Fields and their patterns

- **describe gravitation, magnetism and electricity using a field model**
- **investigate and compare theoretically and practically gravitational, magnetic, and electric fields, including directions and shapes of fields, attractive and repulsive fields, and the existence of dipoles and monopoles**
- **investigate and compare theoretically and practically gravitational fields and electrical fields about a point mass or charge (positive or negative) with reference to:**
  – the direction of the field
  – the shape of the field
  – the use of the inverse square law to determine the magnitude of the field
  – potential energy changes (qualitative) associated with a point mass or charge moving in the field
- **describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel, whereas masses only attract each other.**

Electric Fields

- **analyse the use of an electric field to accelerate a charge, including:**
  – electric field and electric force concepts: $E = k\frac{Q}{r^2}$ **and** $F = k\frac{Q_1Q_2}{r^2}$
  – potential energy changes in a uniform electric field: $W = qV$, $E = \frac{V}{d}$
  – the magnitude of the force on a charged particle due to a uniform electric field: $F = qE$
- **model the acceleration of particles in a particle accelerator (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).**

Gravitational Fields

- **analyse the use of gravitational fields to accelerate mass, including:**
  – gravitational field and gravitational force concepts, $g = \frac{GM}{r^2}$ **and** $F_g = G\frac{M_1M_2}{r^2}$
  – potential energy changes in a uniform gravitational field: $E_g = mg\Delta h$
  – the change in gravitational potential energy from the area under a force- distance graph and area under a field distance graph multiplied by mass.
- **apply the concepts of force due to gravity,** F_g**, and normal reaction force,** F_N**, including satellites in orbit where the orbits are assumed to be uniform and circular**
- **model satellite motion (artificial, Moon, planet) as uniform circular orbital motion** $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$;

Magnetic fields

- **investigate and apply theoretically and practically a vector field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops, and solenoids**

- **identify fields as static or changing, and as uniform or non-uniform.**

Electric fields

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022	4		Field around point charges, vector addition	1	18%	Calculation
		3a	Vq = ΔKE	2	74%	Calculation
		3b	$qV = \frac{1}{2}mv^2$	2	73%	Calculation
2022 NHT	1		$E = \frac{V}{d}$	1	NA	Calculation
		1a	$qV = \frac{1}{2}mv^2$	2	NA	Show
		1b	$qV = \frac{1}{2}mv^2$	2	NA	Calculation
2021	2		Field around point charges	1	92%	Concept
	3		Field between plates	1	56%	Concept
		5b	Force acting on an electron	3	53%	Calculation
2021 NHT	2		Net force due to 2 charges	1	NA	Concept
		1a	$F = Eq$, $E = \frac{V}{d}$, ΔV	1	NA	Concept
		1b	$E = \frac{V}{d}$	2	NA	Calculation
		2a	Vq = ΔKE	3	NA	Calculation
2020	1		Field lines	1	65%	Concept
2019	2		$E = \frac{V}{d}$	1	91%	Calculation
	3		Force	1	60%	Concept
		2	Field lines	2	81%	Concept
2019 NHT		1a	WD = ΔKE = qV	3	NA	Calculation
2018	4		$E = \frac{kQ}{r^2}$	1	81%	Calculation
		1a	$E = \frac{V}{d}$	1	80%	Calculation
		1b	WD = ΔKE	2	60%	Calculation
2018 NHT	3		$E = \frac{kQ}{r^2}$	1	NA	Calculation
		2a	$E = \frac{V}{d}$	2	NA	Calculation
		2b	F = Eq	2	NA	Calculation
		2c	WD = ΔKE	2	NA	Calculation
2017	2		F = Eq	1	89%	Calculation

	3		$E = \frac{V}{d}$	1	84%	Calculation
		1	Field lines, point charges.	1	63%	Concept
		2a	$F = \frac{kQ_1Q_2}{r^2}$	2	84%	Calculation

Field patterns and Electric fields can be grouped into the following ideas.

Point charges

Vector properties	Worked example 1
Shape or direction of field	Worked example 2
$E = \frac{kQ}{r^2}$	Worked example 3
$F = \frac{kQ_1Q_2}{r^2}$	Worked example 4

Uniform fields

Shape or direction	Worked example 5
$E = \frac{V}{d}$	Worked example 6
F = Eq	Worked example 7
WD = ΔKE = qΔV	Worked example 8
Millikan's experiment	Worked example 9

Field lines

A field is a vector, so it has both magnitude (strength) and direction. The magnitude of the field is the force per unit charge or mass. More than one field will combine using vector addition principles.

When drawing field lines there are four basic principles.

1. Field lines do not touch or cross each other
2. The arrow shows the direction of the field
3. The further the field lines are apart, the weaker the field.
4. Field lines start and end perpendicular to the surface.

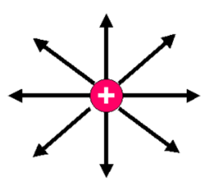
It is often best to draw field lines in pencil, and then, if need be, go over them with pen.

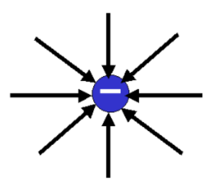
Electrical forces, gravitational forces and magnetic forces act between things that are not in contact with each other. A *force field* exists that influences charged, massive and magnetic bodies, respectively.

Electric fields

An electric field **E** is the region around a charged body where another charged body would experience electric forces of attraction or repulsion. We know if a field is present at a particular space because if we place a point charge there, it will experience a force. The stronger the force, the stronger the field. The magnitude of the field is the size of the force it causes to act on a charge of one coulomb. The direction of the electric field is defined as the direction of the force on a positive charge placed in the field. The strength of the field is indicated by the closeness of the field lines.

Electric field around positive point charge

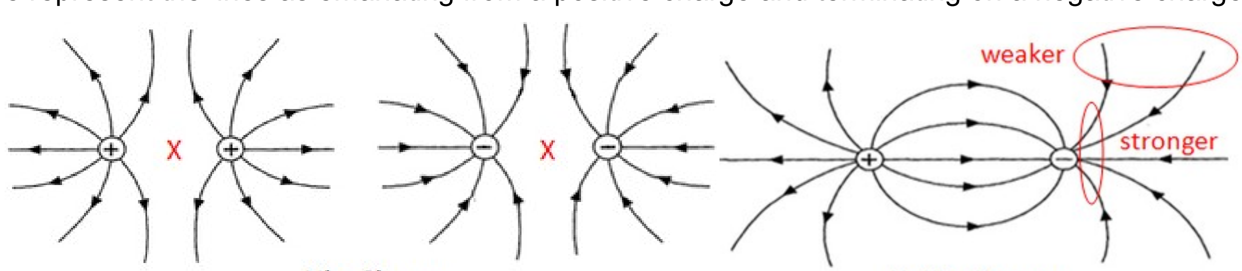




Electric field around negative point charge

Electric field lines

Field lines are lines of force, they indicate the direction of the force acting on a unit positive charge at that point. For an isolated charge, the lines extend to infinity, for two or more opposite charges we represent the lines as emanating from a positive charge and terminating on a negative charge.

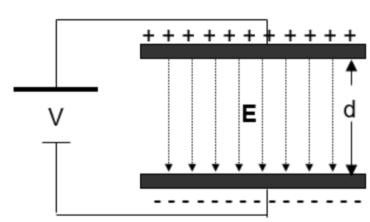


Like Charges   Unlike Charges

Electric fields between charged plates

In the region between parallel charged plates, the electric field **E** is uniform. The strength of the field depends on the potential difference between the plates and the

$$\mathbf{E} = \frac{\Delta V}{d}$$



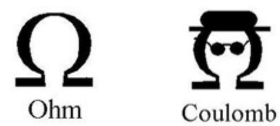
Where E = electric field strength ($V\ m^{-1}$)

ΔV = potential difference (V)

d = distance between plates (m)

Coulombs Law (for point charges)

The force of attraction or repulsion between two charges Q_1 and Q_2 a distance 'r' metres apart is proportional to the product of the charges and inversely proportional to the square of the distance between the charges. $F = \frac{kQ_1Q_2}{r^2}$ where F is the force in newtons, Q_1, Q_2 are measured in Coulomb, and 'r' is measured in metres, $k = 8.99 \times 10^9\ N\ m^2\ C^{-2}$. Only used for two charges in air.



Electric fields about point charges

Combine F = Eq with $F = \frac{kQ_1Q_2}{r^2}$ to get $E = \frac{kQ}{r^2}$

Electric forces

Electric forces are given by the product of the electric field and the quantity of charge.

$F_E = q\mathbf{E}$ Where F_E = electric force (N), q = charge (C), **E** = electric field (N / C)

Therefore, the direction and magnitude of the electric forces represent the direction and magnitude of the electric field at that point.

Linear accelerators (Linac)

Electrical potential energy is stored in an electric field. An electric field exerts a force on charged particles, this can be used to increase their speed and kinetic energy. The field will do work on the charged particles. An electron will experience a force in the opposite direction to the field, due to its negative charge.

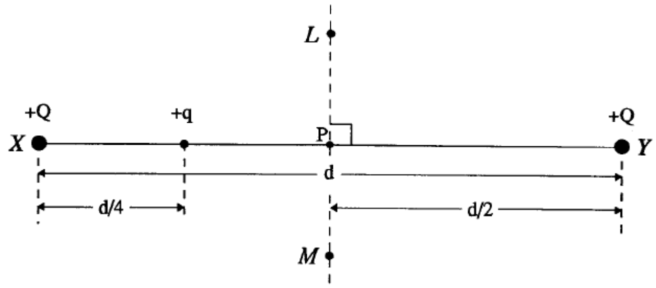
The electric force is F = Eq, and F = ma. Equating these two gives Eq = ma.

The work done is given by $W = F \times d$, (if the force is constant, from a uniform field). The change in KE (typical to assume the particle starts from rest) is the work done.
$\therefore W = \Delta KE = Eqd$, where d is the distance between where the charges enter the field and exit the field.

The work done on a charge is also given by W = qV, and since V = Ed,
we get W = qEd, where d is the distance between where the charges enter the field and exit the field.

