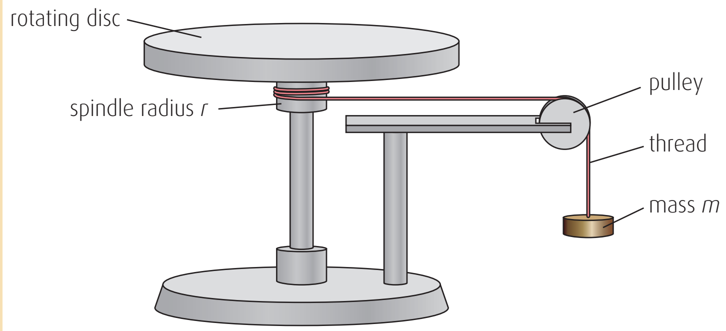


Solution:

a Applied torque = $F \times r = 15 \times 0{\cdot}3 = 4{\cdot}5$ Nm
b Calculate I first.
$I = \frac{1}{2}mr^2 = 0{\cdot}5 \times 0{\cdot}4 \times 0{\cdot}3^2 = 1{\cdot}8 \times 10^{-2}$ kgm^2
Unbalanced torque $T = I\alpha = 1{\cdot}8 \times 10^{-2} \times 35 = 0{\cdot}63$ Nm
c Unbalanced torque = applied torque − frictional torque
Frictional torque = applied torque − unbalanced torque = 4·5 − 0·63 = 3·87 Nm = 3·9 Nm.

Torque-angular acceleration graph

Circular motion can be investigated experimentally using a dedicated rotating low friction turntable. The pulley also has low-friction bearings.



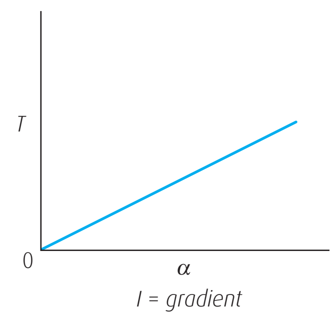
The torque is supplied by the thread wrapped round the spindle. Numerically, it is given by the product of the thread tension and the spindle radius

T = tension × r

Increasing the mass hanging on the thread will increase the tension, so the torque increases.

A rotary motion sensor and computer software can measure the disc's angular velocity and acceleration.

Plotting torque T against angular acceleration α will give a straight line which should pass through the origin if friction is negligible.



The moment of inertia of the rotating disc and spindle can be worked out from the gradient of the straight line.

DON'T FORGET

$T = I\alpha$ so the gradient = I when T is plotted on the y-axis.

ONLINE

Learn more about the apparatus shown here at www.brightredbooks.net

THINGS TO DO AND THINK ABOUT

In the graph above, it is assumed that no frictional torque acts on either the turntable or pulley. If there had been a measurable frictional torque this would have caused a systematic uncertainty if the applied torque T was plotted as the unbalanced torque.

How would the graph above be affected by this systematic uncertainty? Can the frictional torque be estimated from the new graph?

ONLINE TEST

Test your knowledge of torque at www.brightredbooks.net

ROTATIONAL MOTION AND ASTROPHYSICS

GENERAL RELATIVITY: CURVED SPACETIME

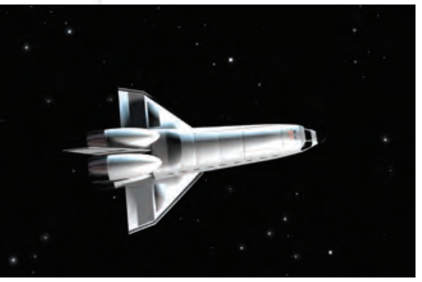
DON'T FORGET

These changes in distance and time are separate from the special relativity changes due to speed.

CURVED SPACETIME: AN OVERVIEW

Classical Newtonian physics treats three-dimensional space and time as separate entities. However, the theory of General Relativity is at odds with this approach.

Between 1907 and 1915 Einstein was trying to incorporate the concept of gravity into his Theory of General Relativity. He proposed that three-dimensional space and one-dimensional time are unified into a four-dimensional entity called **spacetime**.



Consider the following two non-relativistic motions

- a spacecraft in deep space moving at a steady speed
- the International Space Station (ISS) orbiting the Earth at a steady speed.

An astronaut present in either spacecraft will experience weightlessness. The spacecraft in deep space will travel in a straight line at a steady speed well away from any large mass.