Worked example 1: Point charges: vector properties.

Two equal electric charges, +Q, are placed a distance d apart at X and Y, as shown in the figure. The points L and M are perpendicularly above and below the midpoint of the line joining X and Y.



A small positive charge +q is placed on the line between X and Y, a distance $\frac{d}{4}$ from the charge at X.

1991 Question 42, 1 mark

Which of the following expressions gives the magnitude of the force experienced by the charge, +q?
(k is the electrostatic constant).

A. $\frac{kQq}{4d^2}$

B. $\frac{kQq}{d^2}$

C. $4\frac{kQq}{d^2}$

D. $16\frac{kQq}{d}$

E. $16\frac{kQq}{d^2}$

F. $\frac{128}{9}\frac{kQq}{d^2}$

Solution

To find the force from the charge at X, use

$F = \frac{kQ_1Q_2}{r^2}$ where $Q_1 = +Q$, $Q_2 = +q$, $r = \frac{d}{4}$

$\therefore F = 16\frac{kQq}{d^2}$

To find the force from the charge at Y use

$F = \frac{kQ_1Q_2}{r^2}$ where $Q_1 = +Q$, $Q_2 = +q$, $r = \frac{3d}{4}$

$\therefore F = \frac{16kQq}{9d^2}$

The net force is given by

$16\frac{kQq}{d^2} - \frac{16kQq}{9d^2}$

$\therefore F_{net} = \frac{128kQq}{9d^2}$

Current study design:

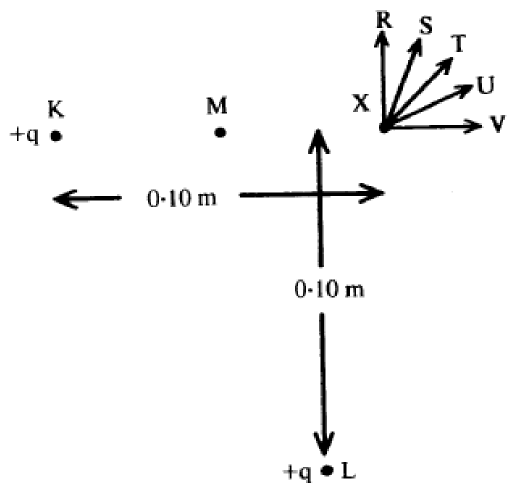
2021 NHT Question 2

2019 Question 3 (60%)

∴ F (ANS)

Worked example 2: Point charges: Shape or direction of field.

Two equal point charges are placed at the points K and L in the diagram below and produce a resultant electric field at the point X of magnitude 100 V m^{-1} in the direction of T.



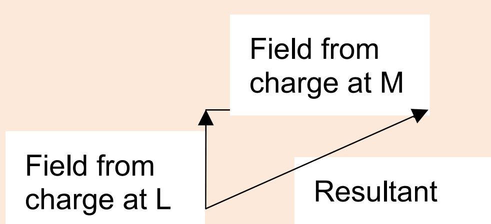
The charge at the point K is then shifted a distance of 0.05 m to M.

1984 Question 52, 1 mark

Which of the arrows (R - V) now best describes the direction of the resultant electric field at the point X?

Solution

The resultant field is the vector sum of the two individual fields. Since the charge at point K is moved towards X, the field from this charge will increase.



∴ U (ANS), 62%

Current study design:

2021 Question 2 (92%)

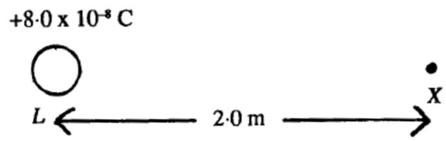
2020 Question 1 (65%)

2019 Question 2 (81%)

2017 Question 1 (63%)

Worked example 3: Point charges: . $E = \frac{kQ}{r^2}$

In a demonstration of electric fields, two small metal spheres, L and M are used.
(The constant in Coulombs Law, $k = 9.0 \times 10^9$ SI units)
In the first demonstration, a charge of $+8.0 \times 10^{-8}$ coulomb is placed on L.
X is a point 2.0 m from L as shown below.



1988 Question 47, 1 mark

What is the magnitude of the electric field at X due to L?

Solution

Use $E = k\frac{Q}{r^2}$

$\therefore E = 9.0 \times 10^9 \times \frac{8.0 \times 10^{-8}}{2^2}$

$\therefore E = 180\ V\ m^{-1}$ (ANS)

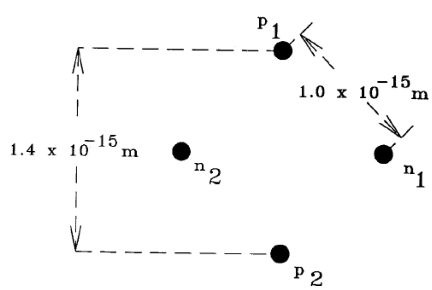
Current study design:

2018 Question 4 (81%)

2018 NHT Question 3

Worked example 4: Point charges: . $F = \frac{kQ_1Q_2}{r^2}$

A helium nucleus contains two protons and two neutrons, and may be pictured at a particular moment as shown below. The protons, p_1 and p_2 each with a charge of $+1.6 \times 10^{-19}$ C are separated by 1.4×10^{-15} m, and the electrostatic force between them is 118 N.



1990 Question 46, 1 mark

What is the magnitude of the electrostatic force between the neutron n_1 and the proton p_1?

Solution

The force between the neutron (zero charge) and the proton (+1 charge) is zero.

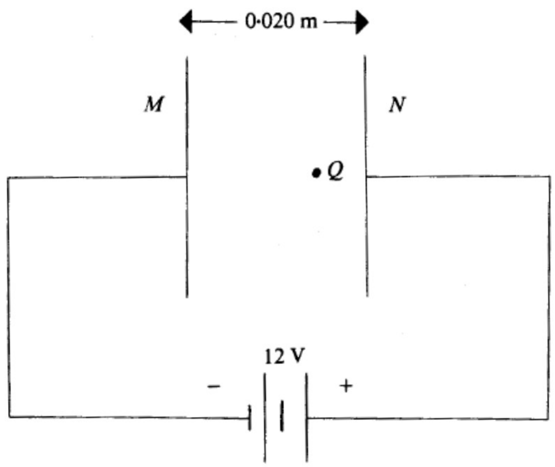
Current study design:

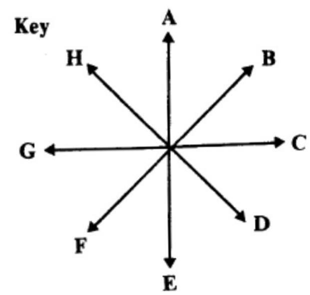
2022 Question 4 (18%)

2017 Question 2a (84%)

Worked example 5: Uniform fields: Shape or direction.

Two metal plates M and N, are separated by 0.020 m. They are connected to a 12 V battery as shown below.





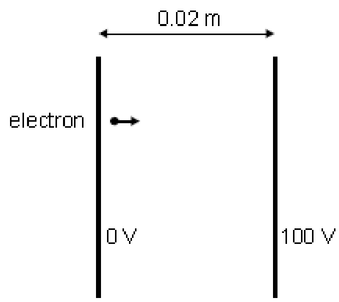
1987 Question 59, 1 mark

Which of the directions **(A – H)** shown in the key above best shows the direction of the electric field at the point Q?

Solution	**Current study design:**
The electric field is the direction of the force on a small unit positive charge. A positive charge will be repelled by N and attracted to M. ∴ G (ANS)	**2021 Question 3 (56%)**

Worked example 6: Uniform fields: $E = \frac{V}{d}$

An electron is accelerated from rest between two parallel charged plates in a vacuum with a potential difference of 100 V as shown below. The plates are separated by a distance of 0.02 m.



2004 Question 4, 2 marks

Calculate the electric field strength between the parallel plates, (in V m^{-1}).

Solution

Use $E = \frac{V}{d}$

$E = \frac{100}{2 \times 10^{-2}}$

∴ $E = 5.0 \times 10^{3}$ V m^{-1} (ANS), (85%)

Current study design:

2022 NHT Question 1

2019 Question 2 (91%)

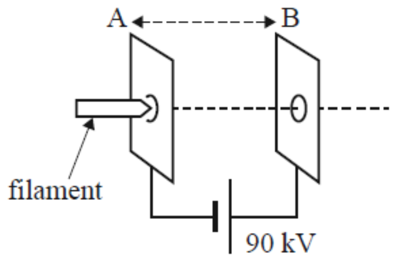
2018 Question 1a (80%)

2018 NHT Question 2a

2017 Question 3 (84%)

Worked example 7: Uniform fields: F = Eq

A simplified diagram of the electron gun in the Australian Synchrotron is shown.



An electron leaving the filament at A is accelerated through a potential difference of 90 kV to B. In the space between A and B, the electron experiences a force of 7.2×10^{-14} N.

2014 Synchrotron Question 1, 2 marks

Which one of the following is closest to the magnitude of the electric field between A and B?

A. 4.5×10^{5} V m^{-1}

B. 4.5×10^{4} V m^{-1}

C. 9.0×10^{4} V m^{-1}

D. 9.0×10^{5} V m^{-1}

Solution	**Current study design:**
Use F = Eq	**2021 Question 5b (53%)**
$\therefore 7.2 \times 10^{-14} = E \times 1.6 \times 10^{-19}$	**2021 NHT Question 1a**
$\therefore E = \frac{7.2 \times 10^{-14}}{1.6 \times 10^{-19}}$	**2021 NHT Question 1b**
$\therefore E = 4.5 \times 10^{5}$ V	**2018 NHT Question 2b**
$\therefore$ A (ANS), (66%)	

Worked example 8: Uniform fields: WD = ΔKE = qΔV

2016 Synchrotron Question 2, 2 marks

In the electron gun of a synchrotron, electrons are accelerated from rest over a distance of 12 cm to reach a final speed of 8.0×10^7 m s^{-1}.

What is the accelerating voltage of the electron gun in kilovolts? (Ignore any relativistic effects.)

A. 2.67 kV

B. 5.30 kV

C. 6.67 kV

D. 18.2 kV

Solution

Use $E = \frac{1}{2}mv^2$, to find the work done.

$\therefore WD = \frac{1}{2} \times 9.11 \times 10^{-31} \times (8.0 \times 10^7)^2$

$\therefore WD = 2.915 \times 10^{-15}$

Use WD = qV

$\therefore 2.915 \times 10^{-15} = 1.6 \times 10^{-19} \times V$

$\therefore V = 1.82 \times 10^4$ V

∴ D (ANS), (58%)

Current study design:

2022 Question 3a (74%)

2022 Question 3b (73%)

2022 NHT Question 1a

2022 NHT Question 1b

2021 NHT Question 2a

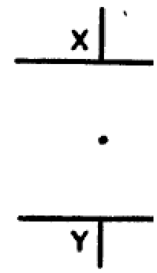
2019 NHT Question 1a

2018 Question 1b (60%)

2018 NHT Question 2c

Worked example 9: Uniform fields: Millikan's experiment.

A charged oil droplet is stationary between a pair of horizontal parallel plates, X and Y, as shown. The drop carries a charge of 3.2×10^{-19} coulomb, and has a mass of 1.6×10^{-15} kg.



Take g = 9.8 N kg^{-1}.

1975 Question 61, 1 mark

What is the magnitude of the electric field, E, between the plates?

Solution

The electric field is exerted an upward force to balance the weight.

$\therefore Eq = mg$

$\therefore E = \dfrac{mg}{q}$

$\therefore E = \dfrac{1.6 \times 10^{-15} \times 10}{3.2 \times 10^{-19}}$

$\therefore E = 5 \times 10^{4}$ V m^{-1} (ANS), (73%)

Current study design:

2017 Question 2 (89%)

Gravitational fields

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022		2a	Geostationary orbit	2	18%	Explanation
		2b	Geostationary, altitude	4	63%	Calculation
		2c	Geostationary, orbit speed	3	64%	Calculation
2022 NHT	3		$g \propto \frac{1}{r^2}$	1	NA	Calculation
	4		WD = area under graph	1	NA	Calculation
		2a	$v = \sqrt{\frac{GM}{r}}$	2	NA	Calculation
		2b	$v = \sqrt{\frac{GM}{r}}$	2	NA	Calculation
		2c	$\frac{r^3}{T^2} = \frac{r^3}{T^2}$	3	NA	Calculation
		8a	$a \propto \frac{1}{r^2}$	2	NA	Calculation
		8b	F_{net} is radially inwards	1	NA	Concept
		8c	$\frac{r^3}{T^2} = \frac{r^3}{T^2}$	3	NA	Concept
2021	4		$g = \frac{GM}{r^2}$	1	44%	Calculation
		3	$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$	3	65%	Calculation
2021 NHT	4		W = mg	1	NA	Calculation
	5		Orbital period $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$	1	NA	Concept
		3a	$F = \frac{GMm}{r^2}$, sig figs	3	NA	Calculation
		3b	$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$	3	NA	Calculation/ Explanation
2020	2		$g = \frac{GM}{r^2}$	1	86%	Calculation
	11		Energy/momentum	1	31%	Concept
		4a	$r = R_E$ + altitude	1	76%	Calculation
		4b	$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$	4	64%	Calculation
		4c	Circular motion definition	2	23%	Explanation
		4d	ΔGPE = area under graph	3	32%	Calculation

2019	4		$g = \frac{GM}{r^2}$	1	58%	Calculation
		4a	g	1	84%	Concept
		4b	Net force	2	17%	Concept
		4c	GPE	2	26%	Calculation
		5a	Net force	2	46%	Concept
		5b	Kepler's Law	3	58%	Calculation
2019 NHT	4		∆GPE	1	NA	Calculation
		10a	Kepler's Law	4	NA	Calculation
		10b	Kepler's Law	2	NA	Concept
2018	7		$g \propto \frac{1}{r^2}$	1	16%	Calculation
		9a	W = mg	2	60%	Calculation
		9b	∆GPE	3	43%	Calculation
		9c	Kepler's Law	3	63%	Calculation
2018 NHT	2		$g = \frac{GM}{r^2}$	1	NA	Calculation
		1a	Kepler's Law	3	NA	Calculation
		1b i	$g = \frac{GM}{r^2}$	3	NA	Calculation
		1b ii	GPE	3	NA	Calculation
2017		4a	$g = \frac{GM}{r^2}$	3	80%	Calculation
		4b	Kepler's Law	3	43%	Calculation
		4c	Kepler's Law	3	36%	Explanation

Field patterns and Gravitational fields can be grouped into the following ideas.

Circular motion	
Definition	Worked example 10
Forces acting/acceleration	Worked example 11
Use $g = \frac{GM}{r^2}$, $F = \frac{GMm}{r^2}$	
Find g, r, or F	Worked example 12
Vector properties of g/F	Worked example 13
$v^2 = \frac{GM}{r}$, $g = \frac{v^2}{R}$, $a = \frac{v^2}{R}$	Worked example 14
Applications of Kepler's law	
Find m	Worked example 15
Period	Worked example 16
Speed	Worked example 17
Geostationary orbits	Worked example 18
Weight	
W = mg	Worked example 19
g /(F) vs r (h) graphs	
Read values	Worked example 20
ΔGPE/ΔKE = area under graph	Worked example 21
Gravitational potential vs d graph	Worked example 22
ΔGPE = mgh	Worked example 23
Calculations involving sig figs	Worked example 24
$r = R_E$ + altitude	Worked example 25
Energy/momentum	Worked example 26

Gravitational fields

Newton determined that gravity is a force of attraction that exists between any two bodies. In fact, any two objects that have mass will exert a gravitational force of attraction. Gravitational forces are very weak and only become noticeable when at least one of the objects is extremely massive. The gravitational force can be calculated using the formula below.

The force acts equally on both masses $F = mg = \frac{GMm}{r^2}$

where F = gravitational force on each mass (N)
G = universal gravitational constant
M, m = masses (kg)
r = distance between the centres on the masses (M, m)
The Universal Gravitational constant $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

For a body on, or above, the surface of the Earth, the mass of the Earth may be considered to be concentrated at its centre. The gravitational field is found by dividing the gravitational force by the mass of the smaller object.

The gravitational field $g = \frac{GM}{r^2}$

Satellites

The moon is the Earth's only natural satellite but there are thousands of artificial satellites orbiting. For a satellite in a stable circular orbit, the only force acting on a satellite is the gravitational attraction between it and the central body. This force acting on it is always perpendicular to its motion. Therefore the energy of the satellite is unchanged as it orbits. The kinetic energy and gravitational potential energy both stay the same. The force of gravity holds the satellites in their orbits and causes them to have acceleration towards the central mass.

Since satellites are in a continual state of free-fall, their acceleration will equal the gravitational field strength at that point.

$\therefore a = \frac{v^2}{r}$ Using $v = \frac{2\pi r}{T}$ $\therefore a = \frac{4\pi^2 R}{T^2}$

Using $F = \frac{GMm}{R^2}$ and $F = mg$ $\therefore \frac{GM}{R^2} = g$

The acceleration of the satellite is independent of the mass of the satellite.

Solving questions

The common problems that students have are:

- Determining the radius/distance (it is always the distance between the two centres of mass)
- Finding the ‘r’ when given the ‘altitude’
- Managing the powers of ten on their calculator.
- Squaring the bottom line in calculations.
- Solving problems involving ratios.

At the surface of the Earth, the gravitational field strength, g, is 9.8 N kg^{-1}, it becomes weaker further from the Earth. 400 km above the Earth g is 8.7 N kg^{-1}.

Any object that is falling freely through a gravitational field will fall with acceleration equal to the gravitational field strength at the point.

Solving calculation questions

Many students struggle on the exam doing the calculations involved in Gravity. This is primarily due to the answer being a number that has no conceptual meaning. They are basically too large to comprehend. The technique that I encourage you to use is to divide each calculation into two parts, the number part and the power part.

Example

What is the centripetal force experienced by the Moon due to Earth's influence?

Mean orbital radius of the moon = 3.83×10^8 m

Mass of Earth = 6.0×10^{24} kg

Mass of the moon = 7.35×10^{22} kg

Solution

Use $F = \frac{GMm}{R^2}$

$\therefore F = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 7.35 \times 10^{22}}{(3.83 \times 10^8)^2}$

Instead of proceeding straight to your calculator rewrite this as

$\therefore F = \frac{6.67 \times 6.0 \times 7.35 \times 10^{-11} \times 10^{24} \times 10^{22}}{(3.83)^2 \times (10^8)^2}$

By dividing the problem into two parts, the numbers and the powers

$\therefore F = \frac{294.17 \times 10^{35}}{14.6689 \times 10^{16}}$

It should make more sense to you that $6.67 \times 6.0 \times 7.35 = 294.17$ and $3.83^2 = 14.6689$ so that $294.17 \div 14.6689 = 20.05$

$\therefore F = 20.05 \times 10^{19}$

$\therefore$ **F = 2.0×10^{20} N**

This final answer is beyond your realm of knowledge, you are completely dependent on the calculator being correct. You wouldn't normally have a mechanism to check that the answer makes sense. This means that you need to be totally accurate with your calculator use. You should always double check these calculations.

Kepler's Law

Use $\frac{GMm}{r^2} = \frac{mv^2}{r}$

$\therefore \frac{GM}{r} = v^2$

Use $v = \frac{2\pi r}{T}$

$\therefore \frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$

$\therefore \frac{GM}{4\pi^2} = \frac{r^3}{T^2}$

For all bodies orbiting the same central body the ratio $\frac{r^3}{T^2}$ is constant.

Worked example 10: Circular motion: Definition.

1981 Question 19, 1 mark

A satellite is orbiting the earth in a circular path at constant speed. Four students are discussing its motion. Who is giving the best account of the forces on the satellite?

A. Albert: 'The satellite is kept up by an outward force, ($\frac{mv^2}{r}$) which counteracts the force due to gravity (*mg*)'.

B. Betty: 'There is one force, that of gravity, acting on the satellite, and this results in an inward acceleration of ($\frac{v^2}{r}$)'.