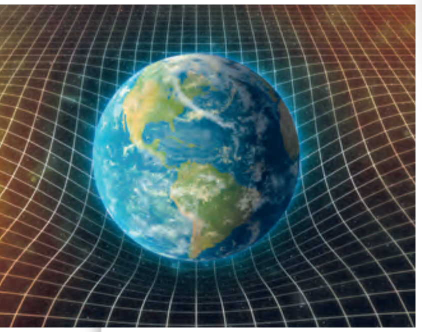
The ISS travels in a curved path at a steady speed near a large mass (the Earth).

Einstein reasoned that four-dimensional spacetime would be affected by the presence of a large mass and concluded that spacetime would be curved near a large mass. The General Theory of Relativity states that both lengths and times will change near large masses and these changes in the spacetime coordinates can be interpreted as non-linear or curving.

Einstein described gravity as the bending or curving of spacetime geometry.

The General Theory of Relativity can show that a satellite will travel in a straight line in curved four-dimensional spacetime.

This is difficult to visualise but the following analogies are useful when thinking about curved spacetime.



RUBBER SHEET ANALOGY

Imagine a large mass placed on a horizontal rubber sheet. The rubber sheet has square grid lines on its surface representing a coordinate system (in two dimensions).

The sag in the middle is caused by the mass placed on the rubber sheet and the square grid lines are now curved near the mass. The grid lines remain unchanged in regions well away from the mass. The sag in the region around a large mass is sometimes called a **gravity well**.

This analogy is one way of trying to visualise how the presence of a mass can bend spacetime coordinates even although the analogy itself is not in four dimensions.

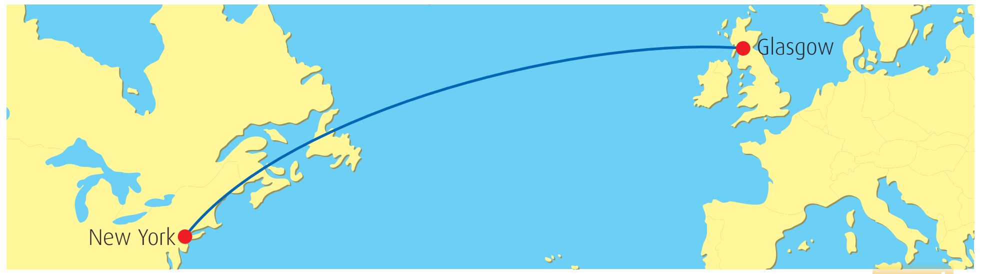
DON'T FORGET

There is no time dimension in this analogy.

TWO-DIMENSIONAL MAP ANALOGY

A map of the Earth's surface is normally drawn on a flat (2D) page. This is not completely accurate, because the Earth is a sphere with three dimensions, so the map is a representation of a 3D region.

Consider a plane journey from Glasgow to New York.