C. Caren: 'The satellite has escaped from the earth's gravitational field, so the gravity is negligible. It is kept in orbit by its momentum, equal to *mv*. The net force on the satellite is zero.

D. David: 'I agree with Caren about the negligible effect of gravity, but there is an inward force equal to $\frac{mv^2}{r}$ which holds the satellite in orbit.

Solution	**Current study design:**
The only force acting on the satellite is that of gravity. This gravitational attraction results in an inward acceleration of $\frac{v^2}{r}$	**2020 Question 4c (23%)**
∴ B (ANS), (44%)	

Worked example 11: Circular motion: Forces acting/acceleration.

The **Jason 2** satellite reached its operational circular orbit of radius 1.33×10^7 m on 4 July 2008 and then began mapping the Earth's oceans.

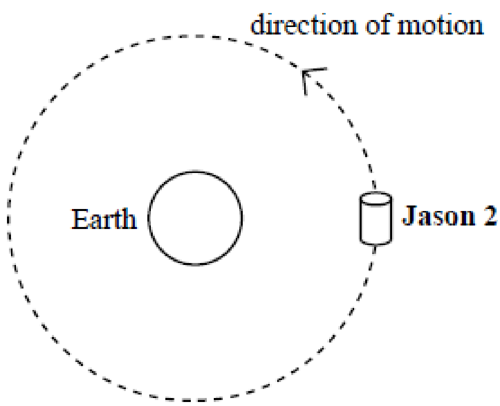
mass of the Earth = 5.98×10^{24} kg

mass of **Jason 2** = 525 kg

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

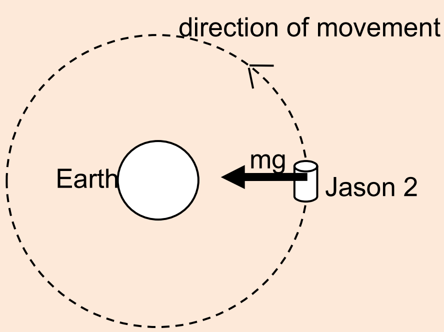
2009 Question 13, 2 marks

On the figure below, draw one or more labelled arrows to show the direction of any force(s) acting on **Jason 2** as it orbits Earth. You can ignore the effect of any astronomical bodies other than the Earth.



Solution

There is only one force acting on Jason 2 as it orbits, that is its weight force and this acts towards the centre of the Earth.



Students were required to draw and label arrow(s) to represent any force(s) acting on the satellite orbiting the Earth.
The required answer was one arrow from the satellite and pointing towards the Earth, with a label *weight* or *gravitational force* or *mg* or *Fg*. It was not acceptable to label it F_{net}. (40%)

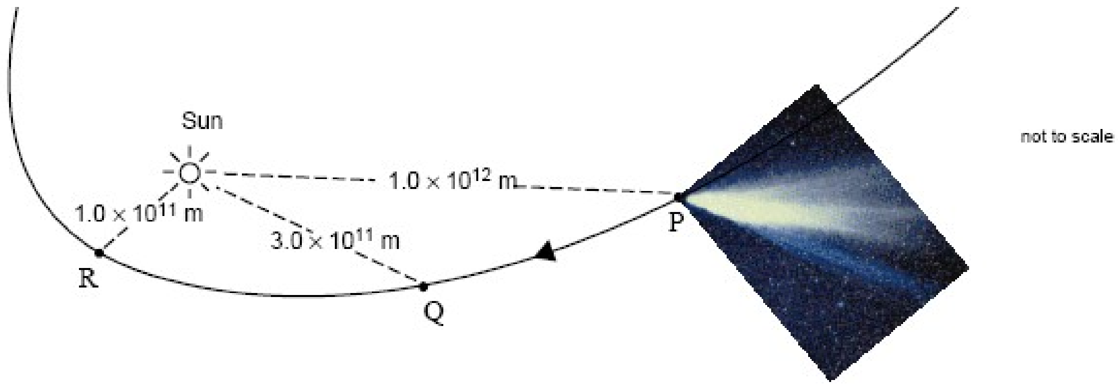
Current study design:

2022 NHT Question 8b

2019 Question 5a (46%)

Worked example 12: Use $g = \frac{GM}{r^2}$, $F = \frac{GMm}{r^2}$: Find g, r, or F.

Halley's Comet last passed by Earth in 1986. The path of this comet is elliptical. Part of this ellipse is shown below, with P, Q and R representing three points along the path. Point P is 1.0×10^{12} m from the Sun.



2000 Question 1, 2 marks

Calculate the magnitude of the gravitational field strength at point P due to the Sun.

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M_{SUN} = 2.0 \times 10^{30}$ kg)

Solution

g is the gravitational field strength. So using;

$$F = mg = \frac{GMm}{R^2}$$

The m cancels and we can write $g = \frac{GM}{R^2}$

Sub the values in ∴ $g = \frac{6.67 \times 10^{-11} \times 2.0 \times 10^{30}}{\left(1.0 \times 10^{12}\right)^2}$

∴ $g = 1.33 \times 10^{-4}$ N kg^{-1} (ANS), (80%)

Current study design:

2022 NHT Question 3

2022 NHT Question 8a

2021 Question 4 (44%)

2020 Question 2 (86%)

2019 Question 4 (58%)

2018 Question 7 (16%)

2018 NHT Question 2

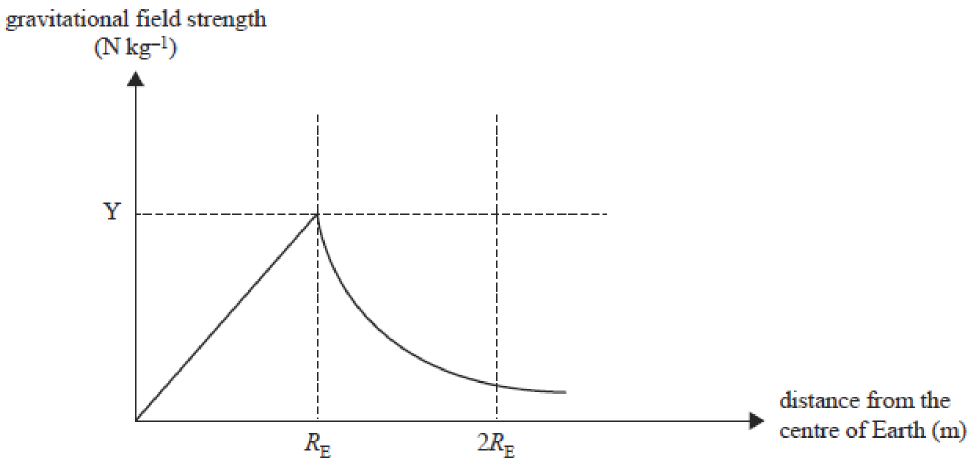
2017 Question 4a (80%)

Use $g = \frac{GM}{r^2}$, $F = \frac{GMm}{r^2}$

Worked example 13: *:Vector properties of g/F.*

Assume that a journey from approximately 2 Earth radii ($2R_E$) down to the centre of Earth is possible. The radius of Earth (R_E) is 6.37×10^6 m. Assume that Earth is a sphere of constant density.

A graph of gravitational field strength versus distance from the centre of Earth is shown below.



2019 Question 4b, 1 mark

Explain why gravitational field strength is 0 N kg^{-1} at the centre of Earth.

Solution	Current study design:
Gravitational force is the attraction between two masses. At the centre of the Earth the gravitational force of attraction (from all the mass surrounding the centre) is equal in all directions. Therefore the vector sum is zero. (17%)	**2019 Question 4b (17%)**

Worked example 14: Use $g = \frac{GM}{r^2}$, $F = \frac{GMm}{r^2}$: $v^2 = \frac{GM}{r}$, $g = a = \frac{v^2}{R}$.

Last year astronomers discovered a new body, Quaoar, in our solar system just beyond Pluto. This very large asteroid orbits our Sun in a near perfect circle of radius 6.5×10^{12} m.

2003 Question 3, 3 marks

Calculate the speed of Quaoar in its orbit around the Sun.

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M_{Sun} = 2.0 \times 10^{30}$ kg)

Solution

You need to equate $\frac{GMm}{R^2} = \frac{mv^2}{R}$

$\therefore v^2 = \frac{GM}{R}$

$= \frac{6.67 \times 10^{-11} \times 2.0 \times 10^{30}}{6.5 \times 10^{12}}$

$= 2.05 \times 10^7$

$\therefore v = 4\,530$

$\therefore v = 4.5 \times 10^3$ m s^{-1} (ANS), (68%)

Current study design:

2022 NHT Question 2a

2022 NHT Question 2b

2021 Question 4 (44%)

Worked example 15: Applications of Kepler's law: find 'm'.

A distant star has a planet orbiting it. The period of the planet's circular orbit is 1200 hours. The radius of the planet's orbit is measured to be 7.0×10^{10} m.

2014 Question 5a, 4 marks

Use the data above to calculate the mass of the star. Show your working.

Solution

Period = 1200 hours

$= 1200 \times 60 \times 60$

$= 4.32 \times 10^6$ s

Use $\frac{r^3}{t^2} = \frac{GM}{4\pi^2}$ which is Kepler's Law.

$\therefore \frac{(7.0 \times 10^{10})^3}{(4.32 \times 10^6)^2} = \frac{6.67 \times 10^{-11} \times M}{4\pi^2}$

$\therefore M = \frac{1.354 \times 10^{34}}{1244.78208}$

$\therefore M = 1.09 \times 10^{31}$

$\therefore M = 1.1 \times 10^{31}$ (ANS), (60%)

Current study design:

2021 Question 3 (65%)

Worked example 16: Applications of Kepler's law: find 'period'.

The dwarf planet Pluto has an orbital period of 248 Earth years (1 Earth year = 365 days). Assume the orbit is exactly circular.

The mass of the sun is 2.0×10^{30} kg. $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

2017 NHT Question 6a, 1 mark

Calculate Pluto's orbital period.

Solution

Period = 248 × 365 × 24 × 3600

$\therefore T = 7.82 \times 10^9$ s (ANS)

Current study design:

2022 NHT Question 2c

2022 NHT Question 8c

2021 NHT Question 5

2021 NHT Question 3b

2019 NHT Question 10a

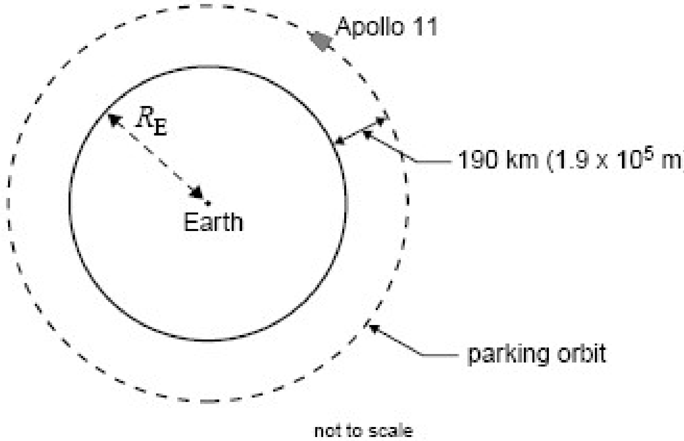
2018 Question 9c (63%)

2018 NHT Question 1a

2017 Question 4b (43%)

Worked example 17: Applications of Kepler's law: find 'speed'.

When people went to the Moon in the Apollo 11, the spacecraft was initially placed in a 'parking orbit' 190 km above Earth's surface. This is shown below.



2000 Question 3, 3 marks

Calculate the speed of Apollo 11 in the parking orbit.

($R_E = 6.37 \times 10^6$ m, $M_E = 5.98 \times 10^{24}$ kg, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2})

Solution

In order to do this question you need to understand that the net force on the spacecraft is the gravitational force, and that this gravitational force is the centripetal force required to keep the spacecraft in orbit. Therefore you can write;

$$F_{net} = \frac{GMm}{R^2} = m\frac{v^2}{R}$$

divide both sides by m $\frac{GM}{R^2} = \frac{v^2}{R}$

multiply both sides by R $\frac{GM}{R} = v^2$

take the square root of both sides $v = \sqrt{\frac{GM}{R}}$

Let's establish what R is; it is the distance from the centre of mass of the Earth to the centre of mass of the spacecraft. So it's the radius of the earth plus the distance the spacecraft is above the Earth's surface.

$R = R_E + 1.9 \times 10^5$

$R = 6.37 \times 10^6 + 1.9 \times 10^5$

$\therefore R = 6.56 \times 10^6$ m

M is the mass of the earth = 5.98×10^{24} kg

$\therefore$ $v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{6.56 \times 10^6}}$

$\therefore v = 7.8 \times 10^3$ m s^{-1} (ANS), (59%)

Current study design:

2019 NHT Question 10b

2018 NHT Question 1b i

2017 Question 4c (36%)

Worked example 18: Applications of Kepler's law: Geostationary orbits.

A spacecraft is placed in orbit around Saturn so that it is Saturn-stationary (the Saturn equivalent of geostationary – the spacecraft is always over the same point on Saturn's surface on the equator).

The following information may be needed to answer Question 7:

- mass of Saturn 5.68×10^{26} kg
- mass of spacecraft 2.0×10^{3} kg
- period of rotation of Saturn 10 hours 15 minutes

2015 Question 7b, 3 marks

Calculate the radius of the orbit of the spacecraft. Show your working.

Solution

Use $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ which is Kepler's Law.

T = 10.25 × 60 × 60

∴ T = 36900

∴ T = 3.69×10^4 s

$$\therefore \frac{r^3}{(3.69 \times 10^4)^2} = \frac{6.67 \times 10^{-11} \times 5.68 \times 10^{26}}{4\pi^2}$$

$$\therefore r = \sqrt[3]{\frac{6.67 \times 10^{-11} \times 5.68 \times 10^{26} \times (3.69 \times 10^4)^2}{4\pi^2}}$$

∴ R = 1.09×10^8

∴ R = 1.1×10^8 m, (ANS), (66%) (66%)

Current study design:

2022 Question 2a (18%)

2022 Question 2b (63%)

2022 Question 2c (64%)

Worked example 19: Weight = mg.

The International Space Station (ISS) is currently under construction in Earth orbit. It is incomplete, with a current mass of 3.04×10^5 kg. The ISS is in a circular orbit of 6.72×10^6 m from the centre of Earth.

In the following questions the data below may be needed.

Mass of ISS 3.04×10^5 kg,

Mass of Earth 5.98×10^{24} kg,

Radius of Earth 6.37×10^6 m

Radius of ISS orbit 6.72×10^6 m,

Gravitational constant 6.67×10^{-11} N m^2 kg^{-2}

2010 Question 18, 2 marks

What is the weight of the ISS in its orbit?

Solution

Weight = $\frac{GM_e m_{ISS}}{r^2}$

= $\frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 3.04 \times 10^5}{(6.72 \times 10^6)^2}$

= 2.69×10^6 N (ANS), (57%)

Current study design:

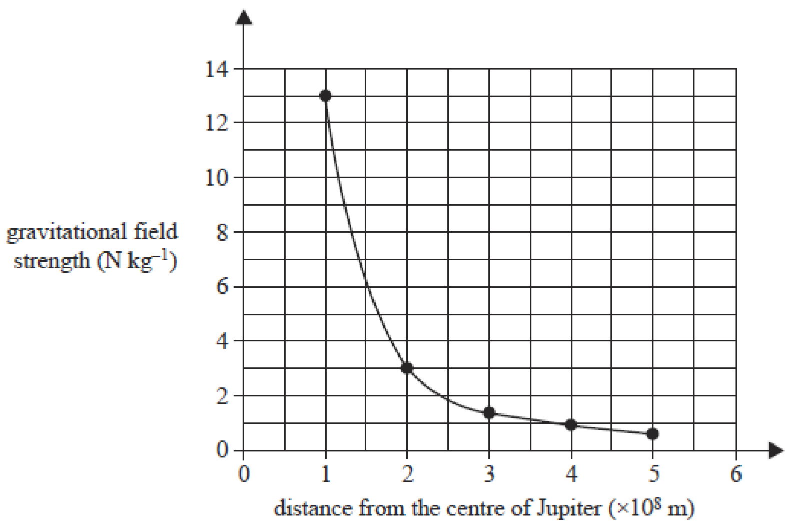
2021 NHT Question 4

Worked example 20: g /(F) vs r (h) graphs: read values.

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft *Juno*. The figure below shows gravitational field strength (N kg^{-1}) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg

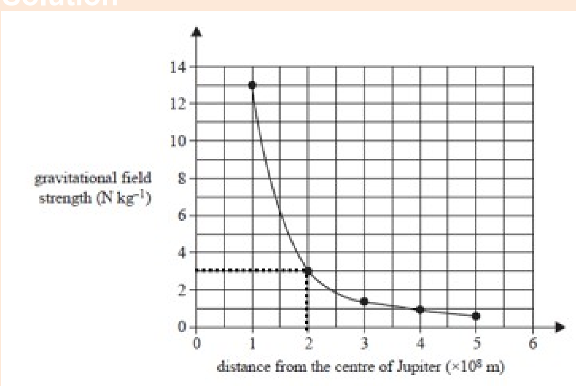


2018 Question 9a, 2 marks

Calculate the gravitational force acting on *Juno* by Jupiter when *Juno* is at a distance of

2.0×10^{8} m from the centre of Jupiter. Show your working.

Solution



From the graph g = 3 N kg^{-1}

∴ W = m × g

∴ W = 1500 × 3

∴ W = 4.5×10^{3} N (ANS), (60%)

Current study design:

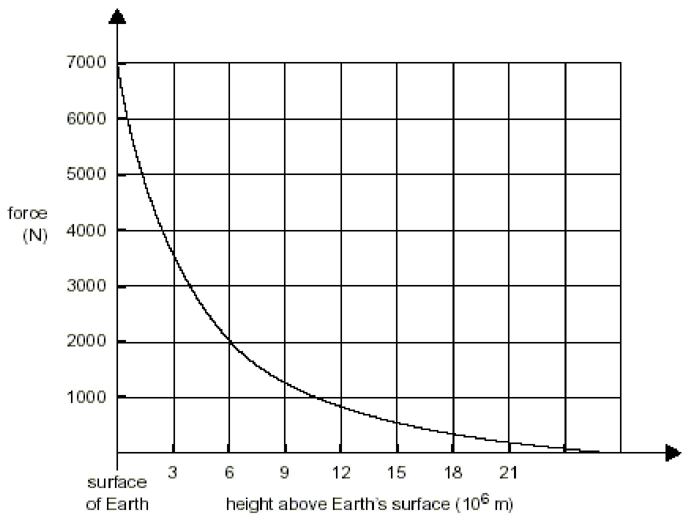
2019 Question 4a (84%)

2019 Question 4c (26%)

2018 Question 9a (60%)

Worked example 21: g /(F) vs r (h) graphs: ∆GPE/∆KE = area under graph.

The Mars Odyssey spacecraft was launched from Earth on 7 April 2001 and arrived at Mars on 23 October 2001. The figure below is a graph of the gravitational force acting on the 700 kg Mars Odyssey spacecraft plotted against height above Earth's surface.



2002 Question 1, 3 marks

Estimate the minimum launch energy needed for Mars Odyssey to escape Earth's gravitational attraction.

Solution

Area under graph is something between 11 to 13 squares.
Each square has a value of
$1000 \times 3 \times 10^6 = 3 \times 10^9$ J
∴ at least 3.3×10^{10} J (ANS), (53%)
Allowing for a variation in the number of squares counted, a range of values
3.3 to 4.4×10^{10} J, was accepted.