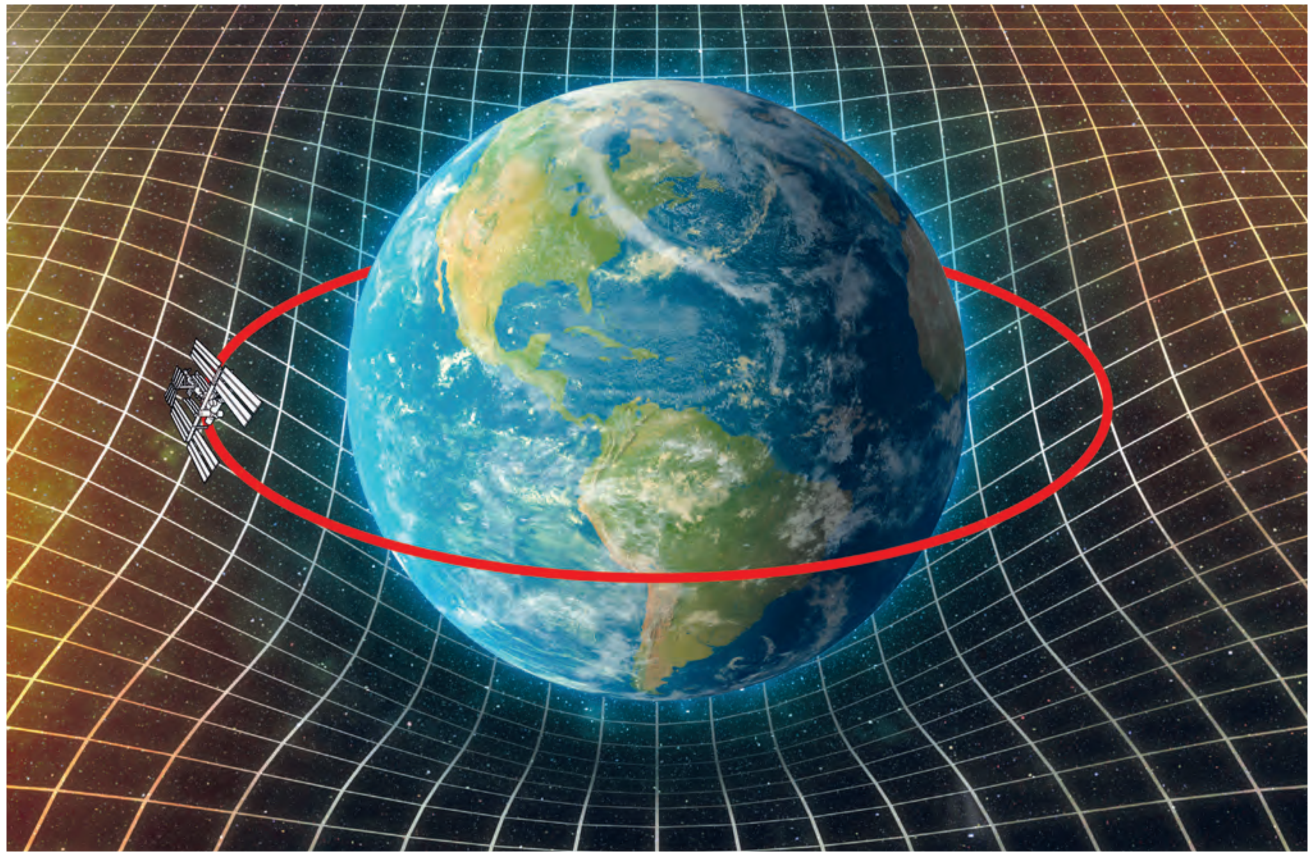
contd

The shortest distance between Glasgow and New York is drawn as a curved line on this 2D map.

The actual surface of the Earth is curved and not a flat 2D surface. This gives rise to the shortest journey between Glasgow and New York appearing as a curved line on the map with the aircraft continually changing direction.

SATELLITE MOTION

Let's go back to the ISS orbiting the Earth in a circular orbit. Einstein's theory of General Relativity suggests that the ISS is in fact moving in the straightest line allowed through the curved spacetime near the Earth.



We 'see' the ISS orbiting in a curved path because we are thinking in 3D not 4D and we are not taking into account that 4D spacetime is curved near the Earth.

In the flight path analogy above, we 'see' a curved path on the map because we are viewing a 3D journey in 2D. The aircraft is moving in the straightest line allowed between Glasgow and New York yet the 2D diagram shows a curved line.

The shortest journey between two points may be a straight line in 4D spacetime but it can appear to be a curved line if pictured in less than four dimensions. The shortest distance between two points in curved spacetime is called a **geodesic**.

ONLINE

Many good videos and animations have been made on curved spacetime. An internet search to find them will reinforce your understanding of this challenging topic.

THINGS TO DO AND THINK ABOUT

Einstein became something of an expert in the mathematics of curved space as he developed the General Theory of Relativity. The rules in curved space are different from those in the plane geometry we learn at school. To illustrate this, draw a triangle on a plastic ball. Measure all the angles with a protractor as best you can. Do they add up to 180°? Can you draw a triangle with three right angles on the surface of the ball?

ONLINE TEST

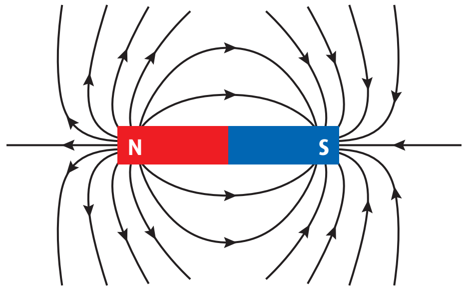
Head to www.brightredbooks.net and test yourself on curved spacetime.

ELECTROMAGNETISM

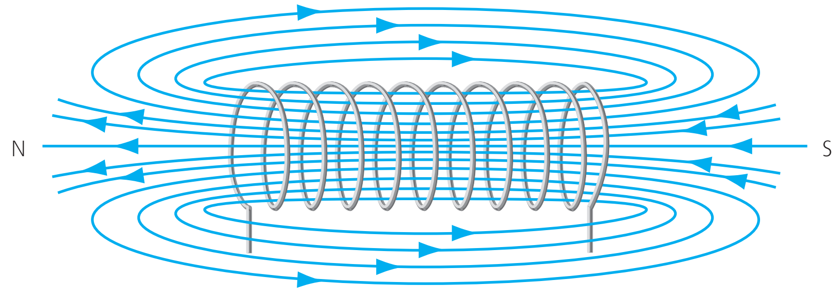
FIELDS: MAGNETIC FIELDS

MAGNETIC FIELDS: OVERVIEW

We are familiar with the concept of a magnetic field from earlier studies of physics, and we will now look in some detail at the **magnetic forces that arise on conductors** and **moving charged particles in magnetic fields**. The magnetic field lines show the direction that a compass needle would be forced to align with and **not** the direction of the force on any charges.