Current study design:

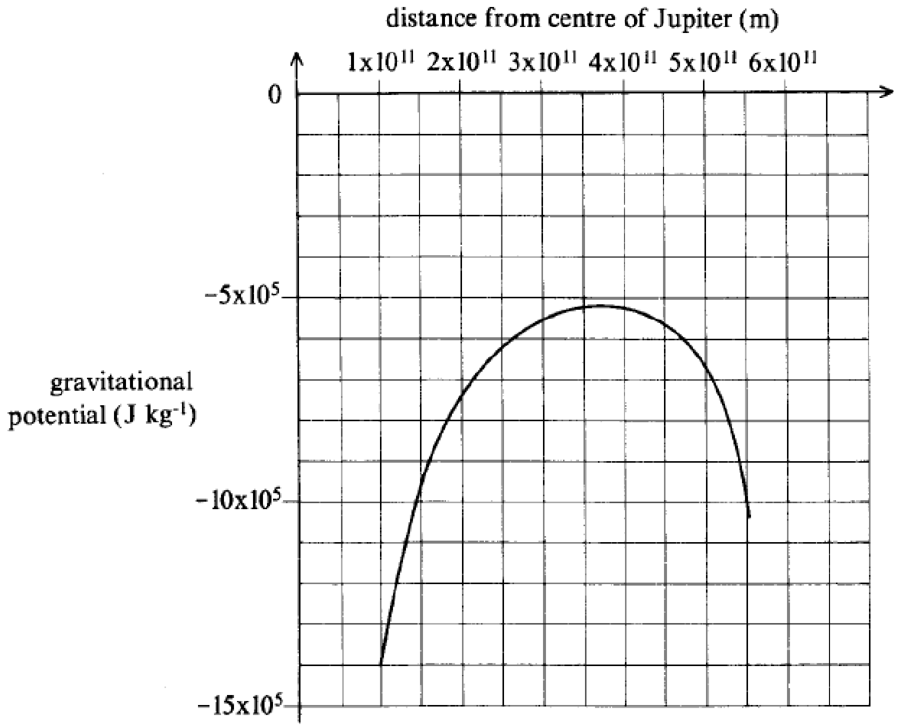
2021 Question 8c (22%)

2020 Question 4d (32%)

2018 Question 9b (43%)

Worked example 22: g /(F) vs r (h) graphs: Gravitational potential vs d graph.

Consider the VOYAGER spacecraft on the journey between Jupiter and Saturn. The graph below shows the gravitational potential at different distances from the centre of Jupiter.



1983 Question 31, 1 mark

Given that the spacecraft has a mass of 1.0×10^4 kg, determine the gravitational potential energy of the craft at a distance of 3.0×10^{11} m from the centre of Jupiter.

Solution	**Current study design:**
The gravitational potential energy is given by the mass × gravitational potential (at that point) ∴ GPE = $1.0 \times 10^4 \times 5.5 \times 10^5$ ∴ GPE = 5.5×10^9 J (ANS), (57%)	**2022 NHT Question 4**

Worked example 23: g /(F) vs r (h) graphs: ΔGPE = mgh.

The gravitational potential difference between the surface of a planet and a point 10 m above it is 8.0 J kg^{-1}. The gravitational field in this region is uniform.

1985 Question 28, 1 mark

How much work is done in moving a mass of 5.0 kg from the surface to a point 10 m above the surface?

Solution

The work done is given by the mass × the gravitational potential difference. In this case:
WD = 5 × 8.0
= 40 J (ANS), (71%)

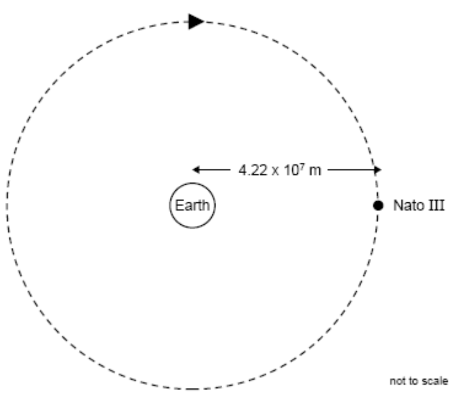
Current study design:

2019 NHT Question 4

2018 NHT Question 1b ii

Worked example 24: g /(F) vs r (h) graphs: Calculations involving sig figs.

Nato III is a communication satellite that has a mass of 310 kg and orbits Earth at a constant speed at a radius of 4.22×10^7 m from the centre of Earth.



1999 Question 1, 1 mark

Calculate the magnitude of Earth's gravitational field at the orbit radius of Nato III.

Give your answer to **three significant figures**. You **must** show your working.

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}) ($M_e = 5.98 \times 10^{24}$ kg)

Solution

The gravitational field strength is given by

$$g = \frac{GM_e}{R^2}$$

Substituting the values given yields

$$g = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(4.22 \times 10^7)^2}$$

= 0.223976325

∴ $g = 0.224$ m s^{-2} (ANS), (71%)

Current study design:

2021 NHT Question 3a

2020 Question 4b (64%)

2019 Question 5b (58%)

Worked example 25: g /(F) vs r (h) graphs: $r = R_E$ + altitude.

2012 Question 8a, 4 marks

Before the spacecraft *Apollo 11* landed on the Moon, it travelled around the Moon in an orbit with a period of 2.0 hours.

Calculate the **height** of *Apollo 11* above the Moon's surface during its orbit of the Moon. Take the orbit to be circular.

Take $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2} ; $M_{moon} = 7.36 \times 10^{22}$ kg ; $R_{moon} = 1.74 \times 10^6$ m.

Solution

Use $F = \frac{GMm}{R^2}$ and $F = \frac{mv^2}{R}$, combined with $v = \frac{2\pi R}{T}$ to get $\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$.

This is known as Kepler's Law. It is not on the course, but it is extremely useful.

$$R^3 = \frac{GMT^2}{4\pi^2}$$

$$\therefore R^3 = \frac{6.67 \times 10^{-11} \times 7.36 \times 10^{22} \times (2 \times 60 \times 60)^2}{4\pi^2}$$

$\therefore R^3 = 6.45 \times 10^{18}$

$\therefore R = 1.86 \times 10^6$

This is the radius of orbit, the question asks for the height above the moon's surface.

$\therefore h = 1.86 \times 10^6 - 1.74 \times 10^6$

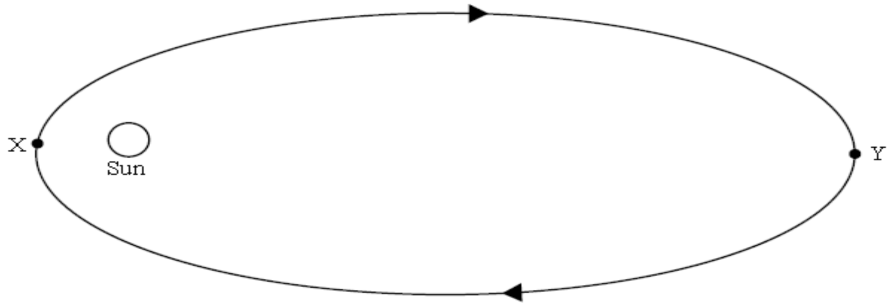
$\therefore h = 1.2 \times 10^5$ m (ANS), (71%)

Current study design:

2020 Question 4a (76%)

Worked example 26: g /(F) vs r (h) graphs: Energy/momentum.

The figure shows the orbit of a comet around the Sun.



2008 Question 15, 2 marks

Describe how the **speed** and **total energy** of the comet vary as it moves around its orbit from X to Y.

Solution	Current study design:
The comet will basically have a constant energy as it orbits the Sun. (Even though it is losing a minute amount as it burns). The total energy is the sum of the PE and KE. The comet will gain PE as it moves away from the sun, therefore it must lose KE. This means that it will travel faster at X than Y. **As the comet moves from X to Y, the speed will decrease and the energy will remain constant (ANS), (48%)**	**2020 Question 11 (31%)**

Magnetic fields

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022	1		Direction of field about current carrying wire	1	80%	Concept
	3		Direction of force acting	1	83%	Concept
		3c	D = 2r, r = $\frac{mv}{Bq}$	3	61%	Calculation
2022 NHT		3	RH rule, circular motion	4	NA	Concept
2021		1a	Field, 2 bar magnets	1	39%	Concept
		1b	Sum of fields	2	33%	Calculation
		2a	Field lines, 2 circular magnets	1	73%	Concept
		5a	F = Bqv	2	35%	Concept
		5c	F = Bqv, F = Eq, directions	4	17%	Explanation
2021 NHT		2b	Circular motion definition, q	2	NA	Explanation
		2c	r = $\frac{mv}{Bq}$	3	NA	Calculation
2020	3		Speed, circular motion	1	63%	Explanation
	4		r = $\frac{mv}{Bq}$	1	58%	Concept
		1	Field lines, bar magnets	2	86%	Concept
		2	Monopoles/dipoles	3	74%	Concept
		3a	Bqv = Eq	1	46%	Concept
		3b	Bqv = Eq	2	76%	Calculation
		3c i	Bqv = Eq	1	42%	Concept
		3c ii	Bqv = Eq	2	13%	Explanation
2019	1		Force direction	1	95%	Concept
		1a	Direction of force	1	44%	Explanation
		1b	F = $\frac{mv^2}{r}$	2	27%	Explanation
2019 NHT	1		Field lines	1	NA	Concept
		1b	F = Bqv	2	NA	Calculation
		1c	F = $\frac{mv^2}{r}$	2	NA	Explanation
2018	3		Field lines, current	1	90%	Concept
		1c	r = $\frac{mv}{Bq}$	2	70%	Calculation
2018 NHT		3a	RH rule, circular motion	3	NA	Explanation
		3b	F = Bqv	3	NA	Calculation

2017	1		Monopoles	1	65%	Concept

Field patterns and Magnetic fields can be grouped into the following ideas.

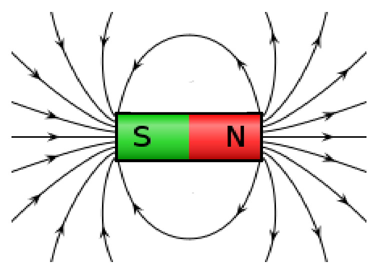
Magnetic fields
- Basic concepts, vector properties — Worked example 27
- Bar magnets — Worked example 28
- Current carrying wire — Worked example 29
- Coils/Solenoids — Worked example 30

Charges moving in magnetic fields
- Field/force direction — Worked example 32
- Circular motion definition — Worked example 33
- $F = Bqv = \frac{mv^2}{r}$ — Worked example 31
- $Bqv = Eq$ — Worked example 34
- $Bqr = mv$ — Worked example 35

Magnetic fields

All magnets have two poles, the North Pole and South Pole. The North-seeking pole, called the North Pole, on a magnet will point towards the Earth's North Pole.