Bar magnet



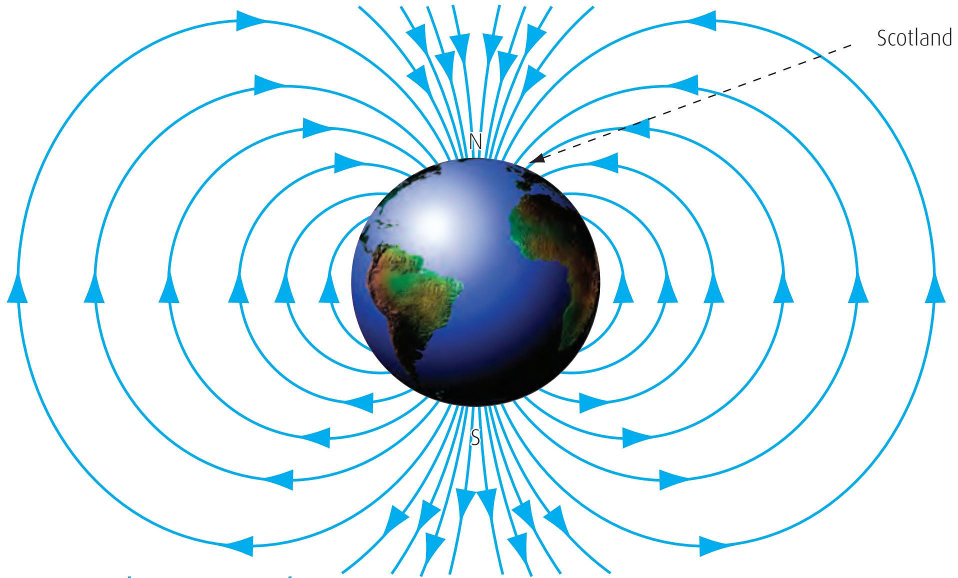
Current carrying coil

DON'T FORGET

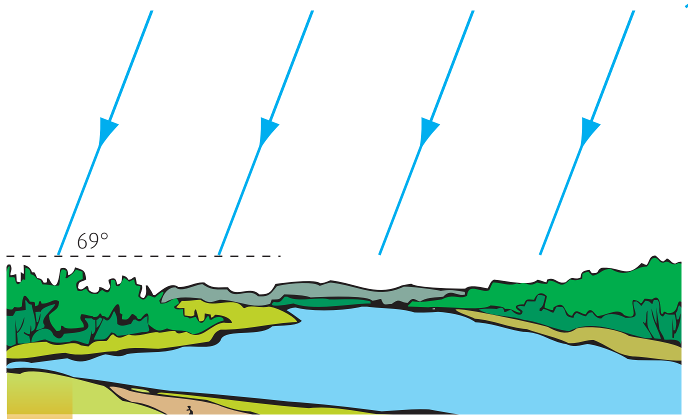
A moving charge will have an electric field around it as well as a magnetic field.

The magnetic field lines travel from **north to south** by convention. When the current in the coil is switched off, the magnetic field disappears, so the **magnetic field** must be caused by the **moving charges** (electrons) in the wire.

The Earth's magnetic field is thought to be caused by electrons moving in its molten iron core by convection currents. The Earth's magnetic field is similar to a giant bar magnet.



Looking east in Scotland



The Earth's magnetic field lines are horizontal at the Equator and vertical at the North Pole. In Scotland, the magnetic field lines are at an angle of approximately 69° to the horizontal. This angle increases with latitude.

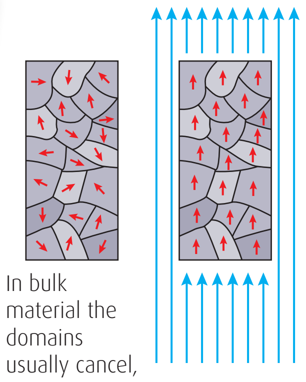
Magnetic induction

The strength of a magnetic field at a point is called the **magnetic induction** and has the symbol *B*. The **unit of magnetic induction** is the **tesla** (*T*). A more precise definition of magnetic induction *B* will follow.