Every magnet is surrounded by a magnetic field, a zone where magnetic characteristics can be experienced. The direction of the magnetic field is given by the direction of the force on an (imaginary) north monopole at that point.



Recent exam questions have asked you to draw field lines. To do this successfully you need to show the correct polarity (direction), some had to be complete loops, and field lines were not allowed to touch or cross. Students have also had a lot of trouble adding fields as vectors.

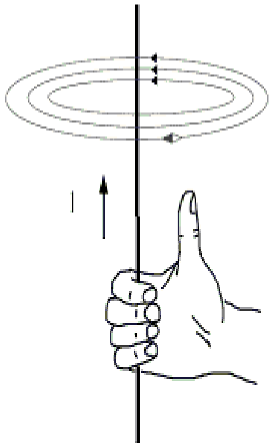
Magnetic Field Strength

- The symbol **B** is given to the magnetic field strength
- Its unit is the Tesla (T).
- It is a vector quantity, therefore

  It has both magnitude and direction.

  Two or more magnetic fields need to be added as vectors.
- Permanent magnets typically have **B** = 10^{-3} to 1 T.
- Earth's magnetic field is about 5×10^{-5} T.

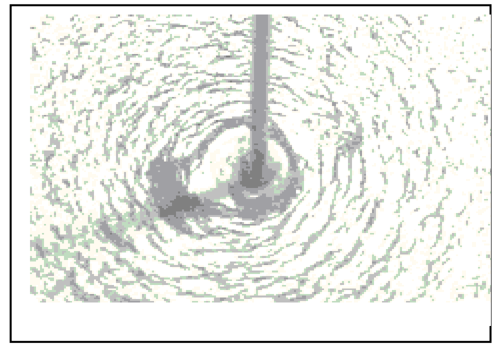
Magnetic Fields around Wires



A conductor carrying an electric current is always surrounded by a magnetic field.

Every current-carrying wire becomes a magnet.

Electromagnetism is a temporary effect caused by the flow of electric current and it disappears when the current flow is stopped.



The magnetic field lines due to the current in a straight wire are concentric circles with the wire at the centre. The direction of the magnetic field can be found using the right-hand screw (grip) rule.
The wire is gripped with the **right** hand so that the thumb lines up with the direction of current flow. The direction of the magnetic field is given by the curl of the fingers.

The strength of the magnetic field caused by a current is given by **B** = $\frac{kI}{r}$ (k is a constant).

Force on a moving charge

Current is defined as I = $\frac{q}{t}$. The force on a current is given as F = BiL, which can be considered as F = $\frac{BqL}{t}$. This can be rewritten as F = Bqv, where v is the speed of the charge, given as $\frac{L}{t}$.
Using the right hand rule the direction of the force can be determined.

If an electron is moving to the left, it can be considered as a current to the right. The force will always be perpendicular to the direction of motion, so it will result in circular motion as the speed remains constant.

Therefore we can equate F = $\frac{mv^2}{r}$ with F = Bqv.

$\therefore$ Bqv = $\frac{mv^2}{r}$.

This applies when the velocity is low so that relativistic effects do not need to be taken into consideration.

Bqv = $\frac{mv^2}{r}$ can be simplified

$\therefore$ Bq = $\frac{mv}{r}$,

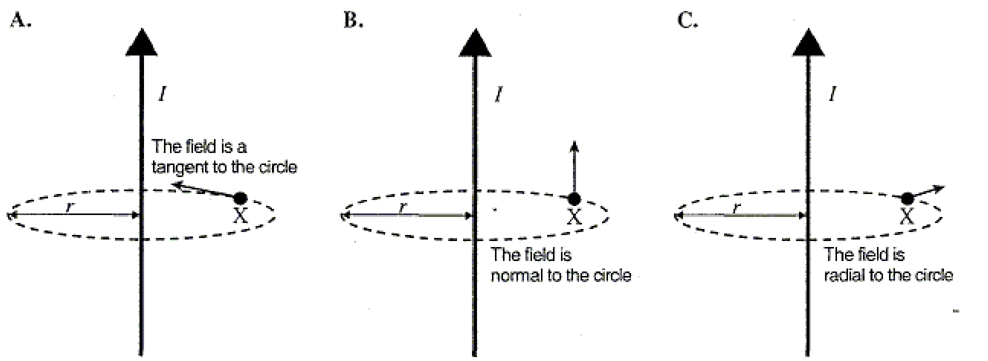
$\therefore$ Bqr = mv, where mv is the momentum of the electron.

Worked example 27: Magnetic fields: Basic concepts, vector properties.

The current in the lightning stroke passes from ground to cloud. The result of this is to generate a magnetic field in the region of the stroke.

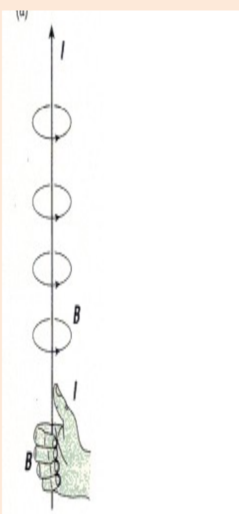
2000 Question 2, 2 marks

Which **one** of the diagrams (A - C) best indicates the **direction** of the magnetic field at point X, a distance r from the lightning stroke? The direction of the current I is shown. The field at X is shown as an arrow.



Solution

Using the right hand grip rule, the magnetic field is given by the direction of the curled fingers.



∴ A (ANS)

Current study design:

2022 Question 1 (80%)

2021 Question 1b (33%)

2021 Question 2a (73%)

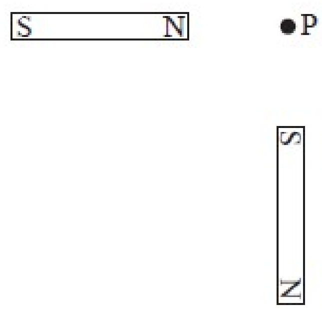
2020 Question 2 (74%)

2019 Question 1 (95%)

2017 Question 1 (65%)

Worked example 28: Magnetic fields: Bar magnets.

Two identical bar magnets of the same strength are arranged at right angles and are equidistant from point P, as shown below.

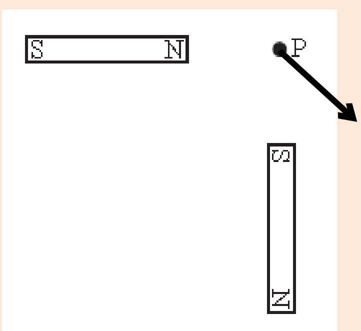


For Question 1 only, ignore the Earth's magnetic field.

2011 Question 1, 1 mark

At point P on the diagram, draw an arrow indicating the direction of the combined magnetic field of the bar magnets.

Solution



The direction of the field is given by the sum of the fields from the horizontal magnet (to the right) and from the vertical magnet (down). The two components have the same size so the angle needed to be 45^0. The arrow also should touch point P. (44%)

Current study design:

2021 Question 1a (39%)

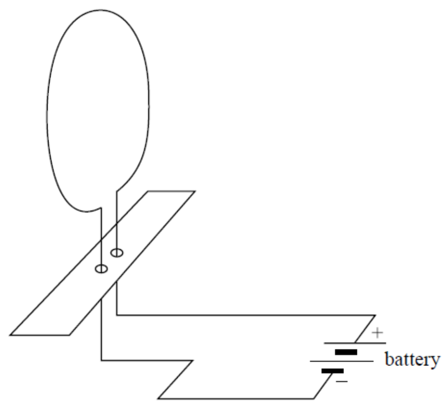
2020 Question 1 (86%)

2019 NHT Question 1

Worked example 29: Magnetic fields: Current carrying wire.

2008 Question 1, 2 marks

The figure below shows a coil of wire connected to a battery. The plane of the coil is perpendicular to the page.

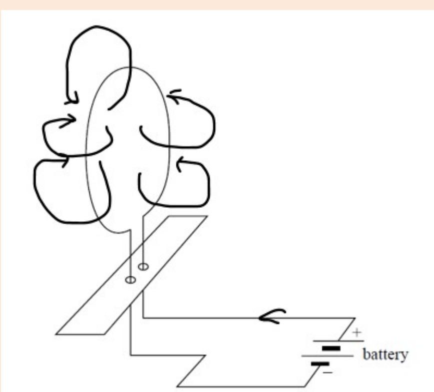


Draw five magnetic field lines to show the magnetic field through the coil. You should include arrows to show direction.

Solution

The current flows from the +ve terminal to the –ve terminal of the battery.

Use the right – hand grip rule to find that the direction of the field inside the loop is going from left to right through the loop, as shown.



Make sure that you draw 5 magnetic field lines that pass through the loop. The direction should be indicated on your field lines by an arrow. (60%)

Current study design:

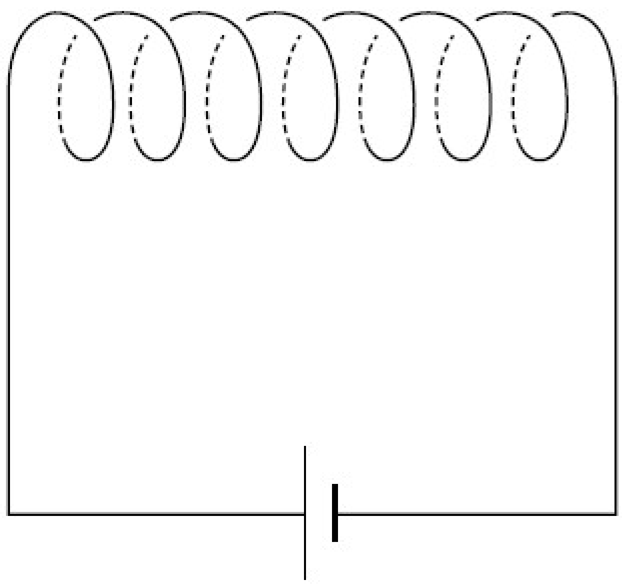
2018 Question 3 (90%)

Worked example 30: Magnetic fields: Coils/Solenoids.