FERROMAGNETISM

Magnetic materials like iron have groups of atoms called **domains** where many of the electrons orbiting the atoms line up with orbits parallel to each other producing a magnetic field. Domains are quite small in size but have a locally intense magnetic field. Normally in a piece of iron the domains are not lined up and the iron is unmagnetised. If the iron is placed in a magnetic field the domains line up with the magnetic field and the iron becomes magnetised.

This effect of materials becoming magnetized by an external magnetic field is called **ferromagnetism**. Iron, cobalt, nickel and some rare earths are ferromagnetic materials.



In bulk material the domains usually cancel, leaving the material unmagnetised

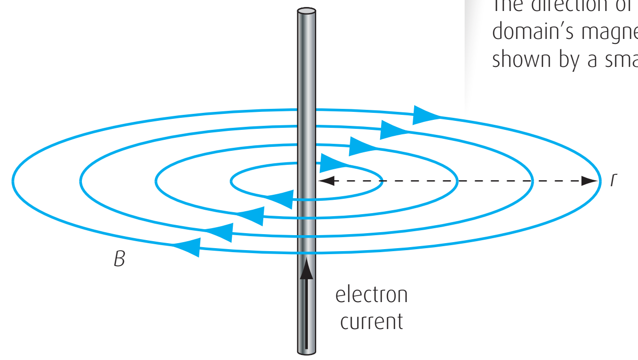
Externally applied magnetic field

The direction of an individual domain's magnetic field is shown by a small red arrow.

MAGNETIC FIELD AROUND A CONDUCTOR

The magnetic field around a long straight current-carrying conductor is a series of concentric circles centred on the conductor.

The **magnetic induction *B*** at a **distance *r*** from the conductor is **directly proportional** to the **current *I*** and **inversely proportional** to the **perpendicular distance *r*** from the conductor.



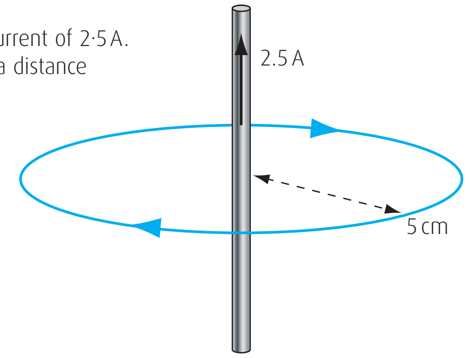
$B \propto \frac{I}{r}$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

The constant of proportion is $\frac{\mu_0}{2\pi}$ where μ_0 is called the **permeability of free space** and has a value $\mathbf{4\pi \times 10^{-7}\,TmA^{-1}}$. Permeability is the magnetic constant of the medium.

Example

A long straight conductor carries a current of 2·5 A. Calculate the magnetic induction at a distance of 0·050 m from the conductor.



Solution:

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$= \frac{4 \times 3{\cdot}14 \times 10^{-7} \times 2{\cdot}5}{2 \times 3{\cdot}14 \times 0{\cdot}05}$

$= 1{\cdot}0 \times 10^{-5}\,T = 10\,\mu T$

THINGS TO DO AND THINK ABOUT

1. In the above example, calculate the value of the magnetic induction at 0·20 m from the conductor.
2. What current will give a magnetic induction of 65 μT at a distance of 40 mm from a long straight conductor?
3. A long straight conductor carries a current of 8·5 A. At what distance from the conductor will the magnetic induction be 1·5 mT?

VIDEO LINK

For a video link on magnetic domains visit www.brightredbooks.net

ONLINE TEST

Take the test on magnetic fields at www.brightredbooks.net

BrightRED Study Guides

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PHYSICS

Andrew McGuigan

This BrightRED Study Guide is the ultimate companion to your CfE Advanced Higher Physics studies! Written by our trusted author and experienced Physics teacher, Andrew McGuigan, this book is full-colour and packed with clear and accessible information, excellent examples, activities and advice. Inside, you will find:

- **All the essential course information fully up-to-date with SQA course changes,** arranged in easily digestible double-page topic spreads.
- **Detailed full-colour diagrams, illustrations and data boxes** to make sure all that study sticks!
- ***Don't forget*** pointers offering advice on the key facts to remember, and on how to avoid common mistakes.
- ***Things to do and think about*** sections encouraging the regular review of key points covered.
- ***Digital Zone* activities and tests** to supercharge your learning efforts online!
- **An index of key terms** to help when revising.

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