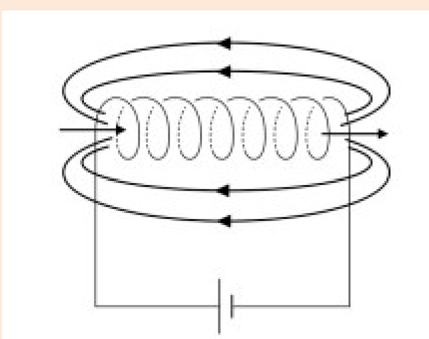
2015 Question 15, 2 marks

The diagram below shows a solenoid.

Draw five lines with arrows to show the magnetic field of the solenoid.



Solution



The current is up the left-hand wire, so it goes down at the front of the solenoid. (62%)

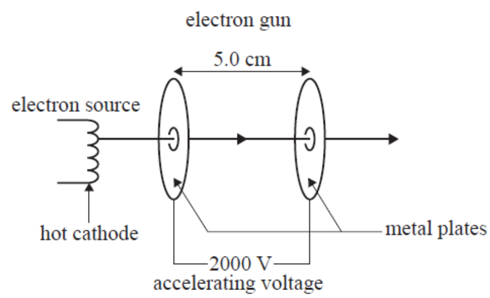
Current study design:

No questions in current study design, but necessary knowledge

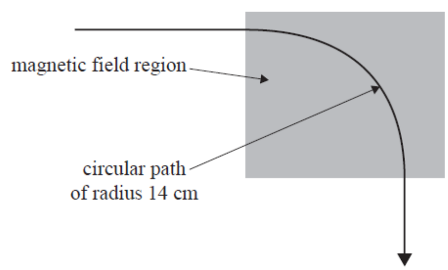
Worked example 31: Charges moving in magnetic fields: $F = Bqv = \frac{mv^2}{r}$.

An electron gun is used to inject electrons into the linac of a synchrotron. The figure below shows a schematic diagram of the electron gun.

The mass of an electron is 9.1×10^{-31} kg, the charge on an electron is 1.6×10^{-19} C.



An electron leaves the electron gun travelling at 2.7×10^{7} m s^{-1}. The electron enters a uniform magnetic field and moves in a circular path of radius 14 cm, as shown below.



2012 Question 3 (Synchrotron), 2 marks

Which of the following is the best estimate of the magnitude of the strength of the magnetic field?

A. 1.1 mT

B. 0.11 T

C. 910 T

D. 30 kT

Solution

Use $\frac{mv^2}{r} = Bqv$.

$\therefore mv = Bqr$

$\therefore B = \frac{mv}{qr}$

$\therefore B = \frac{9.1 \times 10^{-31} \times 2.7 \times 10^{7}}{1.6 \times 10^{-19} \times 0.14}$

$\therefore B = 1.1 \times 10^{-3}$ T

Current study design:

2022 Question 3c (61%)

2021 Question 5a (35%)

2019 Question 1b (27%)

2019 NHT Question 1b

2019 NHT Question 1c

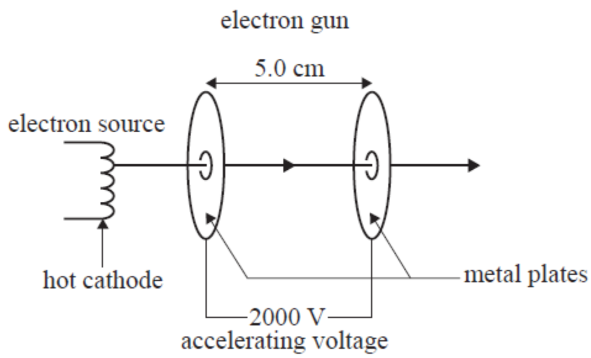
2018 NHT Question 3b

∴ A (ANS), (80%)

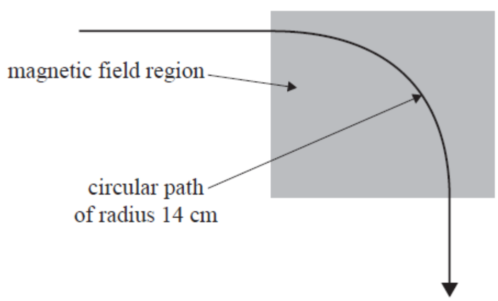
Worked example 32: Charges moving in magnetic fields: Field/force direction.

An electron gun is used to inject electrons into the linac of a synchrotron. The figure below shows a schematic diagram of the electron gun.

The mass of an electron is 9.1×10^{-31} kg, the charge on an electron is 1.6×10^{-19} C.



An electron leaves the electron gun travelling at 2.7×10^{7} m s^{-1}. The electron enters a uniform magnetic field and moves in a circular path of radius 14 cm, as shown below.



2012 Question 4 (Synchrotron), 2 marks

Which of the following best describes the direction of the magnetic field?

A. down the page

B. out of the page

C. up the page

D. into the page

Solution

Initially the current is to the left (negative charge), and the force is down the page. This means that the field is into the page.

∴ D (ANS), (68%)

Current study design:

2022 Question 3 (83%)

2022 NHT Question 3

2019 Question 1a (44%)

Worked example 33: Charges moving in magnetic fields: Circular motion definition.

A charged particle of mass *m* kg, charge *q* coulomb enters a region of uniform magnetic field *B* N A^{-1} m^{-1} with speed *v* m s^{-1}, and moves in a circle of radius *R* m.

1977 Question 62, 1 mark

Which of the following statements is true?

A. The directions of the field, the force on the particle and its velocity are all at right angles to one another.

B. The force is at right angles to the velocity of the particle, and is parallel to the direction of the field.

C. The force is at right angles to the velocity of the particle, and is opposite to the direction of the field.

D. The field is a circular one, and the direction of motion follows the field; the force is at right angles to the plane of the field.

Solution

For a particle to move in circular motion, the acceleration (force) needs to be constant in size and perpendicular to the motion (speed). From the right-hand force rule, the force is perpendicular to the field.

∴ A (ANS), (69%)

Current study design:

2021 NHT Question 2b

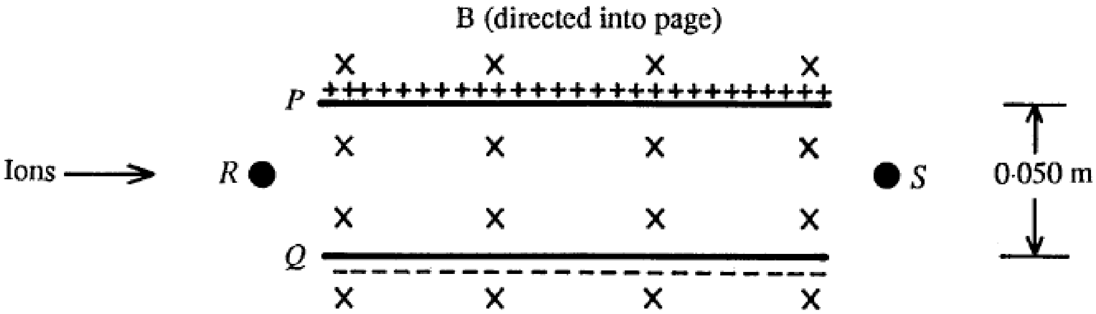
2020 Question 3 (63%)

2018 NHT Question 3a

Worked example 34: Charges moving in magnetic fields: Bqv = Eq.

The velocity selector of a mass spectrograph is shown below. By adjusting the uniform magnetic field B, (directed into the page), and the uniform electric field between the plates P and Q, ions with a particular velocity can be made to move in a straight line through the region.

(The charge on the electron = 1.6×10^{-19} C.)



In an experiment, singly charged ions of lithium (Li^+) enter the region at R at a speed of 5.0×10^5 m s^{-1}

The electric and magnetic fields are adjusted so that the lithium ions travel in a straight line RS.

1988 Question 51, 1 mark

If the electric field strength, E, is adjusted to 2.0×10^4 V m^{-1}, what is the magnitude of the magnetic field strength B, for the ions to travel in this straight line?

Solution

If the charged ion, travels straight through along RS, the net force acting on the ion must be zero. The two forces acting on the ion, are due to the Electric field and the magnetic field, they must be equal in magnitude, but opposite in direction.

Use Bqv = Eq

$\therefore B \times 1.6 \times 10^{-19} \times 5.0 \times 10^5 = 2.0 \times 10^4 \times 1.6 \times 10^{-19}$

$\therefore B = \frac{2.0 \times 10^4}{5.0 \times 10^5}$

$\therefore B = 0.04$ T (ANS)

Current study design:

2021 Question 5c (17%)

2020 Question 3a (46%)

2020 Question 3b (76%)

2020 Question 3c i (42%)

2020 Question 3c ii (13%)

Worked example 35: Charges moving in magnetic fields: Bqr = mv.

A magnetic field of 4.0×10^{-4} T makes electrons travelling at a speed of 8.0×10^{7} m s^{-1} turn through a part of a circle.

2016 Question 3 (Synchrotron), 2 marks

What is the radius of the circle? (Ignore any relativistic effects.)

A. 1.1 m

B. 0.88 m

C. 2.6 cm

D. 1.1 cm

Solution

Link F = Bqv, and F = $\frac{mv^2}{r}$

∴ Bqv = $\frac{mv^2}{r}$

∴ r = $\frac{mv}{Bq}$

∴ r = $\frac{9.1 \times 10^{-31} \times 8.0 \times 10^{7}}{4.0 \times 10^{-4} \times 1.6 \times 10^{-19}}$

∴ r = 1.14 m

∴ A (ANS), (82%)

Current study design:

2021 NHT Question 2c

2020 Question 4 (58%)

2018 Question 1c (70%)